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Microstructure evolution of Al-5wt. %Cu based alloy under compound Strengthening

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Microstructure evolution of Al-5wt. %Cu based alloy under compound Strengthening

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Abstract. The effects of yttrium(Y) additions (0, 0.05, and 0.1wt. %) and partial remelting treatment on microstructure, grain size, phase composition of Al-5wt. %Cu based alloy were investigated in the present work. The microstructure and phase composition of samples were examined by optical microscopy (OM), scanning electron microscopy (SEM), and transmission electron microscope (TEM). We demonstrate that the AlCuY phase which had hexagonal lattice structure was precipitated by adding Y. Especially, Y+ returns refines the grain size, decreases the quantity of eutectic on grain boundaries, and narrows the crystallization range. Quantitative metallography shows that the grain size is reduced to about 25μm for alloys with 0.1 wt. %Y+20wt. %R.

1. Introduction

Al-5wt. %Cu based casting alloys are extensively used in the foundry in industry due to the high mechanical properties, low density and good castability [1-3]. Refinement and modification can be achieved by several methods, such as fast solidification, mould vibration, melt agitation in mushy state or melt inoculation by using alloying elements [4]. The most commonly used chemical elements in industry today are La and Sc [5-7], which remarkably affect the θ'-Al2Cu precipitation, increase the number density, reduce the sizes of precipitates, and promote the anti-corrosion capability. As for Y [8, 9], it causes grain refinement and changes the shape of θ-Al2Cu from network to fish-bone form. Refinement of grain size after partial remelting treatment can promote the mechanical property of Al-5wt. % based casting alloys [10, 11]. Hereditary relations exist in the structure and property between the liquid alloy and solid alloy, which have been confirmed by previous investigations [12, 13]. However, the effect of Y addition on microstructure and property of Al-5wt. %Cu based alloy followed by partial remelting treatment is largely unknown. Therefore, the aim of the present work is to investigate the effects of Y addition (0-0.1wt. %) and partial remelting treatment on the microstructure evolution of Al-5wt. %Cu based alloy.

2. Experimental procedures

The base alloy used in this study was an Al-Cu alloy (Al-5 wt. % Cu-Mn-Cd-V-Zr-Ti). The addition of returns was 20wt. % according to literary. The alloys were melted in a graphite crucible with resistance furnace to 740 oC. Al-Cu, Al-Mn, Al-Zr, Al-V master alloys and returns were placed into the crucible at room temperature. Pure Cd and Al-Ti-B master alloys were added at a holding temperature of 720 oC and 725 oC, respectively. The preheated Al-10.54Y master alloy was added into the melt at 740 oC. Additions of Y to the alloy were 0, 0.05 and 0.1wt. %, respectively. The specimens were prepared by the standard technique of grinding using SiC abrasive paper and polishing with a Al2O3 suspension solution, followed by etching using a solution of 5 vol. % concentrated HF in 95 vol. % H2O. The microstructure of alloys was examined by SEM, TEM and OM.

3. Results and discussion

Mechanical properties, and hot-tearing susceptibility and creep resistance of Al-5wt. %Cu alloy are fundamentally dependent with its microstructure. The microstructure of alloys with different contents of Y and 20wt. % returns addition are shown in Fig.1. It can be clearly seen that the grain size of alloy is refined by the addition of Y and returns significantly. Quantitative metallography shows that the grain size is reduced to ~30μm and 25μm for alloys with 0.05wt. %Y +20wt. %R, and 0.1 wt. %Y+20wt. %R, as shown in Fig.1b-c. According to the previous studies [8, 11], fine grains, with the average particle size being about 45μm, 40μm and 33μm, respectively, can be obtained by adding 0.05%Y, 0.1%Y and 20%returns. It is noteworthy that, the grain size is clearly finer than the alloys with the same proportion of either Y or returns alone.

The microstructure of the eutectic of Al-5wt. %Cu alloy with different amount of returns and Y are illustrated in Fig.2. However, it is worth pointing out that microstructural modification was not discovered at the Al-5wt. %Cu alloy with returns addition presented by Wei. Z J [8]. It is appropriate to assume that the introduction of Y causes form change of the eutectic θ (Al2Cu) phases from network to fish-bone shape, and decreases the amount of eutectic, resulting in narrow and continuous grain boundaries. Additionally, it can be seen that Y is enriched in grain boundary (marked by red circle, as shown in Fig.2c).

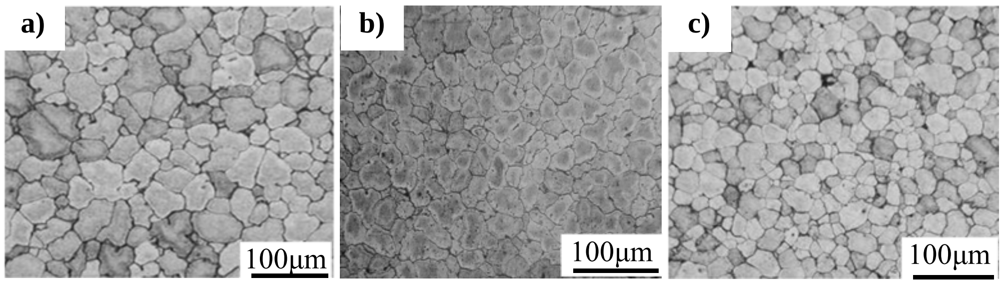

Figure 1. Microstructure of as-cast Al-5wt. % alloy + x%R+y%Y
a) Primary alloy, b) 20%R+0.05Y and c) 20%R+0.1Y

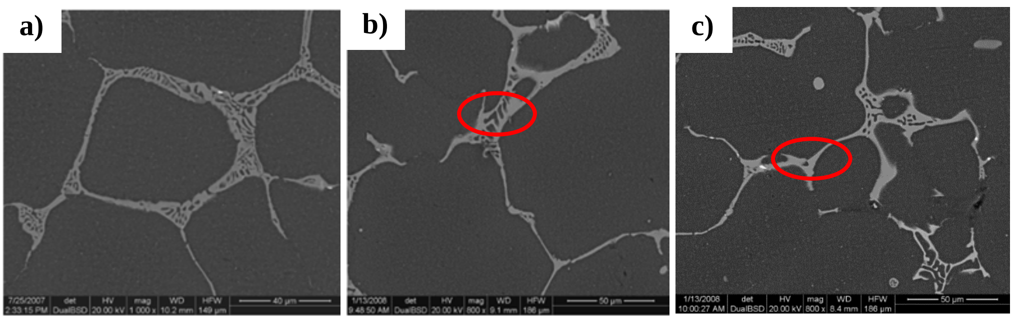

Figure 2. Microstructure of as-cast Al-5wt. % alloy + x%R+y%Y
a) Primary alloy, b) 20%R+0.05Y and c) 20%R+0.1Y

Fig.3a) shows the Transmission electron microscope (TEM) photographs and selected area electron diffraction (SAED) pattern of rich Y phase. It is deduced that the phase has hexagonal lattice structure, and the lattice constants are about a=b=0.703nm and c=0.403nm by calibration. Energy dispersing spectroscopy (EDS) analysis shows that the composition of this phase mainly contains Al, Cu and Y, which is symbolized by AlCuY. Differential thermal analysis (DSC) curve of the as-cast alloy is displayed in Fig.4. The exothermic peaks are attributed to the formation of α (Al) phase, AlCuY phase and eutectic phase, respectively. DSC curve illustrates that AlCuY phase were formed at 592.1oC which is higher than the eutectic transformation temperature, 534.6oC. The variation in morphology of θ eutectic phase (Al2Cu) represents that Y can modify the eutectic structure of Al-5wt.%Cu alloy. The modification efficiency enhances with the increasing amount of Y in the alloy (seen in Fig.2 b)-c)).

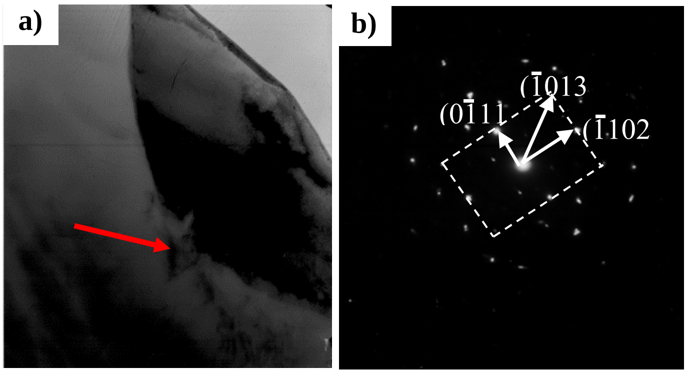

Figure 3. TEM micrographs of AlCuY phase in Al-5wt. % based alloy
a) Morphology, b) diffraction pattern B= $[5\bar{1}\bar{4}3]$

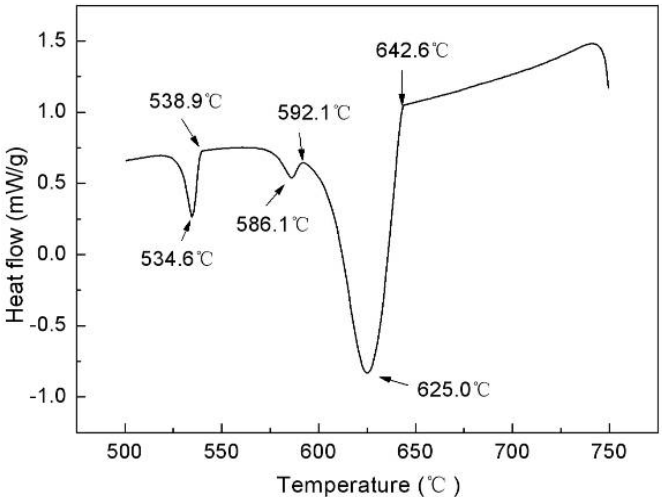

Figure 4. DSC of Al-5wt. % based alloys with Y addition

With regard to the mechanism of grain refinement, the microstructure and properties of returns take on heredity to that of feed alloy. It is noteworthy that, the structure, characteristics of thermo-motion and mechanical properties of melt are similar with the structure of crystal under a minor superheat condition at the melt point. There are many short-range ordered clusters (as potential crystallizing nucleus) and grain finer which have the effect of grain refining on the alloy, due to the maximum temperature of the melt is 735°C and the melting point of aluminum is 660°C, hence the superheat is minor (75°C) in this experiment. These relatively stable atomic clusters act as heterogeneous nucleation particles and provide the original structure and dynamics for corresponding solidification, which make nucleation and growth easier during solidification. Therefore, it can be considered as heredity factors which are able to transmit structural information.

On top of refinement caused by returns, Y further refined the grain size of the alloy at this study. Because of the lattice difference between rare earth compound structure and aluminum great distortion was introduction to the matrix. However, the arrangement of atomic in the grain boundary is loose and the deformation energy caused by rare earth compounds gathered in the grain boundary is bigger than that in the matrix. Rare earth atomic radius of 0.174~0.204 nm is bigger than aluminum atomic radius (0.143 nm). Thereby, the tension between the old and new interface on the surface is reduced, which results in the increase of nucleus growth rate. Besides, some studies present that the rare earth elements do not dissolve in the α-Al matrix, and they will gather at the forefront of the interface in the solidification process in order to shorten the secondary dendrite arm spacing.

A modified eutectic structure is obtained with Y addition to the Al-5wt. % based alloy. The effect of increasing the Y concentration is clearly illustrated in Fig. 2 b) and c). The introduction of Y causes the appearance of modification of eutectic arrest which was not observed in the unmodified alloy. When Al-Cu eutectic phase solidifies, it shows that modifying elements become concentrated in the θ (Al2Cu) phase rather than in the aluminum phase. Then, a constitutional effect is present at the solidification front during solidification and hinders grain growth. TEM and SEM shows that nucleation of AlCuY phase precipitated in grain boundaries and controls the initiation of solidification of the eutectic in Al–5wt. %Cu alloys. Furthermore, the AlCuY phases formed which may also impact eutectic nucleation and growth, as well as reduce the dissolved level of the elements in the liquid. One theory to explain the mechanism of the eutectic in modified alloys is that atoms of the modifier are absorbed onto the growth steps of the Al2Cu solid–liquid interface.

4. Conclusion

1. Introduction of Y and returns have an excellent grain refining effect on the Al-5%Cu based alloy. Quantitative metallography shows that the grain size is reduced to ~30μm with 0.05wt.%Y +20wt.%R. Y can modify the eutectic θ(Al2Cu) phases from network structure form to a fish-bone shape, and the modification efficiency enhances with the increase of Y content in the alloy.

2. The new phase of AlCuY formed at 592.1°C which is higher than eutectic transformation temperature (534.6°C), and is enriched in grain boundary. Introduction of Y and returns refined grain size, decreased the liquidus and shortened the crystallization range of alloy.

Acknowledgments
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