Effect of Convection Solidification on the Halo Formation in Zn-Al Alloys

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Abstract: The formation of halos was investigated for hypoeutectic, eutectic and hypereutectic Zn-Al alloys under conventional and under convection solidification. It was found that the Zn-rich halos occurred in the surroundings of the Al-rich primary phase for the hypereutectic Zn-Al alloys at Al>5 wt.% and no halos occurred for the hypoeutectic and the eutectic Zn-Al alloys at Al<5 wt.% under conventional solidification. However, the Zn-rich halos were completely vanished from the Al-rich phase under intensive convection solidification. The interaction among the solid phases and the liquid phase was found to be responsible for the halo formation.

Keywords: Solidification; Microstructure; Crystal growth; Alloys; Halo formation

1 Introduction

Halo formation is generally characterized by an envelope of non-faceted phase around a faceted primary phase, not vice versa. By controlling the morphology of halo, the alloys with required mechanical properties may be developed, such as the deformation behaviour of ductile iron. This unique feature is important to affect other performance such as corrosion resistant and the heat treatment process of casting alloys. The study for elucidating the origin of halos are generally categorised to nucleation-dominant [1] and/or growth-dominant [2] according to solidification mechanism. The present study aims to find the features of halos in Zn-Al alloys formed in conventional solidification and convection solidification through isolating the growth process. The halos can be then identified as the halo is formed by the simultaneous interaction of the primary solid phase, the halo phase and the melt encompassing the solid phases. The halos were studied on hypoeutectic, eutectic and hypereutectic alloys. The discussion focuses on the effect of convection on the halo formation.

2 Experimental procedure

Pure elemental Zn (99.95 wt.%) and Al (99.995wt.%) were used to make Zn-Al alloy ingots. The chemical composition was measured by optical mass spectroscopy. In the experiments of conventional solidification, the melt were poured into a wedge-shape copper mould at a fixed superheat. The casting was cut at the same thickness for microstructural examination. For the solidification under convection, the melt was sheared using a twin-screw extruder as described in [3] at different temperatures and different times, followed by extruding a φ8mm bar with immediate water quench.

3 Results and discussion

1. Halos under conventional solidification

Fig. 1 shows the Zn-rich halos formed around the primary Al-rich phase. It is seen that three alloys exhibited different characteristics. In the hypereutectic Zn-6.3 wt.% Al alloy, the primary Al-rich phase was surrounded by a halo of Zn-rich phase, and the eutectic microstructure was clearly a lamellar morphology (Fig. 1a). In the eutectic Zn-5 wt.% Al alloy, the eutectic microstructure showed lamellar eutectic cell morphology all over the matrix (Fig. 1b). There was no halo in the microstructure. In the hypoeutectic Zn-4.1 wt.% Al alloy, the primary Zn-rich phase showed no halo in the surroundings of Zn-rich dendrites (Fig. 1c). The results confirmed that halos only occurred on the primary Al-rich phase with Zn-rich halo at the hypereutectic Zn-Al alloys with Al>5 wt.%, and no halos were formed for the hypo eutectic and eutectic Zn-Al alloys at 5 wt.% Al.

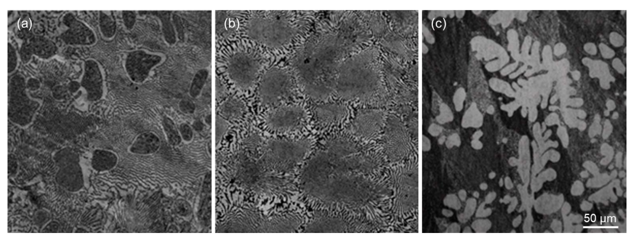

Fig. 1. The optical micrographs showing the typical microstructures and halos of (a) hypereutectic Zn-6.3 wt.% Al, (b) eutectic Zn-5 wt.% Al, (c) hypoeutectic Zn 4.1 wt.% Al alloys (white: Zn-rich phase, black: Al-rich phase).

2. Halos under convection solidification

The halo characteristics of hypereutectic Zn-6.3 wt. %Al alloy under convection solidification are shown in Fig. 2, which were quenched into water from different temperatures. It was seen that only primary Al-rich phase was formed at the initial stage of solidification (Fig. 2a). No halos existed around the primary Al-rich phase before commencing the eutectic solidification, during which two solid phases were created simultaneously in the form of round particles for both the Zn-rich phase and the Al-rich phase (Fig. 2b). The micrograph showed the complete absence of halos around the Zn-rich particles. The primary Al-rich phase had no apparent halos adjacent to the liquid and no halos adjacent to the solid Zn-rich phase.

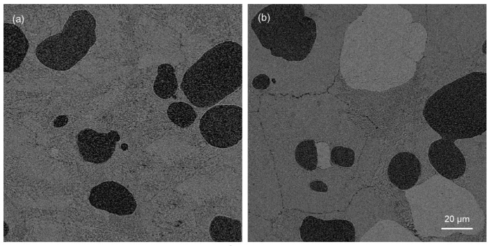

Fig. 2. The back-scattered SEM micrographs showing the microstructures and halo features of water-quenched hypereutectic Zn-6.3 wt.% Al alloy under convection solidification, (a) 389.4 oC, and (b) 380.6 oC.

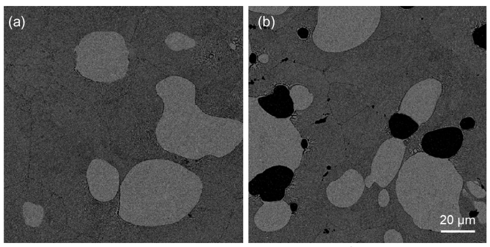

Fig. 3. The microstructures and halos of water-quenched hypereutectic Zn-4.1 wt.% Al alloy under convection solidification, (a) 387.3 oC, and (b) 380.6 oC.

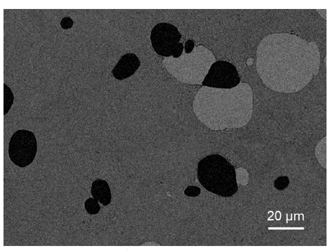

Fig. 4. The microstructures of water-quenched eutectic Zn-5wt.%Al alloy at 380.2 oC under convection solidification.

Fig. 3 shows the halos of the hypoeutectic Zn-4.1 wt.% Al alloy under convection solidification. No halos were found around the Zn-rich particles formed during the primary solidification. For the eutectic solidification of the hypo-eutectic Zn-4.1 wt.% Al alloy, Al-rich particles and Zn-rich particles were formed simultaneously under intensive convection. The eutectic Zn-rich particles exhibited complete absence of halos around the solid phase. The eutectic Al-rich phase showed either no apparent halos adjacent to liquid or completely absent adjacent to the solid Zn-rich phase. Fig. 4 shows the halos of the eutectic Zn-5wt.%Al alloy under convection solidification. The eutectic Zn-rich and Al-rich particles also showed no halos around the another solid phase and no apparent halos adjacent to liquid. Overall, the experimental results confirmed that no any halos were formed under convection around the Al-rich phase, which was contradictory to the conventional solidification.

There are three phases essentially existing simultaneously under conventional solidification when halos are formed.

At the initial stage of solidification to form Al-rich primary phase, the Zn-rich phase starts to nucleate when the melt temperature is lowered to the eutectic point, and attempts to grow on the surface of the Al-rich particles. When applying strong convection on a eutectic alloy, particles of two eutectic phases are precipitated at the same time. Both temperature and composition fields in the melt are uniform with small fluctuations. Both phases nucleate simultaneously at the eutectic temperature and the suppression from one phase to the other phase is much less. Once the nuclei survive in the melt, the subsequent growth is immediately commenced. The growth of solid particles in the eutectic melt is enhanced both the thermal and mass transport, resulting from a very small undercooling, thermal and compositional gradient at the solid/liquid interface. The diffusion boundary layer roughly equals to the lamellar distance for a normal eutectic reaction and it is at the same order during the growth of halos. And, the boundary layer is expected to be thinner than the diffusion boundary layer for a strong convection. Therefore, the halo is not formed because of the significant decrease or even disappear of the diffusion layer, by which the reaction is faster by precipitating the two phases separately. As a result, the solidification process under intensive convection is pretty close for all systems, regardless of their physical properties under conventional condition, which causes the disappearance of halos on the prior Al-rich phase during solidification.

4 Conclusions

(1) In conventional solidification, the Zn-rich halos occurs around the Al-rich primary phase for the hypereutectic Zn-Al alloys and no halos for the hypoeutectic and eutectic Zn-Al alloys.

(2) In convection solidification, the Zn-rich halos are absent from the Al-rich phase formed under the primary solidification and the eutectic solidification of the Zn-Al alloys because of the uniform temperature distribution and the enhanced mass transport by intensive convection.

(3) The halo formation is a growth dominant phenomenon. The interaction among the solid phases and the liquid phase is responsible for the halo formation.

References

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