Divorced Growth of Eutectic Solidification of Hypereutectic Al-Si Alloy in Sand Casting and Its Influence on Mechanical Properties

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Abstract: In this study, divorced growth of eutectic solidification in Al-18Si-5Cu alloy was successively achieved in sand casting. The pouring temperature plays an important role in degree of divorce. At 720ºC, the eutectic solidification isn't divorced, and at 700ºC it is basically divorced, but completely at 680 and 650ºC, companying with significant refinement of Si particles and considerable improvement in its shape factor. The divorced growth of eutectic significantly improves the mechanical property both in ultimate tensile strength (UTS) and elongation (EL). In as-cast state, compared with the un-divorced alloy, the values of UTS and EL of the completely divorced alloy are increased by 60.0% and 92.3%, and, in T6 state, by 113.9% and 64.7%.

Keywords: Hypereutectic Al-Si Alloy, Divorced Growth of Eutectic Solidification, Microstructure, Mechanical Property

1 Introduction

Hypereutectic Al-Si alloys, such as s A390 and ZL108, have been used in Engine cylinders, pistons and other parts due to excellent castability and corrosion resistance, good strength and wear resistance, and low thermal expansivity and excellent dimensional stability. The smaller the size, the higher the shape factor of primary silicon particles, the better the mechanical properties of the alloy. Refining the primary Si particles has been a necessary practice, such as by modification, semi-solid casting, rapid solidification and melt superheating treatment. however, the size of primary Si particles is not enough small and the keen-edged eutectic Si flakes still exist.

In this study, divorced growth of eutectic solidification in Al-18Si-5Cu alloy was investigated in sand casting and the mechanical property was examined.

2 Experimental procedure

The nominal Al-18Si-5Cu-0.1P alloy was prepared in a crucible resistance furnace using Al-24Si, Al-50Cu and Cu-7P master alloys and commercial purity Al ingot. After holding at 850ºC for 2h, the melt was cooled to 720ºC for de-gassing and de-slagging, and then to the designed temperatures (720, 700, 680, and 650 °C) and holding for 10-15min. Finally, the melt was gravity-poured into a sand mold with a cavity of $220\times100\times15mm^3$.

Metallographic samples ($20\times10\times10mm^3$) and tensile specimens (with a gauge size of $18\times3\times3mm^3$) were cut from the cast plates. Some were experienced a T6 heat treatment (520℃/8h + 180ºC/5h). After eroded in Killer reagent, microstructure was examined by optical microscope and SEM. Tensile test was carried out at room temperature with a rate of $1mm\ s^{-1}$. Three specimens were tested to obtain the average of mechanical property.

3 Result and discussion

Microstructure

Fig. 1 shows the microstructure of Al-18Si-5Cu-0.1P alloy cast in sand mold at different temperatures. At 720ºC of pouring temperature, the primary Si particles in Fig. 1 (a)is refined, due to the addition of P. But a great amount of eutectic Si flakes or needles exist in microstructure. In this case, the eutectic growth is coupled, not divorced. However, when the pouring temperature was at 700ºC, the amount of Si particles is significantly increased and the size is greatly refined, as shown in Figure 1(b). Very few Si flakes are observed locally. Thus, the eutectic solidification is basically divorced. At 680ºC and 650ºC, no Si flakes are observed and Si particles become more and smaller, as seen in Figures 1(c-d). The black-grey filiform structure in Figures 1(b-d) was examined by SEM. It is β-Fe phase (demonstrated by Figure 2) along with eutectic θ-Al_2Cu phase. In these two cases, the eutectic solidification is completely divorced.

When pouring at 720ºC, the superheat degree of melt is large. As the melt entered into the temperature range of primary Si phase, the chilling effect of sand mold is greatly decreased that results in a low nucleation rate of primary Si crystal. Divorced growth of eutectic solidification requires that: at the stage of eutectic reaction (L→α-Al+Si), Si atom should epitaxially grow on the surface of Si crystals which have formed at the filling and subsequent cooling stages. In the case of pouring at 720ºC, before the melt enters the temperature range of the eutectic reaction, the formed Si crystals aren't abundant that makes the melt oblige to be undercooled to lower temperature where normal and coupled eutectic nucleation and growth of α-Al+Si phases occur, thus, flake-like or needle-like eutectic Si phase is formed.

With the decrease of pouring temperature, when the melt went thorough the runner and mold walls, the chill-cooling nucleation effect of primary Si phase at the filling stage was greatly enhanced. A great amount of fine Si crystals have formed in the melt. At the subsequent cooling stage, the growth of these Si crystals in the temperature range of primary Si phase rejectes Cu solute in front of liquid at the liquid/solid interface, which causes consitutional supercooling that leads to the continous formation of new Si crystals. It is also important for the divorced eutectic growth. When the liquid enters the temperature range of the eutectic reaction, there are enough abundant and fine Si crystals in liquid. At the same time, the mold walls havre been heated and the cooling ability has been weakened that can't provide the required undercooling for the coupled nucleation of eutectic. Thus, in this case, the Si atoms in liquid prefer to grow on the pre-existed Si crystals epitaxially, leaving Al atoms along. In this way, divorced growth of eutectic occurs. At 680ºC and 650ºC, the chill-cooling nucleation effect becomes more great, thus the amount of Si particles becomes more and the size becomes smaller.

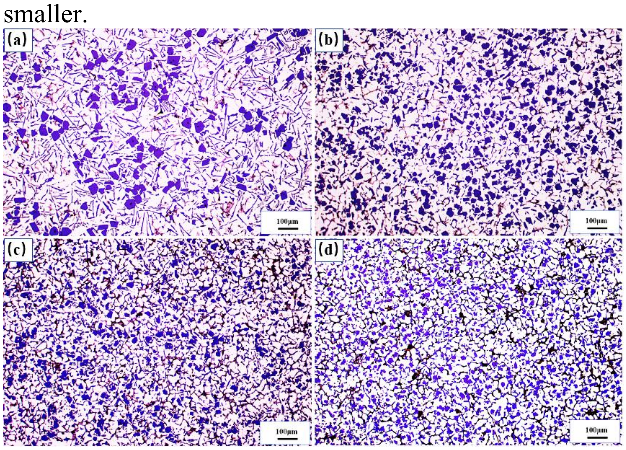

Fig. 1Microstructure of Al-18Si-5Cu-0.1P alloy cast in sand mold at different pouring temperatures: (a) 720oC；(b) 700oC；(c) 680 oC；(d) 650 oC

4 Mechanical Property

Table 1 lists the obtained data of tensile mechanical property. In both as-cast and T6 states, divorcing of eutectic growth of hypereutectic Al-18Si-5Cu-0.1P alloy results in a significant simultaneous improvement in strength and plasticity. In as-cast state, UTS of the un-divorced sample (at 720ºC) is 110MPa and EL is 1.3%, however, UTS and EL of the completely divorced sample (at 650ºC) are 176MPa and 2.5%, respectively, significantly increased by 60.0% and 92.3%. As seen in Figure 1, the divorced eutectic growth greatly refines Si particles, from 39.17μm (in sample at 720ºC) to 16.82μm (in sample at 650ºC) and the shape factor of Si particles is greatly improved from 0.64 to 0.78. At the same time, it makes needle-like eutectic Si disappear completely. During tensile deformation, spiculate edges of primary Si particles and eutectic Si needles severely cut the matrix and cause severe stress concentration that leads to a quick failure, thus the un-divorced sample has lower strength and elongation. After the divorcing of eutectic growth, the eutectic Si needles completely disappear and Si particles are significantly refined and rounded. The cutting effect is greatly reduced. Thus, the matrix can bear more deformation. Therefore, both the strength and elongation are greatly increased simultaneously.

Table 1 Data of Tensile Mechanical Property of Specimens of Al-18Si-5Cu Alloy in Diffirent States

Specimens		R_m /MPa	Elongation%
720 ºC	As-cast	110±8	1.3±0.2
	T6	137±8	1.7±0.2
700 ºC	As-cast	124±3	1.8±0.2
	T6	179±3	2.2±0.2
680 ºC	As-cast	146±7	1.9±0.3
	T6	234±7	2.7±0.3
650 ºC	As-cast	176±6	2.5±0.1
	T6	293±6	2.8±0.1

T6 treatment results in a great increase in both UTS and EL. The increase in strength is due to precipitation hardening effect of nano-size sub-stable particles of θ phase. The improvement in elongation might be related to the divorced eutectic growth. In T6 state, UTS and EL of the un-divorced sample (at 720ºC) are 137MPa and 1.7%, respectively, and of the completely sample (at 650ºC) are 293MPa and 2.8%, respectively. The divorcing effect of eutectic growth greatly improves the strength and elongation of hypereutectic Al-18Si-5Cu-0.1P alloy, by 113.9% and 64.7%, respectively.

Conclusion

(1) Divorced eutectic growth in Al-18Si-5Cu alloy was successively achieved in sand casting. The pouring temperature plays an important role in it. At 680 °C and 650ºC, it is completely divorced, companying with significant refinement of Si particles and considerable improvement in its shape factor.

(2) The divorced eutectic growth significantly improves the mechanical property both in UTS and EL. In as-cast state, compared with the un-divorced alloy, the values of UTS and EL of the completely divorced alloy are increased by 60.0% and 92.3%, and, in T6 state, by 113.9%和 64.7%.