中文摘要

過共晶鋁-矽合金以質輕和耐磨著稱，在汽車製造業方面被廣泛地使用。改善這些合金的強度和加工性的主要方法，就是使其初晶矽顆粒分佈均勻與細微化。不過，傳統的鑄造很難得到這些細微的初晶矽顆粒。另一方面，雖然傳統的粉冶金方法能獲得較好微細化的矽顆粒，卻又不容易生產複雜形狀的零件。

本論文將開發一種新的過共晶鋁-矽合金成形方法，其結合了觸變成形和粉末冶金製程，而可以輕易製造複雜形狀的零件，同時得到微細化的材料組織。

觸變成形是一種金屬半固態成形之方法；此方法係將球狀晶粒構造的原材料，加熱到半融熔狀態，再用傳統壓鑄機加以擠壓成形。首先將粉末壓製成預形體，然後將其加熱至半固態，最後再加以壓鑄成形。本文首先研究製程可行性，進而優化製程參數。實驗結果證明使用粉預形體製造的半固態成形的過共晶鋁矽具有微細的微觀組織，同時成形的試片內部幾乎無傳統壓鑄常見的氣孔與縮孔的缺陷，證實此一新方法淨似成形過共晶鋁矽合金是可行的。

本論文也探討各種半固態成形條件對於鋁-矽過共晶合金試片強度的影響。實驗結果證明，較大的粉末顆粒(120~300μm)、較高的粉末預形體密度 (~90%)、提高感應加熱速率以及提高粉末半固態成形的塑性變型量等可以得到較佳的粉末半固態成形體的強度。

除了製程條件的探討外，本論文也研究利用此一新方法所製造合金之強度與磨耗性能。觸變成形所合金粉末包含 Al-25Si-2.5Cu-1Mg 和 Al-20Si-5Fe 兩種。爲了與傳統作一比較，本實驗同時以傳統傳統觸變成形 Al-25Si-2.5Cu-1M 和以一般鑄造成形 Al-12Si-1Cu-1Mg (商業合金 LM13)。實驗結果證明利用粉末預形體來觸變成形的過共晶鋁矽合金比傳統方法製造的合金，具有較高的強度與更優良的抗磨耗性能，尤其當合金經過 T6 處理的或者在高負荷下的磨耗性能。主要的原因是因為前者具有非常微細的初晶矽顆粒，可以降低磨耗表面的材料從這些矽顆粒產生脆性破裂而產生的磨耗作用。

關鍵字： 過共晶鋁-矽合金； 粉末冶金； 半固體成形

ABSTRACT

Hypereutectic Aluminum-Silicon (Al-Si-X) alloys are well-known for their lightness and good wear resistance, and thus are widely used in the automobile industry. Fine primary Si particles distributed evenly in these alloys improve their strength and machinability. However, it is difficult to create the fine Si particles using conventional ingot metallurgy (IM) routes. Meanwhile, although powder metallurgy (PM) can create the fine Si particles, it is less effective for producing net-shapes involving complex components.

The main object of this dissertation is to assess a new process, introduced as powder thixocasting, for achieving net-shape forming of hypereutectic Al-Si alloys with fine and uniformly distributed primary Si particles. The method combines the techniques of powder densification and semi-solid metal forming (SSMF).

SSMF is a metal forming process in which metals were processed at their semi-solid state. Traditionally, SSMF includes thixocasting and rheocasting. In thixocasting, the feedstock used for semi-solid forming is reheated from its solid state; while in rheocasting, the feedstock is usually fabricated by stirring and cooling a melt to a semi-solid state. Currently, neither of these two SSMF processes can successfully fabricate hypereutectic Al-Si-X alloys containing very fine Si particles. This inability results from the fact that the semi-solid feedstock used in the two processes is typically fabricated using the IM method, while the alloy melt solidifies slowly, making it difficult to refine the microstructure.

In this work, consolidated preforms made of gas-atomized and prealloyed Al-25Si-2.5Cu-1Mg-0.5Mn powder were used as the feedstock for thixocasting. The alloy powder was preheated under protection of argon atmosphere and then was compacted to form powder preforms. The powder preforms were quickly heated into semi-solid state by induction coils and were immediately thixocast using a die-casting machine. A die with a center gate, a long runner and plate-shaped cavities was designed to examine the feasibility of this process. An optimization of the processing procedures and examinations of the properties of the thixocasting components were

made in this dissertation. Besides, a conventional thixocasting using feedstock made by the ingot metallurgy (IM) route was also conducted for comparison.

Experimental results demonstrate that the thixocast specimens produced using powder preforms have better strength and finer Si particles than those produced using the IM feedstock, verifying that the proposed method is feasible. Fractographs show that the strengths were strongly affected by the detrimental oxides that originated in the powder-compacts, and that the oxides could be effectively eliminated by plastic deformation during thixocasting. Isothermal heat-treatment tests of the powders revealed two distinct ranges of Si grain-coarsening rates in the semi-solid temperature range. The Si grains ripened slowly at temperatures from 540℃ to 560℃, considered as the appropriate processing temperature range for obtaining fine Si grain. This low coarsening rate was explained by the diffusion of Si through the semi-solid matrix that only consists of a little liquid, since Si diffuses in solid Al much more slowly then in liquid Al. This novel process was also successfully used to fabricate compressor scrolls for demonstration.

The wear performance of an Al-25Si-2.5Cu-1Mg alloy prepared by powder thixocasting was studied using a pin-on-disc machine. LM13 and an Al-25Si-2.5Cu-1Mg alloy prepared by conventional ingot metallurgy were also investigated for comparison. The sliding tests were performed under ambient conditions and without lubricant. During the tests, the applied load was increased stepwise until wear seizure occurred. Experimental data reveal that the powder thixocast alloys exhibit better wear performance than that of conventional alloys, especially under heavy load conditions and following T6 treatment. This work demonstrates the potential of the new method, powder thixocasting, for fabricating hypereutectic Al-Si-X alloys with a high wear resistance. Moreover, the variation in the wear rate with the applied load for the alloy can be divided into three regions. The mechanisms associated with these wear regions were discussed based on the investigations of the worn subsurface and the wear debris.

Keywords: Hypereutectic Al-Si alloys; Net-shape forming; Semi-solid metal forming; Thixocast; Powder consolidation