行政院國家科學委員會專題研究計畫　期中精簡報告

過共晶鋁矽合金粉末成形新方法之研究(1/3)

計畫類別：個別型計畫
計畫編號：NSC91-2216-E-009-022-
執行期間：91 年 08 月 01 日至 92 年 07 月 31 日
執行單位：國立交通大學材料科學工程研究所

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報告類型：精簡報告

處理方式：本計畫可公開查詢

中　華　民　國 92 年 5 月 8 日

過共晶鋁矽合金粉末成形新方法之研究(1/3)

A novel method for net-shape forming of hypereutectic Al-Si alloys by thixocasting with powder preforms

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計畫編號：NSC91-2216-E-009-022

Abstract

This work presents a novel and feasible method for net-shape forming of hypereutectic Al-Si alloy parts. Consolidated preforms made of gas-atomized Al-25Si-2.5Cu-1Mg-0.5Mn powder were used as the feedstock for thixocasting. Alloy powders were preheated at a high temperature under protection of argon atmosphere and then compacted in a die to form powder preforms. Then, the powder preforms were quickly heated into semi-solid state by induction coils and were immediately thixocast using a die-casting machine. Results demonstrated that the hypereutectic Al-Si powder preforms exhibits very good formability by this unique process. The powder thixocast products have satisfied strength and substantial structure with fine Si particles, while the processing temperature is suitably controlled.

Keywords: net-shape forming of hypereutectic Al-Si alloy; semi-solid metal forming; thixocasting; powder preform

1. Introduction

Hypereutectic Al-Si alloys have outstanding wear resistance, low thermal expansion and good casting characteristics. They have received broad attention due to their potential applications in automobile and compressor fields, such as spiral scrolls, pistons, engine blocks, pumps bodies, etc [1,2]. Among the net-shape forming methods, casting and powder metallurgy (PM) process are the principal techniques adopted for making hypereutectic Al-Si alloys. However, large and segregated primary Si particles may shorten the tools life on machining and also drastically degrade the mechanical properties of the castings [3]. Increasing cooling rate using rapid solidification process (RSP) can make hypereutectic Al-Si alloy with fine and uniform structure. In conventional PM methods, however, the Al-Si powder is difficultly sintered due to the surface oxide films.

Thixocasting is a metal forming process that solid feedstock billets with non-dendrite microstructures were first heated to semi-solid state and then formed into net-shape components by a conventional die-casting machine [4-6]. In this article, we report a novel method to thixocast hypereutectic Al-Si alloy with feedstock billets made by powder consolidation to replace those made by spray forming. Gas-atomized hypereutectic Al-Si alloy powder was consolidated into billets for thixocasting. Results show that this is a feasible method to fabricate net-shape hypereutectic Al-Si products with promising microstructures and mechanical properties.

2. Experimental procedure

Figure 1 schematically depicts the novel process developed in this study. It includes three steps, namely preparing a powder preform (Figs. 1(a) and (b)), heating the powder preform into a semi-solid state (Fig. 1(c)), and thixocasting (Fig. 1(d)).

The hypereutectic Al-Si powder used were supplied by Valimet Inc, USA, and fabricated by gas-atomization with particle size of 201~300μm. Table 1 lists its chemical compositions.

We prepared the powder preforms with diameter of 76 mm by conventional PM consolidation method. The compacting tool, preheated to a temperature of 250℃, was spray coated with a graphite lubricant to reduce its gall against Al-Si powders during compacting. In order to increase the compressibility to obtain sufficient strength of the powder preforms, we first preheated the powders and then hot consolidated them. Around 950 grams of hypereutectic powder was charged in a steel cup with diameter of 90 mm and was preheated in an electric furnace under the protection of an argon atmosphere, as is shown in Fig.1 (a). Then the annealed powders were immediately transferred to a uniaxial hydraulic press and were consolidated in air with a pressure of 85 MPa, as is shown in Fig.1 (b). The compressibility is referred to the relative density of powder performs, which is the ratio of the density of the preforms to theoretical density of powder.

The powder preforms were heated to semi-solid state using an induction coil, as is shown in Fig.1 (c), with variable power input.

Thixocasting was carried out using a commercial high-pressure die-casting machine. As is shown in Fig.1 (d), a plunger extruded the semi-solid powder preforms into mold cavities to form net-shape components. During thixocasting, the mold temperature were kept at 250℃ by using circulating oil heating system. The extrusion pressure was 90MPa and plunger velocity was 1.0m/sec. The plunger was 84mm in diameter.

Tensile test samples were machined from the thixocast products. The dimensions of tensile specimens are 4×3×15mm in width × thickness × length at gage section. All the tests were performed on a Instron 4469 machine at a strain rate

1.1×10^{-3} s^{-1}. The mechanical data for each condition were obtained from the measurements of 3 specimens.

Microstructure of the thixocast products was investigated by optical and scanning electron microscopes. The specimens were ground and polished and subsequently etched with a 0.5%HF water solution.

3. Results and discussion

Thixocasting is one of a semi-solid metal forming (SSM) process. It generally refers to die-casting of metal slurry that has been heated from the fully solid state to a temperature between solidus and liquidus. The feedstock used for thixocasting should have non-dendritic microstructure, i.e. so-called thixotropic structure [6,7]. Since the gas-atomized Al-Si powder is rapidly solidified, it has near spherical shape in appearance and exhibits fine and non-dendritic microstructure, as are shown in Fig.2. So, the powder substantially has the thixotropic structure and is suitable for thixocasting. However, in the novel method presented here there are still some issues should be concerned. First is how to prepare the powder preforms efficiently; the second is how to prevent the fine structure in gas-atomized powder from coarsening during thixocasting; and finally the oxide film and pores exhibited between individual powder particles in the powder preforms are needed to be eliminated to obtain good strength of thixocast products.

Table 2 illustrates the powder preforms consolidated after preheating to different temperatures. It reveals that if the preheating temperature is below 500℃ the powder preforms will have cracks on the surface and also have low density. The relative density of these powder preforms with preheating temperatures of 550℃, 500℃, 400℃, and 250℃ are 90%, 74%, 66% and 60%, respectively. It shows that the density of the preforms increases as preheating temperature increases. This is clearly due to decrease in strength of the powder under high preheating temperatures, leading to their increased compressibility. These results resemble those obtained by Low [8], who also introduced preheating to increase the compressibility of hypereutectic Al-Si powders.

Our experience indicated that adequate density of the powder preforms is crucial in the powder thixocasting process. If the powder preforms are insufficient compressed, not only they are too weak to be handled but also they have an unacceptable induction-heating efficiency, i.e. it takes very long time to heat them to semi-solid state. This is due to the porosities in the powder preforms may retard the transfer of heat from preform surface to interior during induction heating. Accordingly, in this work, preheating temperatures at 550℃ for 1 hours were used to produce the powder preforms for thixocasting.

In squeeze casting, the pouring temperature was 820℃ and the casting pressure was 90MPa. Figure 3 shows the microstructures of these thixocast products. Due to high solidification-cooling rate, squeeze casting can produce the hypereutectic Al-Si with fine primary Si particles. However, this squeeze casting part still exist very large primary Si particles, about 100~300μm as is shown in Fig.3 (a), while the primary Si particles in the powder thixocast product is only about 15~25μm, shown in Fig.3 (b). The powder thixocast product has small and uniform distribution of primary Si particles, indicating to form net-shape powder product by this method is feasible.

As is well known in conventional powder metallurgy (PM), eliminating the detrimental oxide films and pores in powder performs during densification procedure is very important for aluminum alloy PM products to obtain good strength. To achieve this, techniques of powder extrusion/or forging are usually adopted, in which oxide film of the powder is broken through extensive plastic shearing deformation and this leads to weld together the powder particles. The more extent of plastic deformation, the better strength of the powder forging/or extrusion products [4]. The average tensile strength of these specimens is 232 MPa, and that of the T6 specimen is 304 MPa. The strengths are comparable with those obtained by P. J. Ward [5], who uses extruded spray-forming billets to thixocast the hypereutectic Al-Si alloy. Since the extruded spray-forming billets exhibit few oxide films and pores, this comparable values of strength may indicate the detrimental oxide films and pores of the powder performs are approximately eliminated after powder thixocasting.

The tensile fractographs of the thixocast specimens are shown in Fig. 4. The fractographs show coexisting small dimples and cleavages of silicon particles. Since no deep spherical cavities was observed in these fractographs, decohesion of powder particles in tensile fracture surface did not exist; this is also an evidence of eliminating detrimental oxide interfaces after powder thixocasting.

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4. Conclusions

This study presents a novel method to form-shape hypereutectic Al-Si alloy products with uniformly distributed fine Si particles. This method, termed as powder thixocasting here, uses consolidated powder preforms as feedstock for thixocasting. A thixocasting die with center extrusion gate and a long runner was used to assess the feasibility of this process. Results show that when the Al-Si powder preforms were heated to semi-solid temperature, they exhibited very good formability during thixocasting. The optimum strength of the as-thixocast specimens is 224.7MPa and that of the T6 specimens is 304 MPa.

Powder thixocasting can be considered as a new technique that combining the pressure assisted consolidation in conventional powder metallurgy (PM) and newly developed semi-solid casting. We believe that using this combination can also perform net-shape forming of varieties of materials, such as metal matrix composites and metal alloys with high temperature stabilized precipitates.

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Table 1 Chemical composition of the powder (wt%)

Element	Si	Cu	Mg	Mn	Fe	Ni	Ti	Al	
Rate	24.64	2.56	1.04	0.47	0.16	0.01	0.03	Bal	

Table 2 The densities and ratio of densities of the thixocast Al-Si produces in different position

	Annealing Temp. = 500 C			Annealing Temp. = 550 C		
Specimen	Biscuit	Runner	Plate	Biscuit	Runner	Plate

position						
Density	2.56	2.56	2.61	2.57	2.60	2.61
Ratio of density	0.97	0.96	0.98	0.98	0.97	0.98