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Influence of Silicon, Superheat and Injection Speed on the Fluidity of HPDC Al-Si Alloys

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It is generally known that silicon influences the fluidity of aluminum alloys. There are several techniques to evaluate the fluidity of aluminum for gravity casting such as using spiral or serpentine type mold and vacuum suction test. However, fluidity of aluminum in high pressure die-casting has not been sufficiently studied. Therefore, in this study the relationship between the fluidity and silicon contents as well as superheat of pouring aluminum alloy and injection speed were studied. A serpentine and step type dies for evaluating the fluidity of aluminum were designed and actual die casting experiments were conducted for aluminum by varying the parameters such as superheat, injection speed and the content of silicon. As the silicon contents increased up to 0.8wt%, the fluidity length measured was rapidly decreased but it started to increase with more than 0.8wt%Si. Amount of superheat has significant effect on fluidity as well. Markedly improved fluidity length was quite evident with increased superheat. The fluidity step was filled more with the cleaner melt and even 3 minutes of gas purging increased fluidity value significantly.

Keywords: *fluidity, aluminum alloy, HPDC, superheat, injection speed*

1. Introduction

Recently, the importance and demand for aluminum casting alloys has drastically increased in the automotive, aerospace and electric/electronic industries. Aluminum alloys are well known for their unique combination of mechanical and physical properties, such as light weight, strength and corrosion resistance. Among these alloys, aluminum-silicon alloys are one of the most important casting alloys due to their superior casting characteristics and nearly 90% of all aluminum castings manufactured are silicon-based aluminum alloys [1-5].

High pressure die casting widely used in the production of aluminum components is a net shape manufacturing process in which molten metal is injected into a metal mould at high speeds and allowed to solidify under high pressures [6]. There are several non-ignorable important benefits for using HPDC. HPDC is one of the most economical casting processes and efficient method for producing components requiring good surface finish and high dimensional accuracy [7].

The fluidity is one of the most important characteristics for casting alloys. It needs to note that the fluidity of casting alloys is a measure of the distance a molten material can flow in a specific channel before being stopped by solidification, not a term reciprocal of viscosity. It has been investigated by many researchers but the process variations, especially of metal composition, has not been well documented for most common cast alloys, yet.

There are two types of tests that are widely used for measuring fluidity of an alloy: one is spiral test and the other is the vacuum suction technique (Ragone testing method) [8]. However, those fluidity methods are more suitable to gravity casting conditions. The fluidity of a certain alloy in high pressure die casting (HPDC) needs to be considered differently because it should be evaluated under die casting conditions.

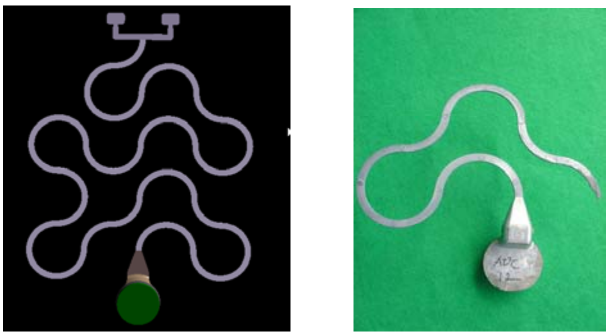
During die casting process, high pressure is applied to molten metal into the die cavity and is maintained throughout the solidification of the casting. Besides the most common factors affecting the fluidity, viscosity, surface tension, impurity and freezing mechanism, applying pressure, die temperature and degree of superheat need to be considered as major factors in measuring the fluidity of aluminum alloys under high pressure die casting condition.

However, still very limited research on the fluidity of aluminum alloys in HPDC process has been conducted. In this regards, the relationship between the fluidity and silicon contents as well as superheat of pouring aluminum alloy and injection speed were studied. A serpentine and step type dies for evaluating the fluidity of aluminum were designed and actual die casting experiments were conducted for aluminum by varying the parameters such as superheat, injection speed and the content of silicon.

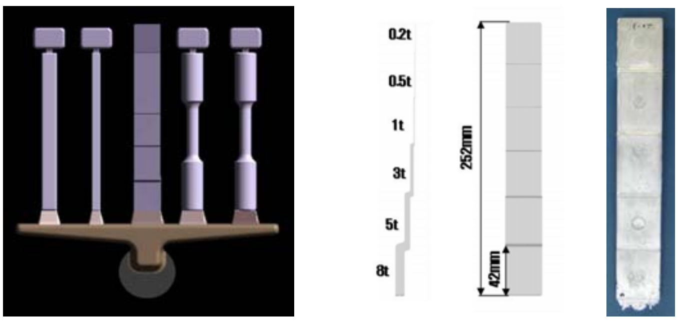
2. Experimental procedure

Two different types of die casting dies were designed and fabricated. As shown in Fig. 1, for evaluating the fluidity of aluminum alloys under die casting conditions, serpentine and step type dies were prepared. The serpentine type die cavity, Fig. 1 (a), consists of continuous circular shape with 90 mm in diameter and thickness and width with 2 and 10 mm, respectively. After the casting was fully solidified, the final length of the metal flows was measured as fluidity of certain alloy system.

The step type die is shown in middle of Fig. 1 (b). There were total of 5 steps with width of 34 mm constant. The thickness was gradually decreased from ingate, 8.0, 5.0, 3.0, 1.0, 0.5, 0.2 mm. The total length was measured as fluidity length of the alloy.



(a)



(b)

Fig. 1 Schematic drawing of fluidity test die for die casting; (a) Serpentine type, (b) Step type

Si-based binary aluminium alloys with 9 different silicon contents of 0, 0.4, 0.8, 1.2, 2.0, 3.0, 11.0, 12.0 and 13.0wt% were melted in electric furnace with the pouring temperature of 670, 720, 770 and 820°C. Commercial pure aluminium ingot with more than 99.8% purity and Al-25%Si master alloy were used for desired compositions. The die was pre-heated up to 180°C using a die temperature controller before the injection of molten metal because maintaining die temperature constant is very important to minimize the additional factors affecting the fluidity of alloy.

The tests were conducted by cold chamber die-casting machine (Locking force: 530ton). The molten aluminum alloy was injected into the die cavity under the conditions of 0.35m/sec in low injection speed until the plunger was travelled up to 370mm in shot sleeve and then the injection speed was accelerated linearly to the high injection speed of 0.35, 0.5, 1.0, 2.0, 3.0 and 4.0 m/sec from 370mm to 390mm in shot sleeve. Table 1 shows the summary of die-casting conditions for this investigation.

Table 1 Die casting experimental conditions

Pouring Temperature		670, 720, 770, 820°C
Die Temperature		180℃
Injection Speed	Low Speed	0.35 m/sec
	High Speed	2.0, 2.5, 3.0 m/sec
Die Open Time		5 sec

3. Results and Discussion

Figure 2 shows the flow the flow length measured under die casting condition. The experiment was conducted at 670°C of pouring temperature by using serpentine type die, as shown in Figure 1 (a). The results exhibited clearly that silicon affects the fluidity of aluminum significantly. As the silicon contents increased up to 0.8wt%, the fluidity length measured was rapidly decreased but it started to increase with more than 0.8wt%Si. Generally, fluidity decreases substantially with alloying in the solid solution region, near the solid solubility limit of the system, and then it increases as the faction of eutectic increases with the highest fluidity at the eutectic composition. The maximum solid solubility of silicon in aluminum at eutectic temperature, 577°C, is about 1.65wt%. The reasons why the minimum fluidity was measured with composition of near 1.65%Si were assumed that the purity of the ingots used and the heat generated during solidification of silicon.

It is also well known that pure metal has higher fluidity than its alloys because of the solidification mode differences. Pure metal solidifies with a progressive mode, therefore the flow of the pure metal will stop at higher fraction of solid than alloys. Because Al-Si system is simple eutectic and they solidify in mushy mode, the fluidity length became less with increased silicon content up to 0.8wt%.

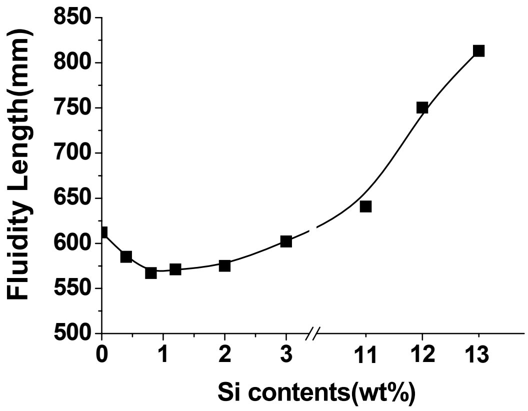


Fig. 2 The results of fluidity serpentine test on the silicon contents

Continuous increase of fluidity beyond the eutectic composition of Al-Si system, about 12%Si, shown in Fig 2 was due to the fact that the latent heat of fusion generated during solidification by silicon is significant, about 3.7 times than aluminum [9]. As a result, the flow length of hypereutectic alloy, Al-13%Si alloy was much longer than that of eutectic alloy, Al-12%Si.

Figure 3 shows the effect of superheat and silicon contents of 11, 12 and 13wt% on the serpentine type fluidity test. Superheat, the difference between the pouring temperature and liquidus temperature, is considered as a key factor influencing fluidity by affecting the viscosity. The result clearly showed increased fluidity with increased silicon content. Amount of superheat has significant effect on fluidity as well. Markedly improved fluidity length was quite evident with increased superheat. Several researchers investigated a relationship between fluidity of a given alloy and its superheat or pouring temperature and found linear relationship between them [10-14]. The tests were conducted in spiral sand casting and the same phenomenon was observed in die casting, as well.

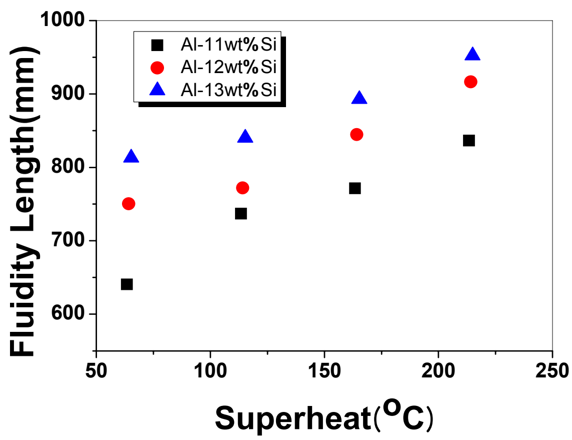


Fig. 3 The effect of silicon contents and superheat on fluidity

Dissimilar to gravity casting, die casting uses high pressure generated by accumulator to fill the die cavity. Therefore, the fluidity length must be governed by applying pressure or the injection speed in die casting process. Step type die design, Figure 1(b), and Al-1.0wt%Si alloy was used for the experiment.

By changing the high injection speed from 2.0 to 3.0m/sec, the flow length of step was measured and displayed in Figure 4in Al-11.0%Si alloy. The figure also shows the effect of melt cleanliness on fluidity under die casting condition. The alloy was cleaned by purging nitrogen gas to remove dissolved gas and inclusions. The melt cleanliness is one of the most significant factors affecting fluidity because inclusions within the melt should effectively decrease the fluidity of the alloys.

Melt treatment time was varied from 0 to 10minutes and the effective flow length was measured. It is apparent from the result that fluidity step was filled more with the cleaner melt and even 3 minutes of gas purging increased fluidity value significantly.

Step type fluidity test die with thickness of 8.0, 5.0, 3.0, 1.0, 0.5 and 0.2 mm was used to analyze the injection speed effect on fluidity. While 0.5mm thickness and 42mm long cavity was successfully filled with 2.5m/sec of injection speed, 0.2mm was too thin to fill even with high fluidity alloy studied, Al-11%Si. By using cleaned melt by gas purging and very high injection speed of 3.0m/sec started to fill 0.2mm thickness cavity. It is because of fact that with high injection speed used to inject molten metal into the cavity, the alloy can flow at much higher solid fractions than under low injection speed conditions.

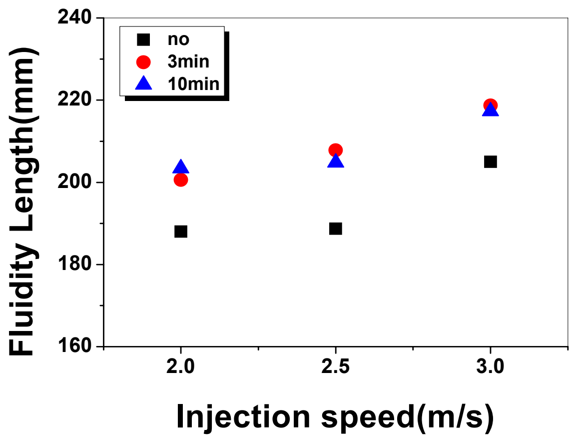


Fig. 4 The effect of melt treatment and injection speed on fluidity

4. Conclusion

1. The serpentine and step type die were designed for evaluation the fluidity of aluminum on die casting process.
2. As the silicon contents increased up to 0.8wt%, the fluidity length measured was rapidly decreased but it started to increase with more than 0.8wt%Si. The reasons why the minimum fluidity length was measured with composition of near 1%Si were assumed that the purity of the ingots used and the heat generated during solidification of silicon.
3 Amount of superheat has significant effect on fluidity as well. Markedly improved fluidity length was quite evident with increased superheat.
4. By increasing the high injection speed from 2.0 to 3.0m/sec, the flow length of step was increased. With high injection speed used to inject molten metal into the cavity, the alloy can flow at much higher solid fractions than under low injection speed conditions.
5. The melt cleanliness is one of the most significant factors affecting fluidity length because dissolved gas and inclusions within the melt should effectively decrease the fluidity of the alloys.

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