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Influence of refining process on the porosity of high pressure die casting alloy Al-Si

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Abstract

This study presents research results of the influence that refining and transfer of AlSi12S alloy on the porosity of high pressure die-castings. Tests were conducted under production conditions of Die-casting Foundry META-ZEL Sp z o.o. The operation of refining was conducted in a melting furnace, with the use of an FDU Mini Degasser. Decay of the refining effect was assessed by evaluating the porosity content and metallographic examination.

Key words: aluminum-silicon alloy, high pressure die casting, molten metal refining, porosity content

1. Introduction

In high pressure die castings made of aluminum-silicon alloy, gas porosity, shrinkage porosity and a combination of both are present. Pure gas porosity may occur in castings of a properly developed feeding system but made of excessively gassed alloys [1].

The reason for creating gas porosity in castings is to lower gas solubility in the process of liquid to solid state transition of metal. The main source of gas porosity is hydrogen which is 90% of the total gas volume in the alloy. At solidification of hypo-eutectic aluminum-silicon alloys, at the first stage of crystallization, phase α(Al) is created. As a result, liquid is enriched with silicon, alloy-forming elements and hydrogen. At an adequately high proportion of solid phase, the hydrogen concentration is so high that gas cavities may occur [2]. Gas cavities occur before the crystallization front, between branches of growing dendrites.

To lower the hydrogen content in aluminum-silicon alloys, the gas refining process is used. An effective refining method is barbotage refining [3].

Improvement of the high pressure die castings quality by lowering their gas porosity is significant due to their material content.

The aim of this work was to assess the influence of barbotage refining as well as the influence of multiple transfers of ALSi12S alloy on its porosity (porosity content).

2. Material and experimental conditions

The material for testing was AlSi12S alloy prepared on the basis of pigs, process scraps and swarfs. The chemical composition of AlSi12S alloy used for the experiment has been presented in Table 1.

The melting process of the metal charge was conducted in an electrical induction furnace of average frequency (250 Hz), produced by Junker GmbH, of a maximum capacity 1,200 kg. The furnace burden was calculated as 1,000 kg.

In the case of the 1st and 3rd melt, process scraps (20%) and pigs (20%) were introduced to the furnace. When they melted, swarfs (20%) were introduced, and then the remaining pigs.

In the case of the 2nd and 4th melt, first process scraps (40%) were introduced to the furnace, then pigs (60%).

Table 1. Chemical analysis of AlSi12S alloy.

Melt no.	Element content, % weight						
	Si	Cu	Fe	Mn	Zn	Ti	Al
I	11,83	0,111	0,49	0,064	0,103	0,015	rest
II	11,88	0,112	0,53	0,074	0,109	0,011	rest
III	11,86	0,110	0,51	0,061	0,098	0,014	rest
IV	11,90	0,113	0,52	0,072	0,108	0,012	rest

Melt number and charge material:
1st – pigs (60%) + process scraps (20%) + swarfs (20%), non-refined,
2nd – pigs (60%) + process scraps (40%), refined,
3rd – pigs (60%) + process scraps (20%) + swarfs (20%), refined,
4th – pigs (60%) + process scraps (40%), refined,

At the first stage of examination, the porosity content of non-refined alloy was evaluated, as well as the porosity content of high pressure die castings made of this alloy. Such tests were conducted on the alloy from the 1st and 2nd melt. As the alloy was prepared in the melting furnace, it was heated to 720 °C, and the surface of molten metal was uncovered to take samples for evaluation of the porosity content and metallographic tests. The samples were poured into a steel die (Fig. 1).

a)

b)

Fig. 1. Taking a sample to evaluate the porosity content and measuring the molten metal temperature with an immersion thermocouple –a). Samples for testing the alloy porosity content –b)

Then, the alloy was poured into a transport ladle of a 200 kg capacity. As the surface of the molten metal was cleaned, samples were taken from the ladle to evaluate the porosity content and conduct metallographic tests. The ladle was transported to the pressure machine stand. As the liquid alloy achieved 690 °C, the pressure mould was poured with the metal. 10 castings were made of each melt. Samples for porosity content evaluation were taken of the castings (Fig. 2).

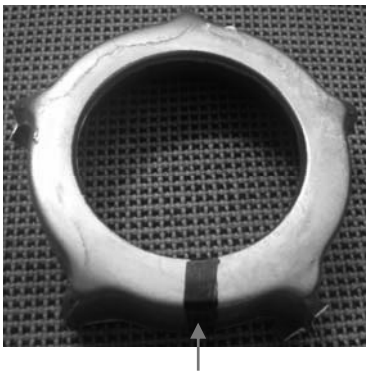


Fig. 2. Place from which samples were taken to evaluate the porosity content of high pressure die castings

Porosity content was calculated of the following formula:

$$P = \frac{\rho_t - \rho}{\rho_t} \cdot 100\% \qquad (1)$$

where: ρ_t – theoretical density, ρ - material density [3]

At the second stage of examination, the porosity content of barbotage refined alloy was evaluated, as well as the porosity content of high pressure die castings made of this alloy. Such tests were conducted with the alloy from the 3rd and 4th melt.

After the molten metal was prepared in the melting furnace, it was heated to 720 °C. The barbotage refining was conducted in the melting furnace. An FDU Mini Degasser was used for this purpose (Fig. 3). The argon output at refining was established as 22 l/min. The rotor speed of rotation was 500 rpm.

Fig. 3. FDU Mini Degasser for barbotage refining

To determine the influence of molten metal refining time on the porosity content it was assumed that the samples would be taken every two or four minutes during refining. At time intervals established, steel dies were poured for porosity content evaluation. The total time of refining was 20 min.

After the refining process finished, covering granular (Ecremal) was spilled over the molten metal surface to bind the non-metallic inclusions.

Then, the metal was poured into the ladle and transported to the high pressure die casting stand. Once the metal achieved 690 ^{o}C, samples were cast for porosity content evaluation, as well as to high pressure die castings. Later, samples for porosity content evaluation were taken of the castings.

Then, the metal was poured into the pressure machine heating furnace. The furnace was of a 250 kg capacity. After oxides were taken of the surface of molten metal, samples were taken for porosity content evaluation and 10 castings were made. Samples for porosity content evaluation were taken of the castings.

To establish the influence of time of keeping molten metal in the furnace at the pouring stand (75 minutes and 120 minutes after the end of refining) on the porosity content, samples were cast and 10 high pressure die castings were made.

3. Experimental results and analysis

Results of the porosity content evaluation of non-refined AlSi12S alloy (1st and 2nd melt) samples taken from the melting furnace, transport ladle and high pressure die castings have been presented in Table 2.

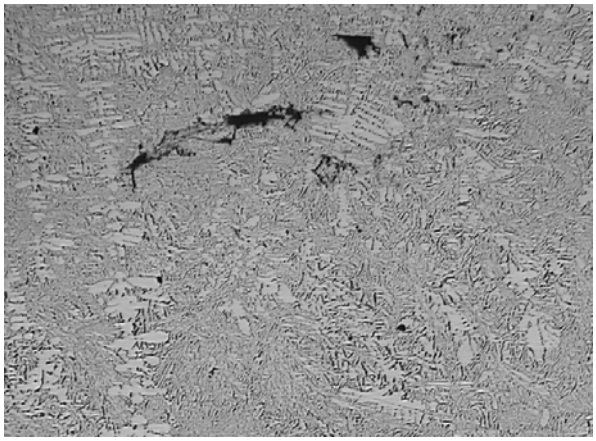
Table 2. The porosity content of the AlSi12S ration evaluated for samples cast in the die and for samples taken from high pressure die castings. 1st and 2nd melt. Non-refined alloy

Melt no.	Location of sampling	Porosity content P, %	
		castings of the die	high pressure die castings
I	inductive furnace	2.8	-
	transport ladle	3.3	5.6
II	inductive furnace	2.6	-
	transport ladle	3.1	5.5

The results obtained indicate that non-refined alloy has a high value of porosity content, i.e. 2.8% (1st melt) and 2.6% (2nd melt). As a result of flowing alloy from the melting furnace to a transport ladle the grows by 0.5%. The porosity content of high pressure die castings material made of the alloy taken from the ladle equals 5.5÷5.6% and is approx. 70% higher than the porosity content of the material of sample poured into the die. Results of metallographic tests confirm the results of porosity content evaluation. They indicate there are discontinuities in the sample material.

Example microstructures of AlSi12S alloy samples (1st melt) cast in the die have been presented in Fig. 4.

a)



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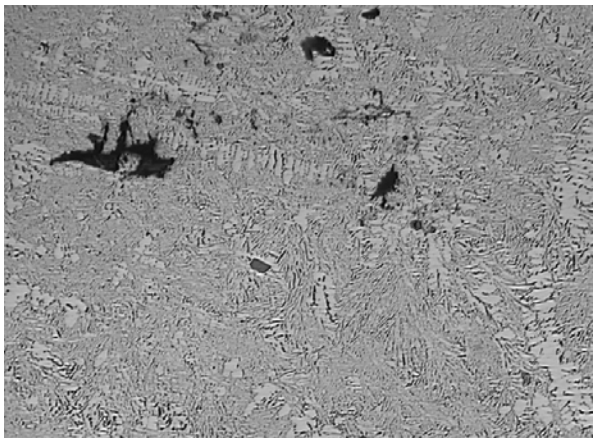


Fig. 4. Example microstructure of AlSi12S from the 1st melt (non-refined alloy). Sample taken from the furnace –a). Sample taken from the ladle –b) Magnification 100x

Values of the porosity content of AlSi12S alloy samples (3rd and 4th melt), taken from the melting furnace at refining, from the transport ladle and from the furnace at the pressure machine, as well as of the samples taken from high pressure die castings made of the alloy taken from the transport ladle and furnace at the pressure machine have been presented in Table 3. The results are also presented graphically in Fig. 5.

An example microstructure of AlSi12S alloy samples (3rd melting) cast in the die during barbotage refining has been presented in Fig. 6.

An example microstructure of refined alloy samples, cast in the die, taken from the transport ladle and from the furnace at the pressure machine has been presented in Fig. 7. Samples of the transport ladle were taken every 5 minutes counted after the end of refining. Samples of the transport ladle were taken after 10 and 75 minutes counted after the end of refining.

Table 3. Results of porosity content evaluation for samples of AlSi12S alloy (refined)

Time passed	Porosity content P, %			
	Samples cast in dies		Samples taken from castings	
	3rd melt	4th melt	3rd melt	4th melt
initial state	2,5	2,4	-	-
2 minutes of refining	2,2	2,1	-	-
4 minutes of refining	2,0	1,8	-	-
6 minutes of refining	1,9	1,7	-	-
8 minutes of refining	1,8	1,7	-	-
10 minutes of refining	1,6	1,6	-	-
12 minutes of refining	1,5	1,4	-	-
16 minutes of refining	1,5	1,4	-	-
20 minutes of refining	1,5	1,4	-	-
5 minutes after refining (after pouring to transport ladle)	1.7	1.5	4.3	4.2
10 minutes after refining (after pouring from ladle to the furnace at the pressure machine)	1.9	1.7	4.8	4.7
75 minutes after refining (after half emptying of the furnace at the pressure machine)	2.0	1.9	5.0	4.8
120 minutes after refining (after leaving a quarter of the furnace charge at the pressure machine)	2.1	2.0	5.1	5.0

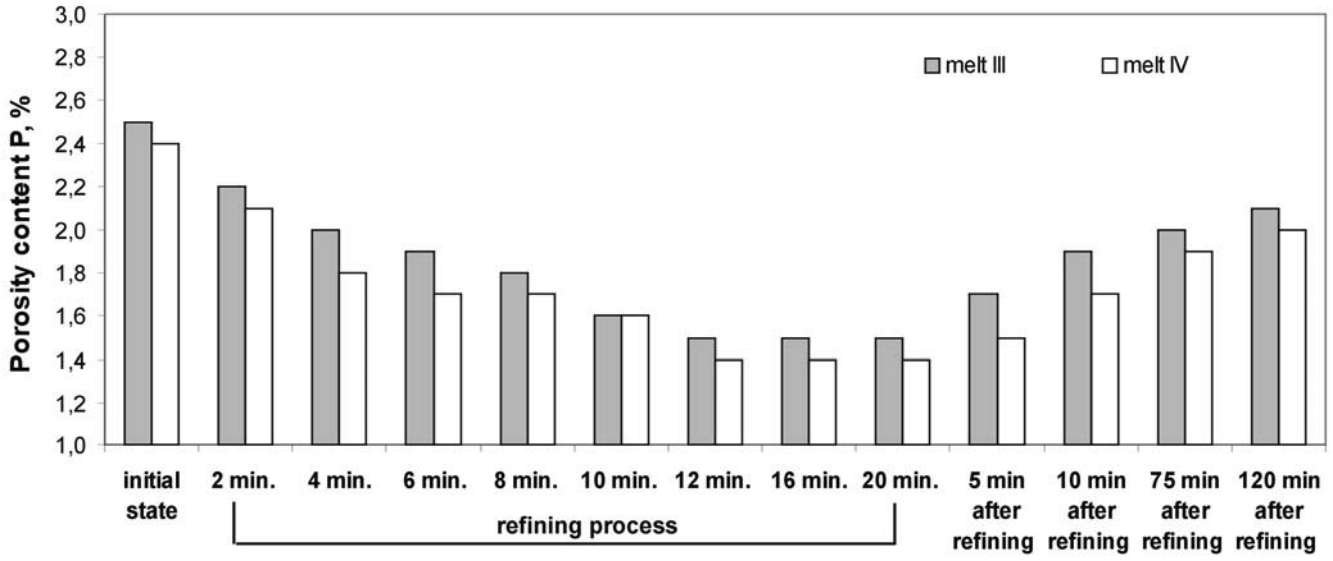
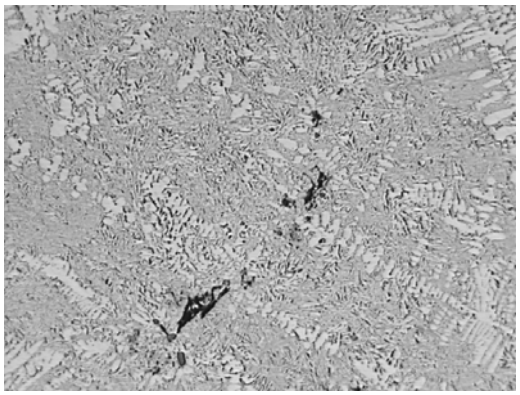


Fig. 5. Value of the porosity content of AlSi12S alloy samples cast to the die, as the time passes since the metal charge is molten until the pouring process finishes

a)



b)

c)

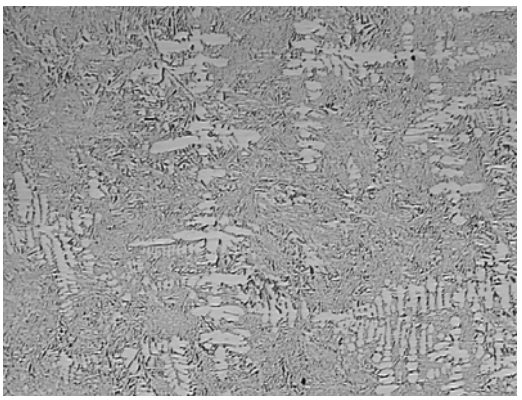
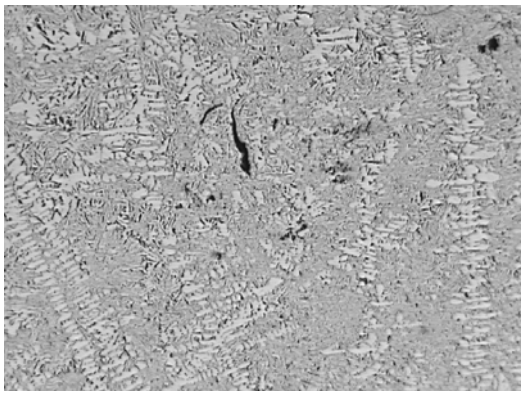


Fig. 6. Microstructure of AlSi12S alloy from the 3rd melt. Sample taken from the furnace after metal is molten –a). Sample taken from the furnace after molten metal is refined, within 4 minutes –b). Sample taken from the furnace after molten metal is refined, within 12 minutes –c). Magnification 100x

a)



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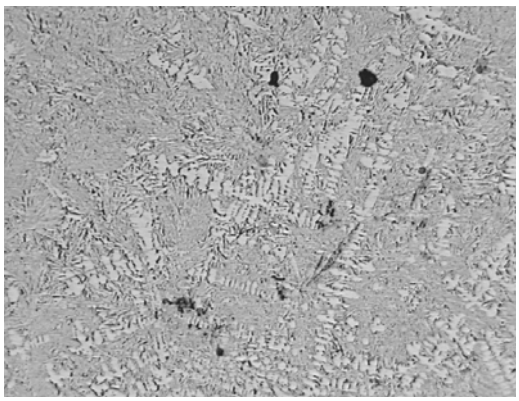

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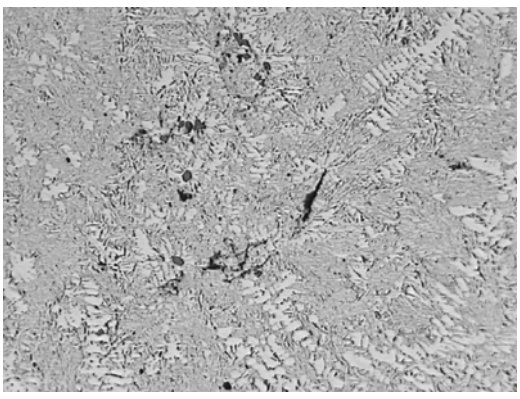

Fig. 7. Microstructure of AlSi12S alloy from 3rd melt, after refining and pouring to the transport ladle (5 minutes after refining) –a). Microstructure of the AlSi12S alloy after refining and pouring from the transport ladle to the furnace at the pressure machine (10 minutes after refining) –b). Microstructure of AlSi12S alloy in the furnace at the pressure machine, 75 minutes after refining –c). Magnification 100x

The results obtained indicate that the initial alloy for testing the 1st – 4th melt was characteristic of the porosity content between 2.4% and 2.8%. There was no evidence that the use of swarfs increased the alloy porosity.

Research on the influence of the alloy (from the 3rd and 4th melt) refining time on its quality has revealed that after 12 minutes the porosity content was established at 1.5 and 1.4%, respectively. Increasing the refining time to 20 minutes did not limit this value. It was found that transferring the alloy and time passing after the end of refining are accompanied by an increase of alloy porosity content. Pouring the alloy to the transport ladle and passage of 5 minutes after the end of refining caused an increase in porosity content of 0.1÷0.2%. Pouring the alloy from the transport ladle to the furnace at the pressure machine and passage of 10 minutes after the end of refining caused an increase in porosity content of another 0.2%. As the time of keeping liquid alloy in the furnace at the pressure machine was passing, the alloy gassing was increasing. 75 minutes after the end of refining the porosity content increased by 0.1%. After another 45 minutes, the value increased again by 0.1%. The maximum time for keeping liquid alloy in the furnace at the pressure machine, assumed for the examination, ensured complete removal of molten metal during the machine operation.

An analysis of porosity content of material of samples cast in the die as well as of high pressure die castings material indicate that in the case of non-refined casting porosity is always higher for the casting material. This is an effect of additional gassing of metal during another transfer at pouring the molten metal to the loading chamber, of interaction between piston lubricant combustion products with mould coating and a turbulent flow of metal at filling the pressure mould cavity.

Material porosity analysis of samples cast in the die of the refined alloy taken from the ladle indicates that the porosity content decreases to 1.5%-1.7%, compared to 3.1%-3.3% in the case non-refined alloy is used.

Material porosity analysis of high pressure die castings made of the alloy taken from the ladle indicates that refining helped to lower the porosity content to 4.2%-4.3%, compared to 5.5%-5.6% in the case non-refined alloy is used.

As the time of keeping liquid alloy in the furnace at the pressure machine was passing, further gassing of the alloy was taking place, which resulted in an increase in the casting porosity content 10 minutes after refining the casting porosity content was 4.7-4.8%, after 75 minutes it was 4.8-5.0% and after 120 minutes it was 5.0-5.1%.

Comparison of the material porosity content of the castings made of non-refined and refined alloy indicates that despite one more transfer of liquid alloy in the second case, a lower casting porosity is achieved.

4. Conclusion

The barbotage refining of AlSi12S alloy allowed for an effective reduction of alloy porosity (porosity content). With the refining parameters used in this work (rotational speed 500 rpm, argon flow rate 22 l/min, 1,000 kg of alloy), a satisfactory effect was achieved after 12 minutes.

It was found that the material porosity content of high pressure die castings is much higher than the liquid alloy porosity content assessed with the samples cast in the die. This is an effect of increased gassing of alloy during another transfer at pouring the molten metal to the loading chamber, of interaction between piston lubricant combustion products with mould coating and of turbulent flow of metal at filling the pressure mould cavity.

Transferring liquid alloy and time passing after the end of refining caused an increase in gassing and thus increased the pressure mould porosity.

The process of refining the liquid AlSi12S alloy, despite multiple later transfers (furnace/ladle/furnace at pressure machine/ pressure mould pouring) and 120 minutes after the end of refining, allowed for obtaining castings of less porosity than in the case of using a non-refined alloy.

The results indicate that barbotage refining in the furnace at the pressure machine would allow for better use of effects of liquid alloy enrichment.

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