ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 8
Issue 3/2008

29 – 36

6/3

Structural analysis of aluminum skeleton castings

M. Cholewa, M. Dziuba-Kałuża*
Foundry Department, Institute of Materials Engineering and Biomaterials, Faculty of Mechanical Engineering,
Silesian University of Technology, 44 – 100 Gliwice, Towarowa 7, Poland
* Corresponding author. E-mail address: maria.dziuba@polsl.pl

Received 18.04.2008; accepted in revised form 29.04.2008

Abstract

In this article authors showed method for manufacturing of skeleton castings with continuous external surface. Wall thickness of the external surface was 6 mm. The experimental casting was manufactured in order to verify the results of filling mould cavity which were obtained by numerical simulation. The aluminosilicate core was used to produce experimental aluminum skeleton castings with dimensions of (115x65x136) mm. Lower ingate with vertical getting system was used. On based on numerical simulations and preliminary experimental tests technological conditions were determined, which enables obtained castings on repeatable satisfactory geometry and requirement quality.

Degree of refinement of structure in typical region of skeleton casting was compared. Qualitative and quantitative different degree of fineness of eutectic was confirmed. Selection of modification conditions AlSi alloy of skeleton casting is necessary. Based on tests, which were performed authors deduced, that manufacturing of skeleton castings is possible with use of traditional casting technology, without use of expensive laboratory – devices, with applied classical gating system and typical pouring temperature of Al alloys (ex. 740ºC).

Keywords: Cellular material; Skeleton casting; Structure; Core; AlSi alloy

1. Introduction

Skeleton castings belong to the group of materials with open cells due to their structure [7,8,9,10], which develop rapidly and find application in today industry. Process manufacturing of skeleton castings enables obtained functionally similar materials with use of traditional casting technology, without use of expensive laboratory – devices. This is a important advantage this materials in comparison to other porous materials, which are using in today industry.

The skeleton casting was be an alternative for porous materials or method of manufacturing. And also it's making up supplement of production technology these groups of materials- also for technology of metallic foams [5,6].

Describe process of manufacture of skeleton casting depends on representing in classic core the geometrical, spatial and repeatable structure of channels. These channels are of specified shape and the dimension of sections.

Process of production of skeleton castings with optional shape and overall dimensions was limited only by ability of penetration the channels of core by liquid metal.

The classic techniques of forming enables manufacturing of opened skeleton castings – with discontinuous external surface and with walls, which closing internal skeleton. The presented in article experimental casting was an verification of numerical simulation results [12,13,14]. The research and experimental test having on aim selection of technological agents, which were shaping process of filling the mould cavity by circa eutectic alloy of Al - Si.

2. Method and result of research

Aluminosilicate material was used for making cores of experimental skeleton castings. Example of core was shown in fig. 1.

In core was reproduction channels on circular section. This channels are creating crystal lattice. Diameter of channels is 5 mm. Channels of core are creation connectors of skeleton. This connectors correspond to the sides of cube. The sides of cube are 15 mm.

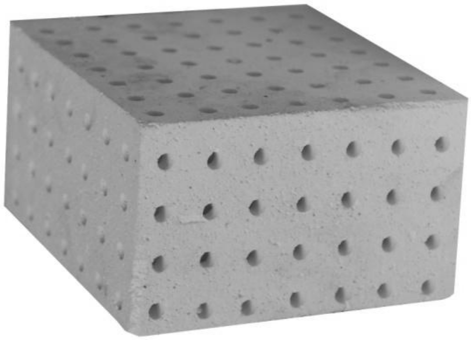


Fig. 1. Aluminosilicate core of skeleton casting

The results of filling ability of metal in interior channels of the core, which were obtained by numerical simulation were verified by experimental research and analysis of structural properties and then analysis of useable properties of skeleton casting.

Experimental test are realized according to Hartley's experiment plan. Basic experiment plan includes performance of 11 experiments (fig. 2), in which input factors are:

1. Pouring temperature (range 680 ÷ 740ºC)
2. Temperature of mould (range 20 ÷ 100ºC)
3. Height of gating system (range 230 ÷ 300mm)

Output factors of process are:

1. Filled space of mould
2. Microstructure of casting
3. Mechanical properties of casting

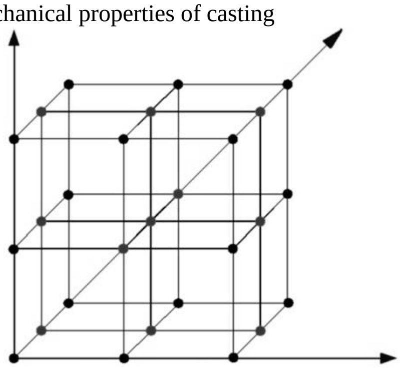


Fig. 2. Hypercube of Hartley's experiment plan three – levels

Experiment plan assumes three levels of controlling factors X: minimal (-1), central (0) and maximal (1). These factors are estimate according to formulas:

$$\check{X} = \frac{X - \bar{X}}{\Delta X} = \frac{2\alpha \cdot (X - \bar{X})}{X_{max} - X_{min}}$$

$$\Delta X = \frac{X_{max} - X_{min}}{2\alpha}$$

$$\bar{X} = \frac{X_{max} + X_{min}}{2}$$

where:

$\check{X}$ – controlling factor of modeling,

$\bar{X}$ – central value of factor on actual scale,

X – factor on actual scale,

ΔX – variation of controlling factor,

α = 1, experiment design based on hypercube.

1. Computation of central value (computation of input factors on the level 0) on pouring temperature, temperature of mould and height of gating system:

$$\bar{X}_{Tzal} = \frac{740°C + 680°C}{2} = 710°C$$

$$\bar{X}_{Tformy} = \frac{100°C + 20°C}{2} = 60°C$$

$$\bar{X}_{h} = \frac{300mm + 230mm}{2} = 265mm$$

2. Computation of variability units on pouring temperature, temperature of mould and height of gating system:

$$\Delta X_{Tzal} = \frac{740°C - 680°C}{2 \cdot 1} = 30°C$$

$$\Delta X_{Tformy} = \frac{100°C - 20°C}{2 \cdot 1} = 40°C$$

$$\Delta X_{h} = \frac{300mm - 230mm}{2 \cdot 1} = 35mm$$

3. Coding of factors on pouring temperature, temperature of mould and height of gating system:

$$\check{X}_{Tzal} = \frac{X - 710°C}{30°C} = x_1$$

$$\check{X}_{Tformy} = \frac{X - 60°C}{40°C} = x_2$$

$$\check{X}_{h} = \frac{X - 265mm}{35mm} = x_3$$

Pouring temperature, temperature of mould and height of gating system were perfomed symetrical condition on all three levels of controlling factor.

Experiment plan matrix was shown in table 1.

Table 1.
Experiment plan matrix based on hypercube

Lp.	x_1	x_2	x_3
1.	+	+	+
2.	+	-	-
3.	-	+	-
4.	-	-	+
5.	+	0	0
6.	-	0	0
7.	0	+	0
8.	0	-	0
9.	0	0	+
10.	0	0	-
11.	0	0	0

Presented experimental casting was manufacturing on the following condictions:

- dimension of casting: 115x65x136 mm;
- thickness of external walls: 6 mm;
- height of gating system h = 300 mm;
- lower ingate;
- temperature of mould T_f=100 ºC;
- pouring temperature T_z = 740ºC;

The casting aluminum alloy AlSi11 was used for making experimental casting. Its thermal properties:

- thermal conductivity λ = 130 W/(m·K)
- specific heat c = 1190 J/(kg·K)
- density ρ = 2500 kg/m^3
- heat of crystallization L= 389 kJ/kg

The AlSi11 alloy is used for casting of complicated shapes. The chemical composition of AlSi11 alloy was presented in table 2. This composition was selection according to PN EN – 1706:2001 norm.

Table 2.
The chemical composition of AlSi11 according to PN EN – 1706:2001 norm, expressed in mass percent [15].

Chemical element	Si	Fe	Mg	Mn	Cu	Zn	Ti	Al
Composition %	10,0 ÷11,8	0,15	0,45	0,10	0,03	0,07	0,15	rest

The skeleton casting was prepared in the mould shown in the fig. 3.

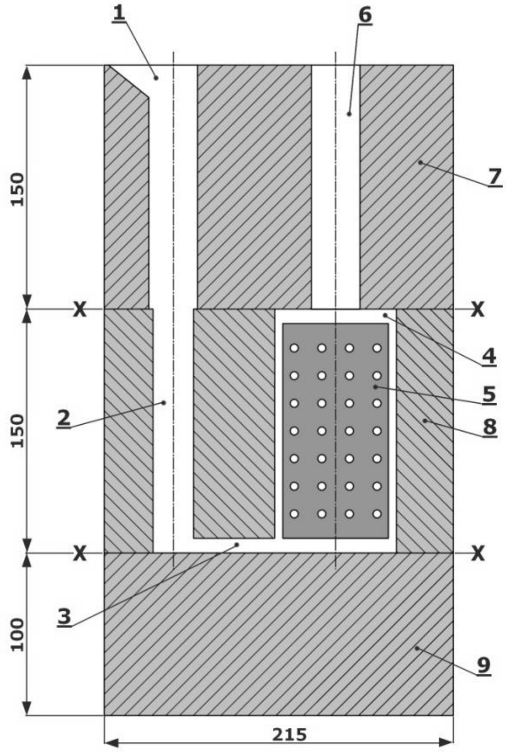


Fig 3. Diagram of mould for skeleton casting: 1 – pouring basin, 2 – getting system, 3 – ingate, 4 –mould cavity, 5 – skeleton casting and core, 6 – over flow, 7 – upper part of the mould, 8 – central part of the mould, 9 – lower part of the mould

Closed aluminium skeleton casting was shown in fig. 4.

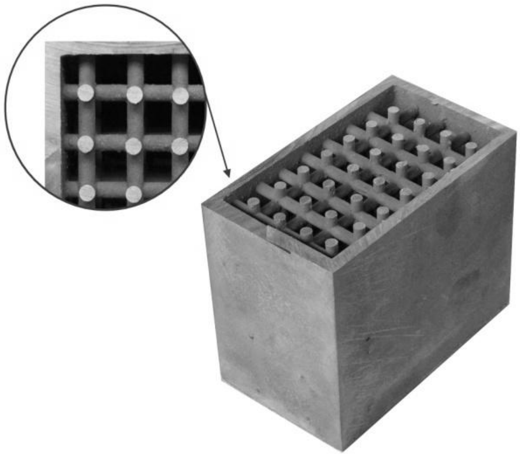


Fig. 4. Example of closed aluminum skeleton casting with eliminate external upper wall, non - modified AlSi alloy, 115x65x136 mm, T_Z - 740°C,T_f - 100°C, h – 300mm)

3. Structural analysis

Structural analysis was performed on metallographic microscope Optihot (magnification 20x). Metallographic photos of microstructure were made on digital camera Nikon CoolPix 5000. Typical region in which author compared microstructure was shown in fig. 5. This microstructure was shown in fig. 6.

3.1. Qualitative analysis

Structural constituent of alloy is: solution α of silicon in aluminium and elongated crystals of non - modified eutectic (α + Si) silicon. During crystallization of the casting was diverse condictions of heat give up occurred. Wall which closed the skeleton solidified fastest. Central elements of skeleton was solidified slowest (fig. 5c). Structures of section element connector of skeleton (fig. 5 a,b point 2,3) and in corner of node (fig. 5a point 1) were compared.

On external surface of wall which closed the skeleton structure was characterized by refined eutectic silicon (fig. 5c point 5 and 6a). Some smaller degree of refinement of eutectic is in central elements of the wall (fig. 5c point 4 and 6b). Smaller degree of refinement of eutectic is on longitudinal section (fig. 5a point 2 and 6c) and on cross-section of skeleton connector (fig. 5b point 3 and 6d and 6e). The lowest refinement was observed in skeleton node corner (fig. 5a point 1 and 6f).

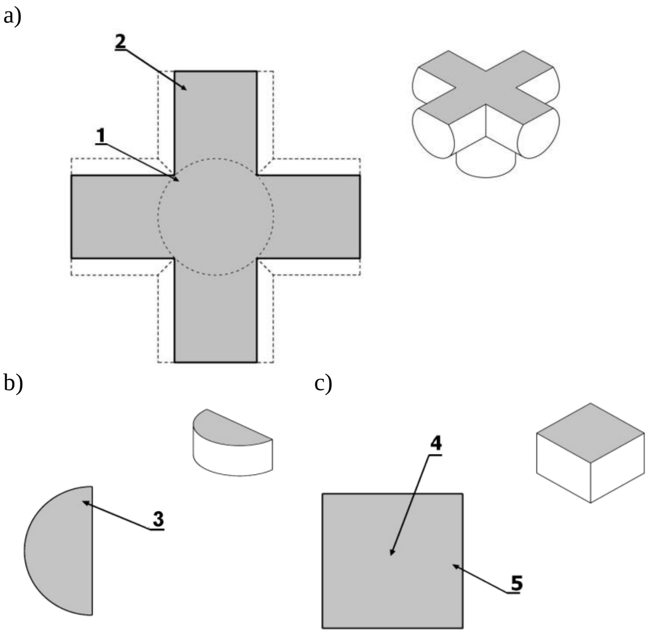


Fig 5. Typical regions in which author compared microstructure: 1 - skeleton node corner; 2 - longitudinal section; 3 - cross-section; 4 - central elements of the wall which closed the skeleton; 5 - external surface of wall which closed the skeleton

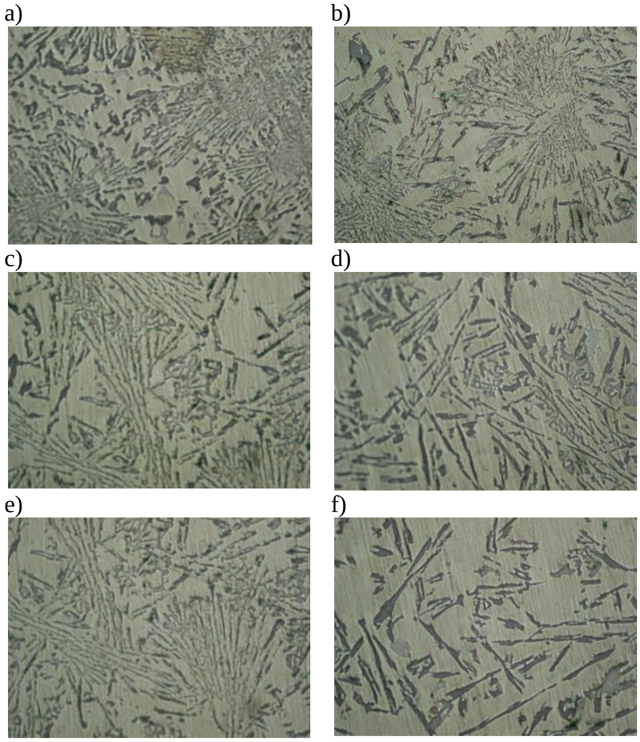


Fig. 6. Microstructures particular elements of skeleton casting, magnification 20x: a- external surface of wall which closed the skeleton, b- central elements of wall which closed the skeleton, c,d,e- connector of skeleton sections, f- corner of node

3.2. Quantitative analysis

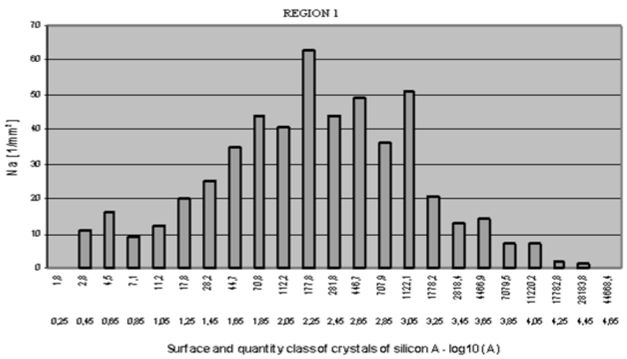
The micrographs of each regions of casting were converted on binary image. Quantitative analysis was prepared on MultiScanBase v 13.01 computer program. For each regions of casting average value of stereological parameters were computed. Average surface of silicon crystals was determined. On based of average surface of silicon crystals refinement of structure was determined. Shape factor and Na parameter, which determinate quantity of silicon crystals in 1mm^2 were determined (table 3).

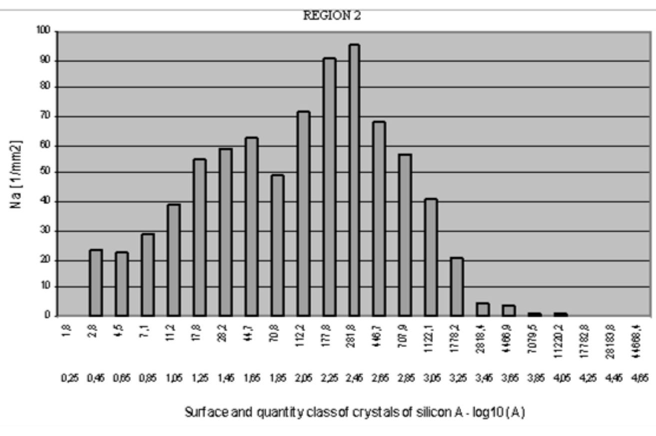
The greatest averages of surface *A* of silicon crystals were in the region 1 (fig. 4a point 1), which confirmed that the least refinement of skeleton casting structure was on the corner of node. The smallest averages of surface *A* of silicon crystals were in the region 5 (fig. 4c point 5), which connected with occurrence the least refined eutectic silicon and rapidly heat give up occurred.

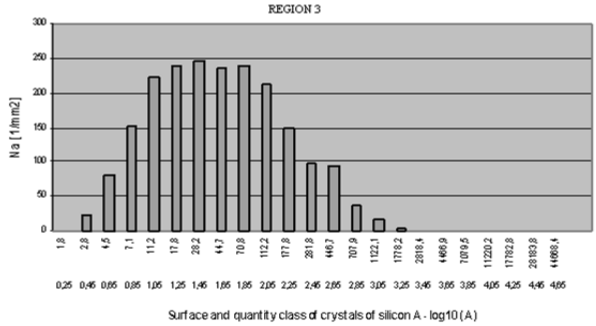
The information about size and quantities *Na* of silicon crystals in classes of size their the surface *A* was shown in the histograms (fig. 7).

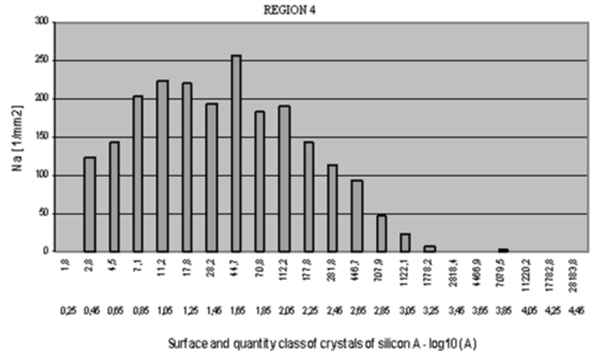
Table 3.
Average of stereological parameters of silicon crystals for each regions of casting

Region	surface A[µm^2]	lenght L [µm]	width B[µm]
1	716.84	46.04	19.23
2	255.02	32.20	12.12
3	80.70	17.90	6.21
4	92.85	16.98	7.03
5	50.86	12.77	4.88
Region	**perimeter P[µm]**	**shape factor B/L**	**Na [1/mm^2]**
1	156.37	0.46	23.68
2	101.91	0.42	36.22
3	49.30	0.39	93.04
4	52.77	0.42	98.59
5	38.99	0.41	173.59









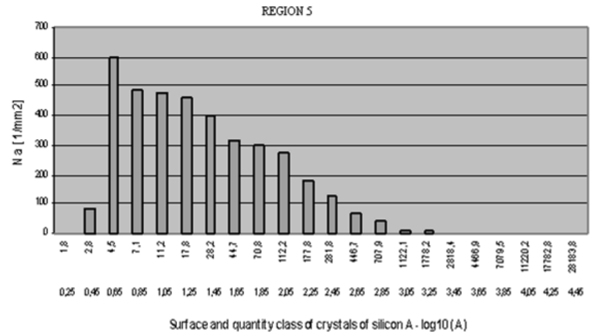


Fig. 7. Quantities Na of silicon crystals in classes of size their the surface

Empirical analysis of distribution Na=f(A) was shown, that the most of silicon crystals were in lowest classes of size their the surface *A* for external surface of wall which closed the skeleton (region 5, fig 5c point 5; ex. for class of surface 4,5 µm^2 is 600 [1/mm^2]). The least of silicon crystals were in higher classes of size their the surface *A*. In the highest classes of size their the surface weren't of silicon crystals (for class of surface above 2818,4 µm^2).

The most of silicon crystals in the highest classes their surface were was in skeleton node corner (region 1, fig. 5a point 1; for class of surface 1122,1 µm^2 is above 50 [1/mm^2]), which is confirmation lowest refinement.

Presented empirical distribution *Na=f(A)* for research regions remained approximate by function:

$$F(X) = \frac{U \cdot Z \cdot \exp[Z \cdot (W - \log(X))]}{[1 + \exp(Z \cdot (W - \log(X)))]^2}$$

where:

X – surface area of silicon crystals [μm^2];

U – index of total volume fraction of silicon crystals [%];

W – average logarithmic quantity of surface of silicon crystals [μm^2];

Z – index of diversification quantity of surface of silicon crystals [$1/\mu m^2$].

Average of stereological parameters crystals of silicon, which were measured and computed and parameters function, which approximate of *Na(A*) distribution were shown in table 4. Functional distributions of quantity of silicon crystals Na at mm^2 in dependence on its surface (where: log(X) is logarithmic quantity of surface of silicon crystals and Y is quantity of silicon crystals *Na* at $1mm^2$) were shown in fig. 8 - 12.

Table 4.
Average of stereological parameters crystals of silicon, which were measured and computed and parameters function, which approximate of *Na(A)* distribution

region	P [μm^2]	Na [$1/mm^2$]	**Function, which approximate of *Na(A*) distribution**				
			Measured parameters function			Statistical parameters	
			U [%]	W [μm^2]	Z [$1/mm^2$]	R	F
1	716,84	23,68	11,144	2,3371	1,9722	0,9471	24,4
2	255,02	36,22	17,702	2,1157	1,9690	0,9413	19,6
3	80,70	93,04	44,576	1,5735	2,4518	0,9829	19,0
4	92,85	98,59	49,662	1,4598	2,0036	0,9667	24,6
5	50,86	173,59	92,100	1,1822	2,4106	0,9157	10,6

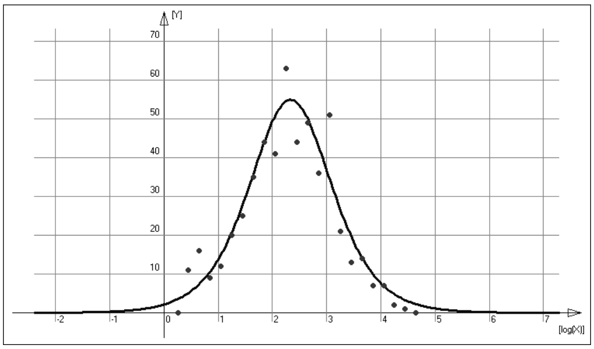


Fig. 8. Distribution of quantity of silicon crystals in function of its quantity for region 1

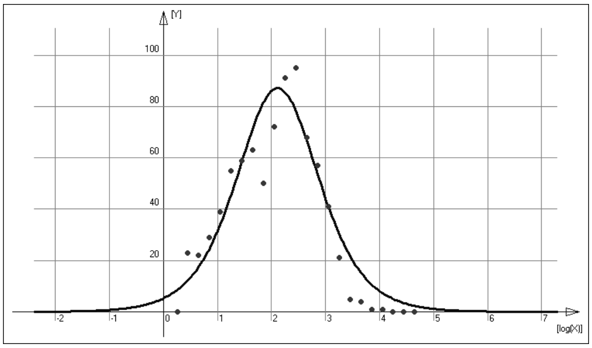


Fig. 9. Distribution of quantity of silicon crystals in function of its quantity for region 2

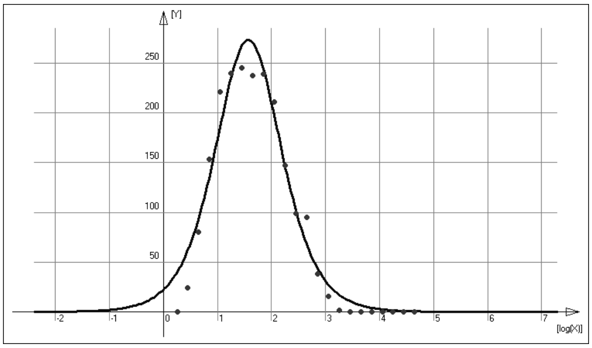


Fig. 10. Distribution of quantity of silicon crystals in function of its quantity for region 3

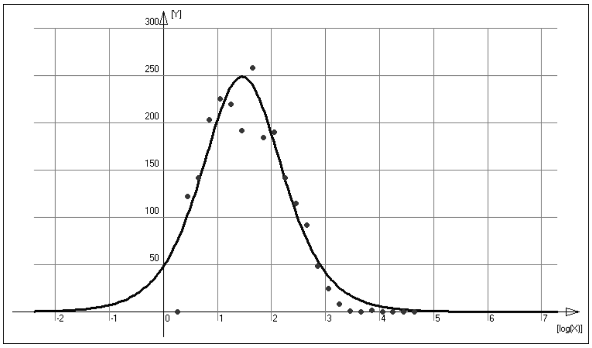


Fig. 11. Distribution of quantity of silicon crystals in function of its quantity for region 4

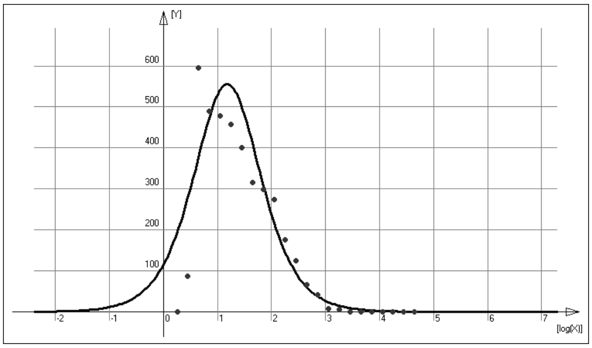


Fig. 12. Distribution of quantity of silicon crystals in function of its quantity for region 5

On basic graphs of approximate function *Na(A)* and values of *U* and **W** parameters reach a conclusion, that index of total volume fraction of silicon crystals for region 5 is highest in comparison to other regions. Whereas average logarithmic quantity of surface of silicon crystals is lower in comparison to other regions. Approximation was investigated by higher value of correlation coefficient – *R*. Correlation coefficient is lowest for region 5.

4. Conclusions

1. Qualitative analysis confirmed influence of cooling rate on structure diversification for skeleton casting, manufactured with non – modified AlSi11. Whereas quantitative analysis confirmed quantitative refinement of structure of skeleton castings. Diversification of structures of skeleton casting, manufactured with use of non – modified AlSi11 alloy remains determined by quantitative analysis. Diversification of structures indicates of increase of silicon crystals size about one order of magnitude.
2. Applied classical gating system and typical pouring temperature on Al alloys (ex. 740ºC) enable very good filling of mould cavity.
3. Selection of modifiers is important, because it influences diversification the refinement of eutectic silicon.

Acknowledgements

The work was supported by the Ministry of Science and Higher Education under the research projects No PBU – 64/ RMT -1 / 2006 and PBU – 18/RMT – 1/2007.

References

[1] J. Banhart, N.A. Fleck, A. Mortensen, Cellular Metals, Manufacture Properties and applications, Berlin Germany 2003.

[2] F. Simanćik, Metallic foams – ultra light materials for structural applications, Eng. Mater., No. 5/2001, p. 823-828.

[3] J. Banatr, Manufacture, characterisation and application of cellular metals and metal foams, Progress in Materials Science, 2001, No. 46, p.559-632.

[4] P. Darłak P. Dudek, Materiały wysokoporowate – metody wytwarzania i zastosowanie, Kompozyty – Nauka i Praktyka, 1/2004, s. 3-17.

[5] J. Sobczak, Metallic foams on the example of composite structures, Archives of Mechanical Technology and Automation, No. spec. 2001, p. 161-169.

[6] J. Sobczak, Piany metalowe monolityczne i kompozytowe oraz gazary, Wydawnictwo Instytutu Odlewnictwa, Kraków 1998.

[7] M. Dziuba, M. Cholewa, Warunki wytwarzania i postać geometryczna odlewów szkieletowych, Archiwum Odlewnictwa, 2006, nr 22, s. 178 – 185.

[8] M. Dziuba, M. Cholewa, Dobór geometrii i materiału rdzenia odlewu szkieletowego o komórkach otwartych, Archiwum Odlewnictwa, 2006, nr 19, s. 95 – 102.

[9] M. Dziuba, M. Cholewa, Projektowanie geometrii rdzenia aluminiowego odlewu szkieletowego o komórkach otwartych, Archiwum Technologii Maszyn i Automatyzacji, 2006, vol. 26, nr 1, s. 15 – 23.

[10] M. Dziuba, M. Cholewa, Rdzenie ceramiczne odlewu szkieletowego o komórkach otwartych, Archiwum Odlewnictwa, 2006, nr 22, s. 170 – 177.

[11] M. Dziuba, M. Cholewa, Selection of core material in skeleton casting with open cells, Slévárenství 2006, No. 10/11 and on the CD – supplement of Conference Proceedings (in English).

[12] M. Cholewa, M. Dziuba, M. Kondracki, J. Suchoń: Validation studies of temperature distribution and mould filling process for composite skeleton castings, Archives of Foundry Engineering, 2007, vol. 7, No. 3, p. 191-198 (in English)

[13] M. Dziuba, M. Cholewa: Simulation of mould filling process for composite skeleton castings, Archives of Foundry Engineering 2008, vol. 8, No. 1, p. 163-168 (in English)

[14] M. Dziuba, M. Cholewa: Simulation of mould filling process and solidification for skeleton castings, Slévárenství 2007 (in English) and on the CD – supplement of Conference Proceedings, (in English)

[15] Norma PN EN – 1706:2001 – Odlewnicze stopy aluminium