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Microstructure quantitative analysis of aluminum skeleton castings

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Abstract

In this article authors showed method for manufacturing of closed skeleton castings with hypo – eutectic and eutectic aluminium alloys. Experimental castings were manufactured in variables technological conditions: range of pouring temperature 680 ÷ 740 °C, temperature of mould 20 ÷ 100 °C and height of gating system above casting level 105 ÷ 175 mm. Structural analysis of studied skeleton castings was conducted. Degree of refinement of structure in typical region of skeleton casting was compared. Qualitative and quantitative different degree of fineness of eutectic silicon was confirmed. Casting in established technological conditions enables manufactured skeletons which repeatable geometry, suitable external geometrical form of casting and required quality.

Keywords: Skeleton casting, Core, AlSi alloy, Microstructure

1. Introduction

Skeleton castings belong to the modern group of porous materials and can find application for: pressure vessels for gaseous and liquid media for example hydrogen, ozone; zones of controlled adsorption of kinetic energy at cars for example fenders, longerons, frames and bearing elements of transport agent, frames of machine tool, supporting structures of machines, military armours, elements of anti – radar shield. Therefore analysis of structural properties and operating properties is fundamental.

Process of production of skeleton castings with optional shape and overall dimensions was limited mainly by ability of penetration the channels of core by liquid metal. Based on numerical simulations technological conditions were determined, which enabled manufacturing of castings with repeatable geometry and required quality.

Describe process of manufacture of skeleton casting depends on representing in core the spatial and repeatable structure of channels. These channels are of specified shape and the dimension of sections. The production process of cores was shown in articles [7,8].

Very important is the selection of core material during design of skeleton castings. In comparison to traditional castings skeleton castings have large self cooling surface, therefore heat-insulating materials were used. Therefore coarse – grained structures were expected. The eutectic aluminum alloy AlSi11 was used for making experimental casting, because this alloy crystallizes forming fine grained structures. The production process of skeleton casting with non - modified AlSi alloy was shown in articles [11]. Diversification of refinement of eutectic silicon for skeleton casting is connected with different cooling rate on research regions. Structural analysis enable determinated refinement of structure of skeleton casting, which manufactured with non – modified AlSi alloy. The aim of structual analysis is to quantitative determine diversification of structure on specific conditions of skeleton crystalliation.

External geometrical form and internal structure and microstructure of skeleton casting depends on geometry of mould – core system [9]. 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 castings were the verification of numerical simulation results [8 ÷ 10], which aim was the selection of technological parameters essential for filling of the mould cavity by eutectic and hypoeutectic AlSi alloys. The aim of research is manufacture closed skeleton castings (Fig 2, 3).

2. Method and result of research

Aluminosilicate material was used for making cores of experimental skeleton castings (λ = 0,17 W/(mK)). In core was reproduction channels on circular section (r = 2,5 mm). The circular section was reproduction on three planes.

Model of core was shown in Fig. 1.

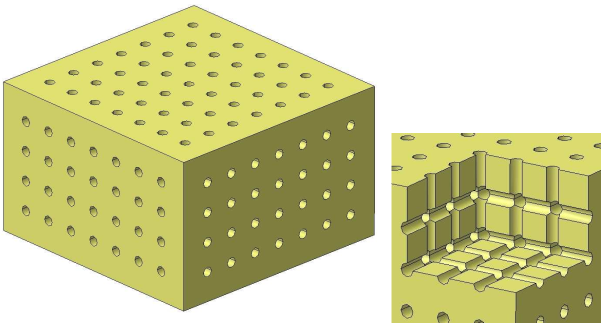


Fig. 1. Model of core

Hypoeutectic and eutectic aluminum alloys with antimony were used for manufacturing the experimental castings. Antimony belong to the group of chemical elements which modify structure of Al-Si alloys. Application of antimony as modifier is often unsatisfactory.

In presented research antymony was applied in order to decrease surface tension of liquid alloy to minimize production of Al_2O_3oxides on stream front and to maximize the castability of the alloy. Application antimony as a modifier of structure was assumed in the background.

Experimental castings were manufacturing on the following conditions:

- dimension of casting: 125x65x125 mm;
- thickness of external walls: 6 mm;
- lower ingate (5x50mm);
- size of elementary skeleton cell a = 15 mm;
- connector of skeleton radius 2,5 mm;

During experimental test received variables technological conditions: pouring temperature 680 ÷ 740 °C, temperature of mould 20 ÷ 100 °C and complete height of gating system 230 ÷ 300 mm.

Technological parameters of experimental castings manufacturing are shown in Table 1.

Table 1.
Technological parameters of experimental castings manuacturing

Technological conditions	Casting alloy AlSi + 0,4%Sb			
	AlSi7Mg	AlSi11	AlSi11	AlSi11
T_z [°C]	705	680	680	710
T_f [°C]	20	20	100	100
comp. heig. of gating system. [mm]	230	300	230	265

The skeleton casting was prepared in the mould shown in the Fig. 2.

Closed aluminium skeleton casting was shown in Fig. 3.

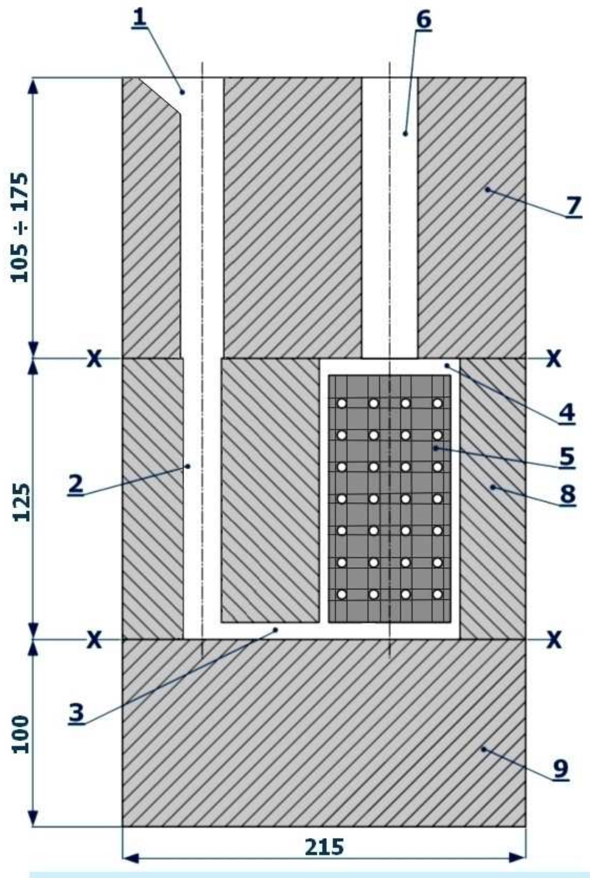


Fig. 2. Diagram of mould for skeleton casting: 1 – pouring basin, 2 – getting system, 3 – in gate, 4 –mould cavity, 5 – skeleton casting and core, 6 – over flow, 7, 8, 9 - lower part of the mould

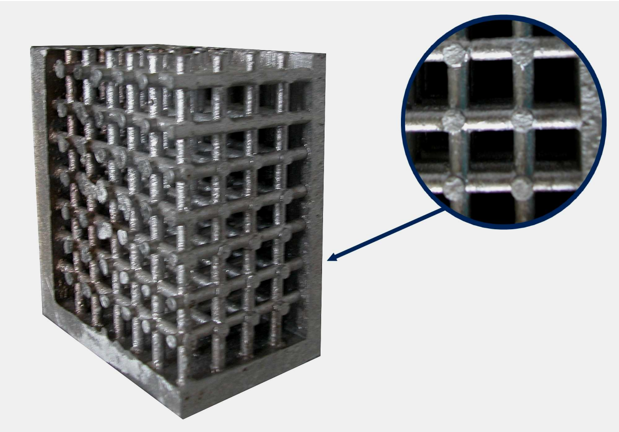
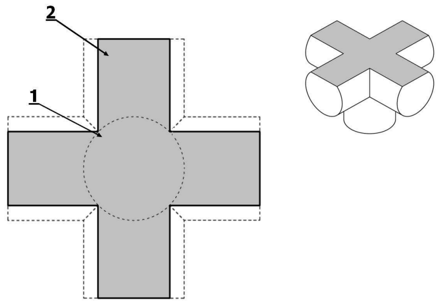


Fig. 3. Example of closed aluminum skeleton casting with eliminate external upper walls, modified AlSi alloy, 125x70x125 mm, T_Z - 680°C,T_f - 20°C, h – 230mm (height of gating system above casting level = 105 mm)

Typical regions in which author compared microstructure shown in the Fig. 4.

a)



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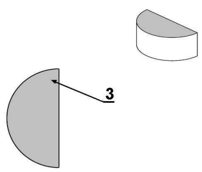

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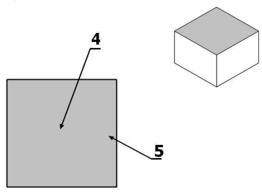


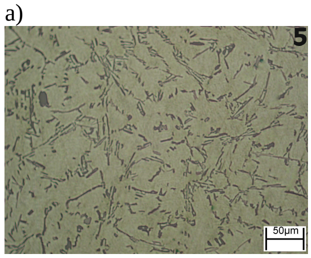
Fig. 4. Typical regions in which author compared microstructure: 1 - skeleton node corner; 2 - longitudinal section; 3 - cross-section; 4 - central elements of the wall which closed the skeleton; 5 - external surface of wall which closed the skeleton

Microstructures particular elements of consecutive skeleton casting were shown in Fig. 5 ÷ 8. Sequence of structure meet the increase of dimension of structural constituent.

Structural constituent of alloy is: solution α of silicon in aluminium and crystals of eutectic (α + Si) silicon in regions interdendritic.

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. 4). Structures of section element connector of skeleton (Fig. 4 a, b. point 2,3) and in corner of node (Fig. 4a. point 1) and on wall which closed the skeleton (Fig. 4c point 4,5) were compared.

a)



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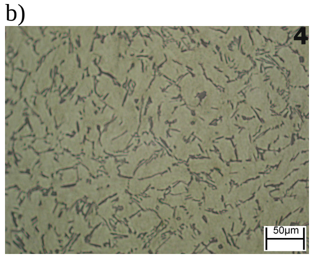

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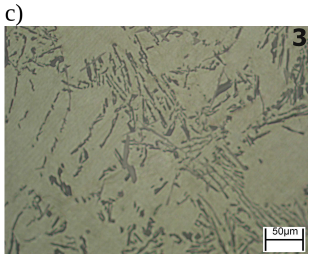

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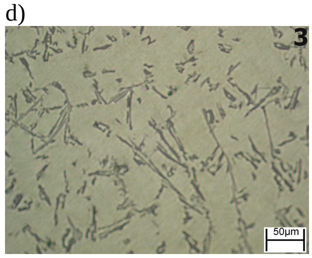

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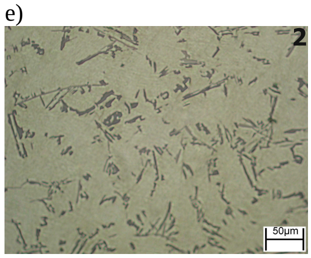


f)

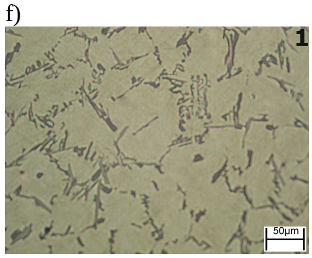


Fig. 5. Microstructures particular elements of skeleton casting (AlSi7Mg, T_z 705 °C, T_f 20 °C, h – 230 mm) magnification 20x: a- external surface of wall which closed the skeleton, b- central elements of wall which closed the skeleton, c,d,- longitudinal section of skeleton connector, e- cross-section of skeleton connector, f- corner of node, designation numerical (1÷5) meet a description in Fig. 4

On external surface of wall which closed the skeleton structure was characterized by refined eutectic silicon (Fig. 4c point 5 and 5 ÷ 8a). Some smaller degree of refinement of eutectic is in central elements of the wall (Fig. 4c point 4 and 5 ÷ 8b). Smaller degree of refinement of eutectic is on longitudinal section (Fig. 4a point 2 and 5 ÷ 8c) and on cross-section of skeleton connector (Fig. 4b point 3 and 5 ÷ 8d and e). The lowest refinement was observed in skeleton node corner (Fig. 4a. point 1 and 5 ÷ 8f).

a) b)

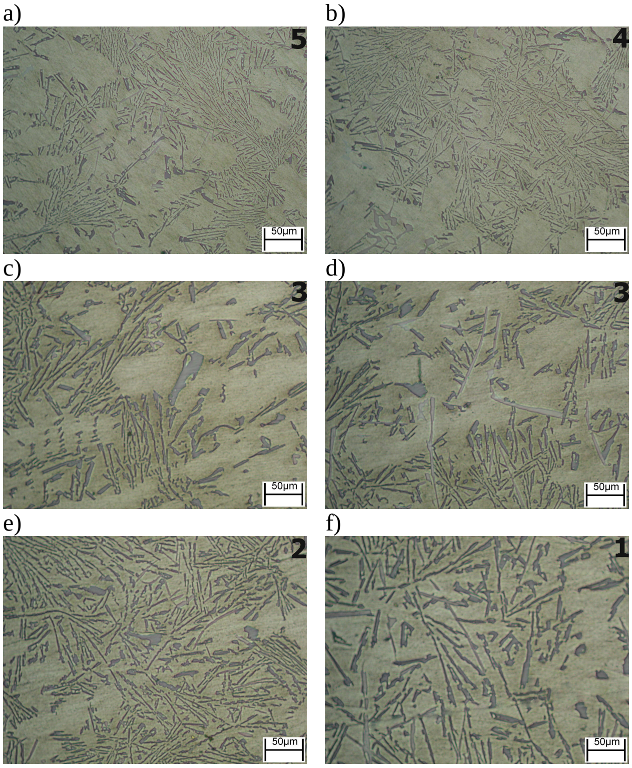
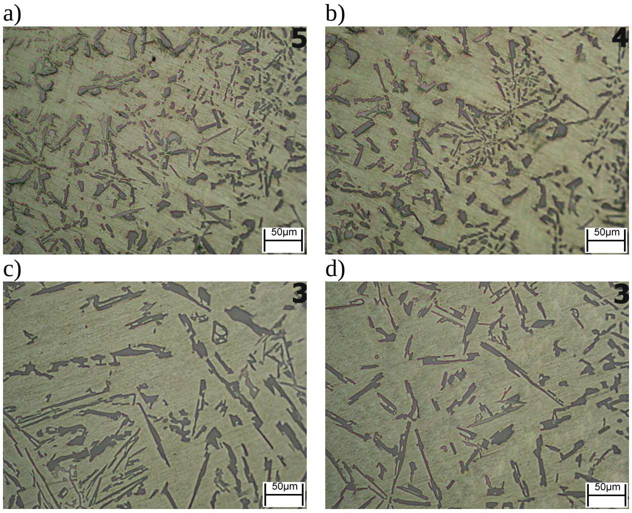


Fig. 6. Microstructures particular elements of skeleton casting (AlSi11, T_z 680 °C, T_f 20 °C, h – 300 mm) magnification 20x: a- external surface of wall which closed the skeleton, b- central elements of wall which closed the skeleton, c,d,- longitudinal section of skeleton connector, e- cross-section of skeleton connector, f- corner of node, designation numerical (1÷5) meet a description in Fig. 4

a) b)



e) f)

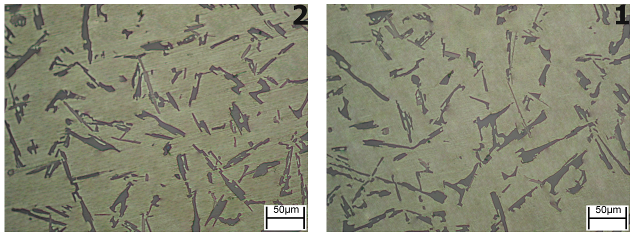


Fig. 7. Microstructures particular elements of skeleton casting (AlSi11, T_z 680 °C, T_f 100 °C, h – 230 mm) magnification 20x: a- external surface of wall which closed the skeleton, b- central elements of wall which closed the skeleton, c,d,- longitudinal section of skeleton connector, e- cross-section of skeleton connector, f- corner of node, designation numerical (1÷5) meet a description in Fig. 4

a) b)

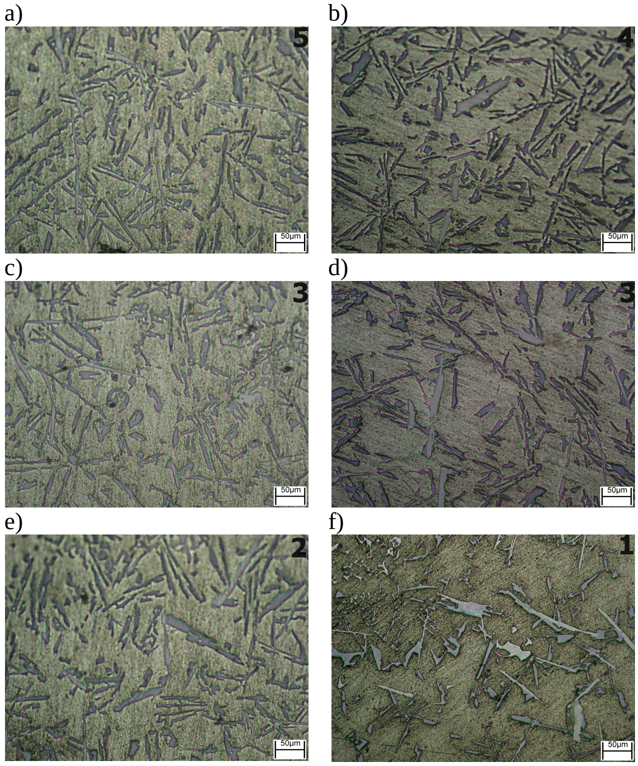


Fig. 8. Microstructures particular elements of skeleton casting (AlSi11, T_z 710 °C, T_f 100 °C, h – 265 mm) magnification 20x: a- external surface of wall which closed the skeleton, b- central elements of wall which closed the skeleton, c,d,- longitudinal section of skeleton connector, e- cross-section of skeleton connector, f- corner of node, designation numerical (1÷5) meet a description in Fig. 4

Quantitative analysis was prepared on MultiScanBase v 13.01 computer program. For research regions of consecutive castings average values of stereological parameters were computed (Table 2). Average values of stereological parameters were determined for 10 measurements.

Table 2.
Average of stereological parameters of silicon crystals for research regions of consecutive castings

AlSi7Mg, T_z 705 °C, T_f 20 °C, h – 230 mm

Region	surface A[μm^2]	lenght L [μm]	width B[μm]	perim. P[μm]	$\frac{B}{L}\left[\frac{1}{1}\right]$	$\frac{P}{A}\left[\frac{1}{\mu m}\right]$
1	94.43	18.12	7.88	54.10	0.46	0.95
2	70.34	15.72	6.44	46.47	0.43	1,15
3	86.76	16.85	6.66	47.58	0.43	1,03
4	45.19	13.12	5.52	37.27	0.44	1,10
5	30.65	10.73	4.11	28.84	0.40	1,32

AlSi11, T_z 680 °C, T_f 20 °C, h – 300 mm

Region	surface A[μm^2]	lenght L [μm]	width B[μm]	perim. P[μm]	$\frac{B}{L}\left[\frac{1}{1}\right]$	$\frac{P}{A}\left[\frac{1}{\mu m}\right]$
1	248.64	22.65	9.55	74.08	0.45	0,83
2	142.13	21.05	7.93	66.47	0.40	0,83
3	127.49	18.36	7.02	57.59	0.42	0,93
4	63.51	16.53	4.70	42.57	0.31	0,96
5	62.40	16.07	4.79	43.01	0.33	0,99

AlSi11, T_z 680 °C, T_f 100 °C, h – 230 mm

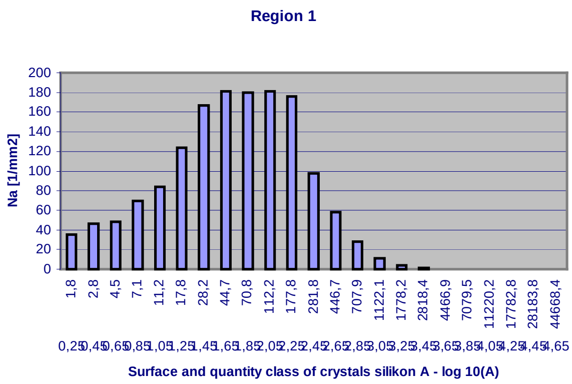
Region	surface A[μm^2]	lenght L [μm]	width B[μm]	perim. P[μm]	$\frac{B}{L}\left[\frac{1}{1}\right]$	$\frac{P}{A}\left[\frac{1}{\mu m}\right]$
1	370,68	27,51	11,70	88,29	0.42	1,02
2	246,50	29,29	12,14	92,53	0.41	0,81
3	132,79	19,39	7,93	61,38	0.42	1,09
4	22,75	26,58	10,88	87,09	0.42	9,33
5	16,03	22,61	10,42	75,59	0.46	7,45

AlSi11, T_z 710 °C, T_f 100 °C, h – 265 mm

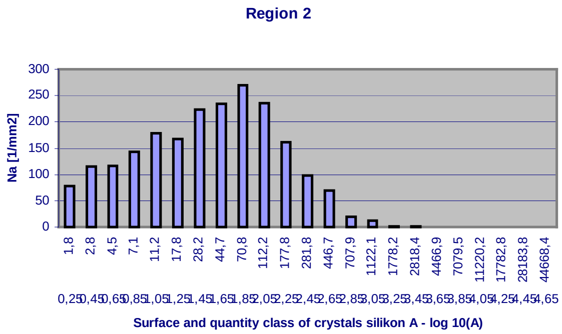
Region	surface A[μm^2]	lenght L [μm]	width B[μm]	perim. P[μm]	$\frac{B}{L}\left[\frac{1}{1}\right]$	$\frac{P}{A}\left[\frac{1}{\mu m}\right]$
1	102,93	15,35	7,72	57,68	0.52	1,07
2	17,34	19,21	8,87	67,39	0.48	9,27
3	41,89	8,32	3,61	27,66	0.40	1,56
4	14,24	19,30	9,23	71,54	0.48	9,94
5	11,65	19,63	8,48	76,06	0.45	12,27

The information about size and quantities *Na* of silicon crystals in classes of size their the surface *A* was shown in the histograms (Fig. 9 ÷ 12).

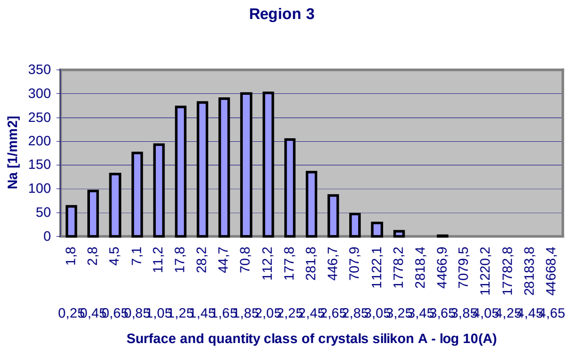
a)



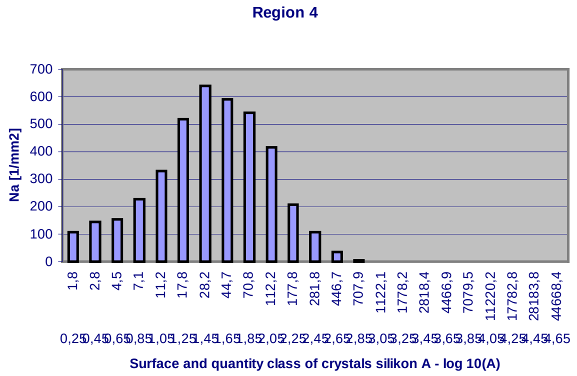
b)



c)



d)



e)

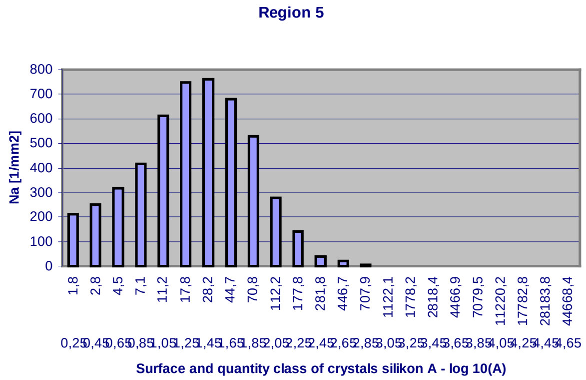
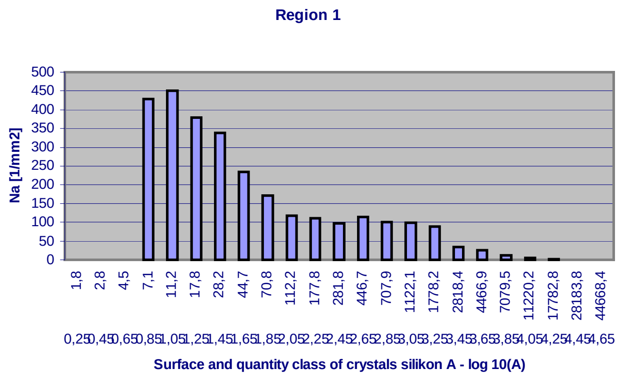


Fig. 9. Quantities Na of silicon crystals in classes of size their the surface (AlSi7Mg, T_z 705 °C, T_f 20 °C, h – 230 mm)

a)



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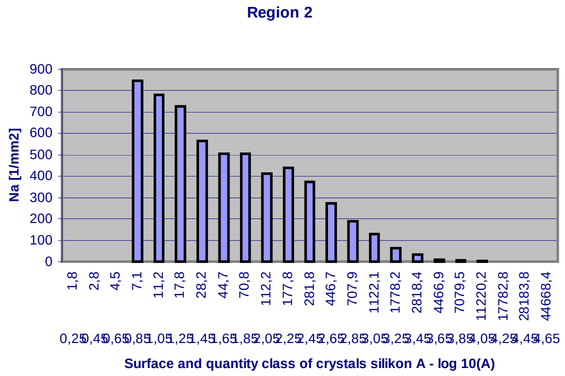

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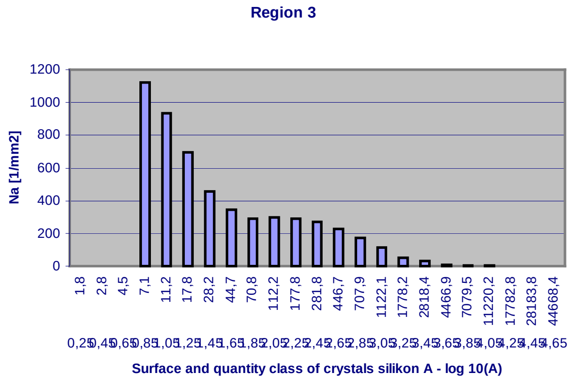

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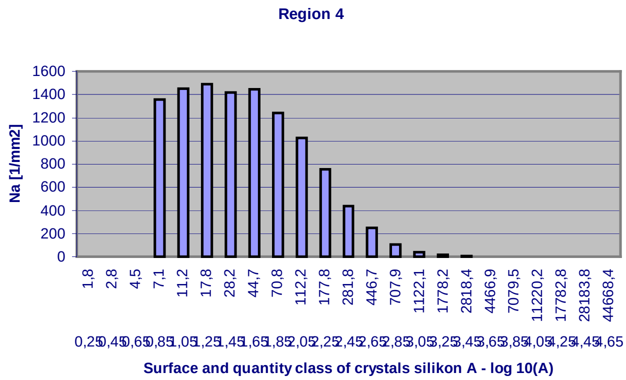

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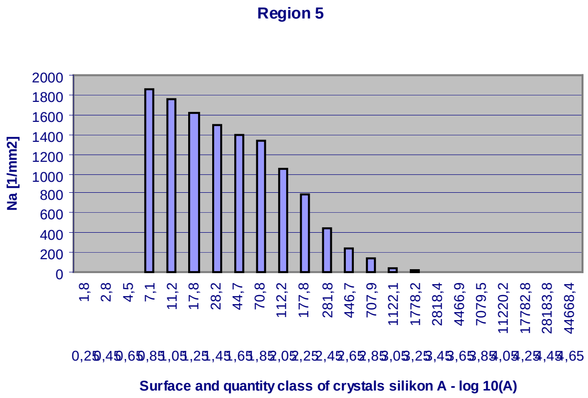
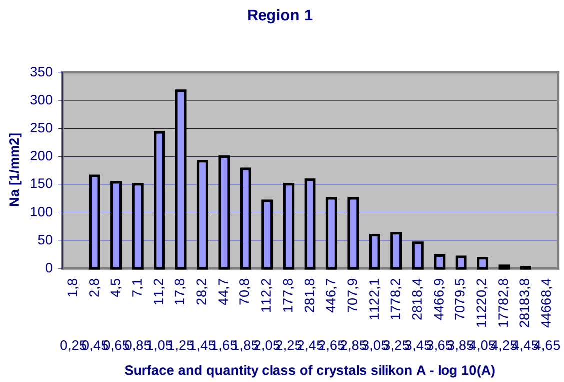


Fig. 10. Quantities Na of silicon crystals in classes of size their the surface (AlSi11, T_z 680 °C, T_f 20 °C, h – 300 mm)

a)



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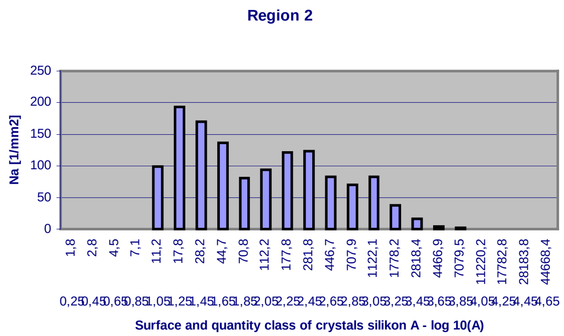

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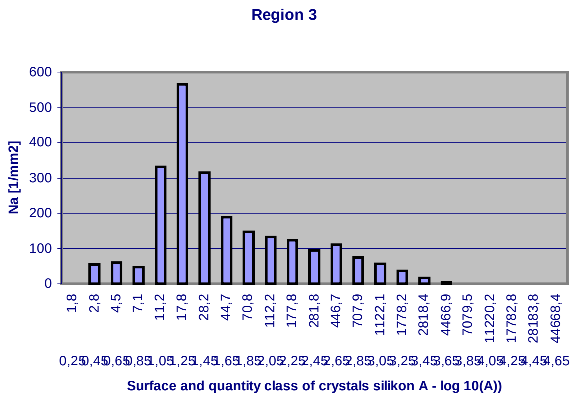

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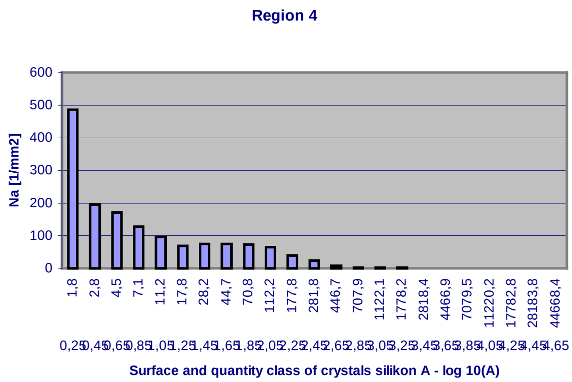

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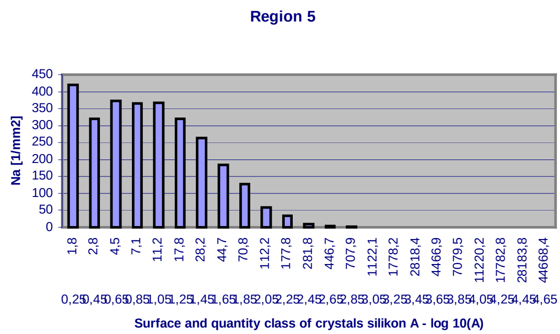
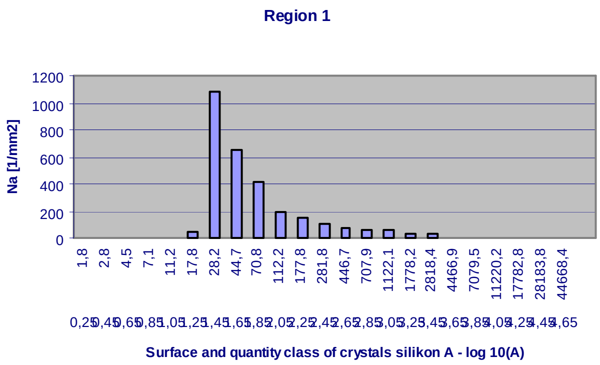


Fig. 11. Quantities Na of silicon crystals in classes of size their the surface (AlSi11, T_z 680 °C, T_f 100 °C, h – 230 mm)

a)



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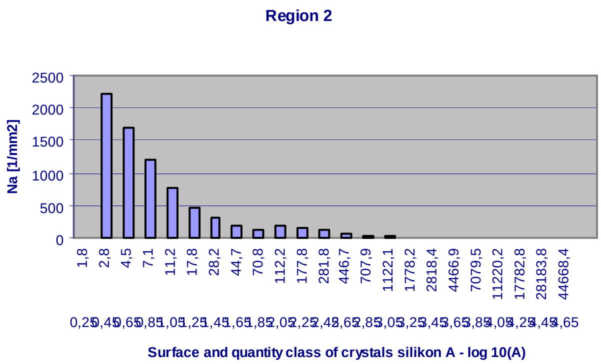

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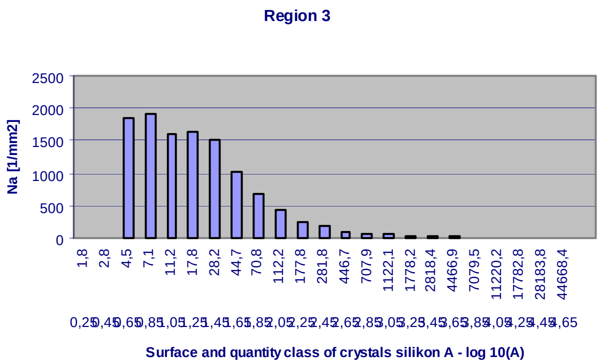

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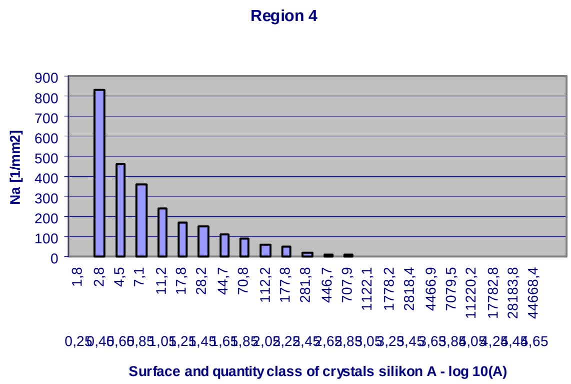

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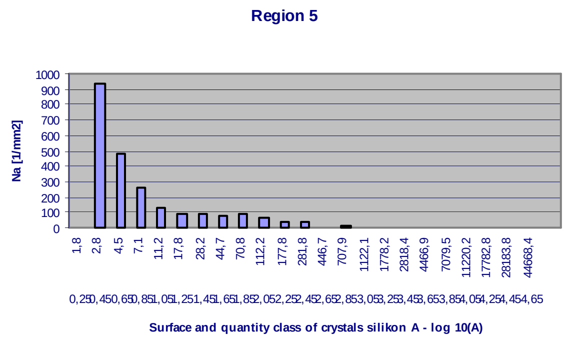

Fig. 12. Quantities Na of silicon crystals in classes of size their the surface (AlSi11, T_z 710 °C, T_f 100 °C, h – 265 mm)

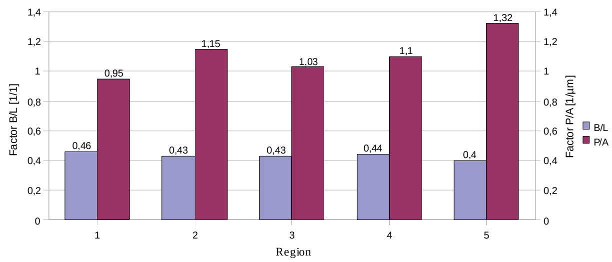

Fig. 13. Shape factor B/L and P/A for particular skeleton regions (AlSi7Mg, T_z 705 °C, T_f 20 °C, h – 230 mm)

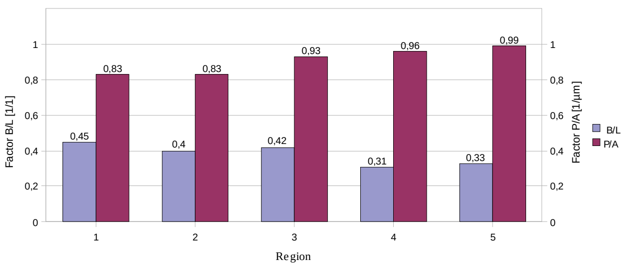

Fig. 14. Shape factor B/L and P/A for particular skeleton regions (AlSi11, T_z 680 °C, T_f 20 °C, h – 300 mm)

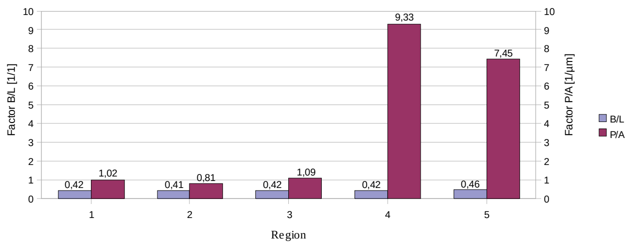

Fig. 15. Shape factor B/L and P/A for particular skeleton regions (AlSi11, T_z 680 °C, T_f 100 °C, h – 230 mm)

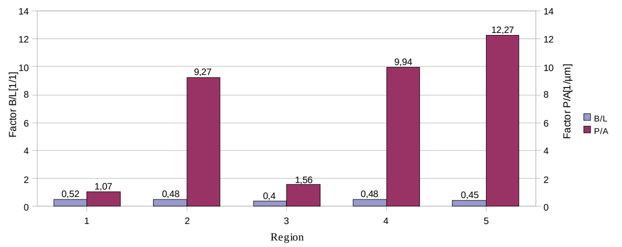

Fig. 16. Shape factor B/L and P/A for particular skeleton regions (AlSi11, T_z 710 °C, T_f 100 °C, h – 265 mm)

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 (Table 2).

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. 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 707,9 μm^2).

The most of silicon crystals in the highest classes their surface were was in skeleton node corner (Fig. 4a point 1) which is confirmation lowest refinement.

B/L factor (Table 2, Fig. 13÷16) determine degree of extension of silicon crystals. The lower value of factor the more elongated silicon crystals are. The greatest values of factor B/L were in the region 1, The smallest values of factor were in the region 5, except for sample 3 (AlSi11, T_z 680 °C, T_f 100 °C, h – 230 mm), where the greatest values of factor were in the region 5. Values of B/L factor were approximate for all analysed regions each research skeleton castings.

For all analysed regions P/A factor (Table 2, Fig. 13 ÷ 16) the greatest values were in region 5 (except for sample 3) next in region 4, which connnected with rapidly heat give up occurred in this regions.

The greatest values of P/A factor were in region 4 and 5 for castings number 3 and 4 (Fig. 15 and 16). These castings were manufactured with increase temperature of the mould (100°C). Factor of P/A in others regions for each casting obtained comparable values.

For greatest cooling rate silicon crystals have the greatest surface development to its volume on edge of casting wall what favours tranport of heat. The temperature of mould at level 100 °C impairs structural properties of skeleton castings.

4. Conclusions

1. Structural analysis confirmed influence of cooling rate on structure diversification for research skeleton castings, manufactured with modified hypo – and circa - eutectic AlSi11 alloys. Whereas quantitative analysis confirmed quantitative refinement of structure of skeleton castings.
2. Application of antimony as a modifier levels appreciable diversification the refinement of eutectic silicon in comparision with skeleton casting which were manufactured with non – modified alloy [13].
3. The smallest refinement of structure for each studied regions was for casting manufactured with AlSi7Mg (AlSi7Mg, (T_z 705 °C, T_{fo} 20 °C, h – 230 mm). This alloy in agreement with certificate was modified with Sr by the producer.
4. Complete analysis was required: distance between dendrite arm spacing. This will be subject of a following research.

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