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Statistical analysis using multiple regression of stereological parameters for skeleton castings microstructure

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Abstract

In this article authors showed influence of technological parameters and modification treatment on structural properties for closed skeleton castings. Approach obtained maximal refinement of structure and minimal structure diversification. Skeleton castings were manufactured in accordance with elaborated production technology. Experimental castings were manufactured in variables technological conditions: range of pouring temperature 953 ÷ 1013 K , temperature of mould 293 ÷ 373 K and height of gating system above casting level 105 ÷ 175 mm. Analysis of metallographic specimens and quantitative analysis of silicon crystals and secondary dendrite-arm spacing analysis of solution α were performed. Average values of stereological parameters for all castings were determined. (B/L) and (P/A) factors were determined. On basis results of microstructural analysis authors compares research of samples. The aim of analysis was selected samples on least diversification of refinement degree of structure and least silicon crystals. On basis microstructural analysis authors state that samples 5 (AlSi11, T_{pour} 1013K, T_{mould} 333K, h – 265 mm) has the best structural properties (least diversification of refinement degree of structure and the least refinement of silicon crystals). Then statistical analysis results of structural analysis was obtained. On basis statistical analysis autors state that the best structural properties for technological parameters: T_{pour} = 1013 K, T_{mould} = 373 K and h = 230 mm [4]. The results of statistical analysis are the prerequisite for optimization studies.

Keywords: AlSi alloy, Microstructure, Microstructural analysis, Statistical analysis, Skeleton castings

1. Introduction

Skeleton castings belong to the high – grade group of frame construction with open cells [9 – 12], which develop rapidly and find application in today industry.

These constructions characterize high stiffness, low density, high compressive strength and energy absorption, high fatigue strength and resistance to vibration.

Therefore skeleton castings 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 [4].

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

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 [4, 5]. Diversification of refinement of eutectic silicon for skeleton casting is connected with different cooling rate on research regions. Structural analysis enable determined refinement of structure of skeleton casting, which manufactured with non – modified AlSi alloy. The aim of structural analysis is to quantitative determine diversification of structure on specific conditions of skeleton crystallization.

2. Method and result of research

Experimental castings were manufactured in variables technological conditions: range of pouring temperature 953 ÷ 1013 K, temperature of mould 293 ÷ 373 K and height of gating system above casting level 105 ÷ 175 mm.

Eutectic aluminum alloys with antimony were used for manufacturing the experimental castings.

Experimental castings were manufacturing on the following conditions:

- dimension of the 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;

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

Table 1.
Variables technological conditions studies

AlSi11+ 0,4%Sb			
number of casting	pouring temperature [K]	temperature of mould and core [K]	height of gating system h [mm]
1.	1013	373	300
2.	1013	293	230
3.	953	373	230
4.	953	293	300
5.	1013	333	265
6.	953	333	265
7.	983	373	265
8.	983	293	265
9.	983	333	300
10.	983	333	230
11.	983	333	265

Qualitative and quantitative microstructural analysis of studied skeleton castings was conducted. Metallographic specimens were not etched.

Structural constituent of alloy is: solution α of silicon in aluminum and crystals of eutectic (α + Si) silicon in regions interdendritic (Fig. 1).

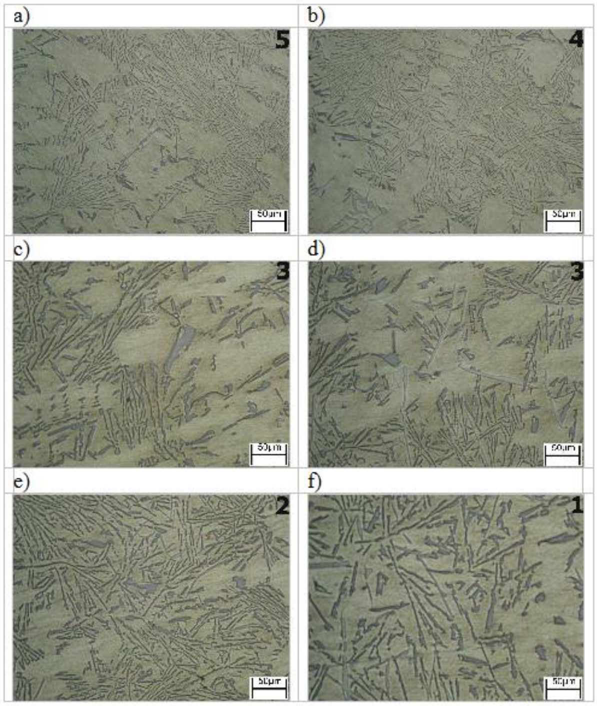

Fig. 1. Microstructures particular elements of skeleton casting (AlSi11, T_{pour} 953 K, T_{mould} 293 K, h – 300 mm) magnification 20x: a- external surface of wall which closed the skeleton, b- central elements of wall which closed the skeleton, c,d,- longitudinal section of skeleton connector, e- cross-section of skeleton connector, f- corner of node,

Quantitative analysis was prepared on MultiScanBase v 13.01 computer program. For each casting average value of stereological parameters were computed [4, 8, 9].

B/L factor determine degree of extension of silicon crystals. The lower value of factor the more elongated silicon crystals are [4].

Whereas P/A factor determine surface development of silicon crystals. P/A factor connected with rapidly heat give up occurred in regions of castings. The greatest values of P/A factor were for castings which were manufactured with increase temperature of the mould (373 K).

For greatest cooling rate silicon crystals have the greatest surface development to its volume on edge of casting wall what favors transport of heat. The temperature of mould at level 373 K impair structural properties of skeleton castings.

On the basis the results of microstructure analysis all studied specimens were compared (Table 2).

Average surface (P) of silicon crystals was calculated. Ranges of values for the (B/L) and (P/A) factors and arm spacing of solution α (DAS) of each casting were determined.

The aim of analysis was selected samples on least diversification of refinement degree of structure and least silicon crystals.

Table 2.
Results of structural analysis [4]

number of casting	$\frac{B}{L}\left[\frac{1}{1}\right]$	$\frac{P}{A}\left[\frac{1}{\mu m}\right]$	DAS [μm]
1	0,42 – 0,51	0,47 – 0,60	47,6 – 51,6
2	0,44 – 0,48	0,44 – 0,54	54,1 – 69,7
3	0,41 – 0,46	0,81 – 9,33	116,2 - 188
4	0,31 – 0,45	0,83 – 0,99	96,6 - 120
5	**0,45 – 0,52**	**0,47 – 0,54**	**49,1 – 50,2**
6	0,39 – 0,44	0,48 – 0,56	44,1 – 59,7
7	0,40 – 0,52	1,07 – 12,27	117 - 164
8	0,45 – 0,51	0,48 – 0,56	52,2 – 52,6
9	0,39 – 0,43	0,47 – 0,56	49 – 53,3
10	0,44 – 0,46	0,47 – 0,55	39 - 49
11	0,40 – 0,48	0,50 – 0,55	48 – 51,3

The least average overall surface of silicon crystals is for sample 5 ($A_{śr}$ = 27,27 [μm^2]). B/L factor highest values is for sample 5, factor value is from 0,45 to 0,52 for extreme regions of skeleton castings, this is connected with least elongated silicon crystals in this sample.

Values of P/A factor for sample 5 are variables in range least in extreme regions. Values of factor are from 0,47 to 0,54. The least values of dendrite arm sparing are for samples 1, 5, 6, 9, 10. Authors selected samples 5 for which DAS are variables in range limited and DAS values are the least for extreme regions of casting. On basis research authors state that the best structural properties for samples 5 (AlSi11, T_{pour} 1013K, T_{mould} 333K, h – 265 mm).

2.1. Statistical analysis

On the basis the results of microstructure analysis all studied specimens mathematical dependence on microstructure of the technological parameters (B/L, P/A, DAS = f (T_{pour}, T_{mould}, h)) was elaborated.
where:
B/L factor determine degree of extension of silicon crystals.
P/A factor determine surface development of silicon crystals.
DAS - secondary dendrite-arm spacing [μm],
T_{pour} – pouring temperature of AlSi alloy [K],
T_{mould} – temperature of mould [K],
h – height of gating system h [mm].

Statistical analysis was prepared on STATISTICA computer software. Multiple regression was used to elaborated mathematical dependence on microstructure of the technological parameters.

Dependence follows were obtained:

$$(B/L)_{average} = 0{,}002\cdot T_{pour} - 0{,}007\cdot h - 1{,}86\cdot (T_{mould}/h)^{0,5} + 3{,}029 \quad +/-0{,}017 \qquad (1)$$

$$(P/A)_{average} = -0{,}0047\cdot T_{pour} - 0{,}89\cdot T_{pour}/(T_{mould}+h) + 3{,}59 \quad +/-0{,}1002 \qquad (2)$$

$$DAS_{average} = 0{,}61\cdot T_{pour} - 0{,}49\cdot (T_{pour}+h) - 27{,}12\cdot (T_{pour}/h) - 11{,}27\cdot (T_{pour}+T_{mould})/h + 229{,}27 \quad +/-0{,}72 \qquad (3)$$

Statistical parameters are shown in Table 3.

Table 3.
Statistical parameters, formula (1 – 3)

	Correlation coefficient R	**Coefficient R^2**	**Corrected coefficient R^2**
$(B/L)_{average}$	0,91110858	0,83011885	0,72819016
$(P/A)_{average}$	0,76050559	0,57836876	0,43782501
$DAS_{average}$	0,98824989	0,97663785	0,92991356
	Fisher's test F	**Significance level p**	**Standard error of estimation**
$(B/L)_{average}$	F(3,5)=8,1441	p<0,02271	0,01719
$(P/A)_{average}$	F(2,6)=4,1152	p<0,0749	0,10022
$DAS_{average}$	F(4,2)=20,902	p<0,04618	0,72491

Authors showed graphic interpretation of equations (1 - 3) in Fig. 2 – 10.

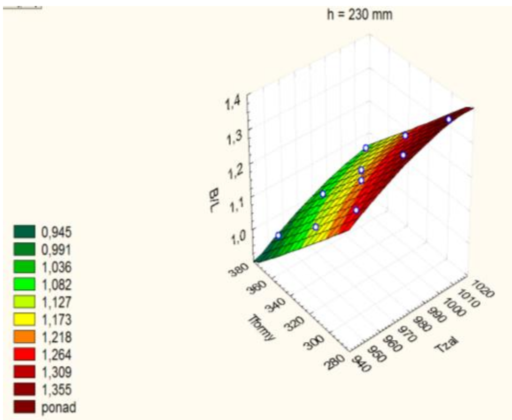

Fig 2. Relation of B/L factor and pouring temperature, temperature of mould, height of gating system 230 mm

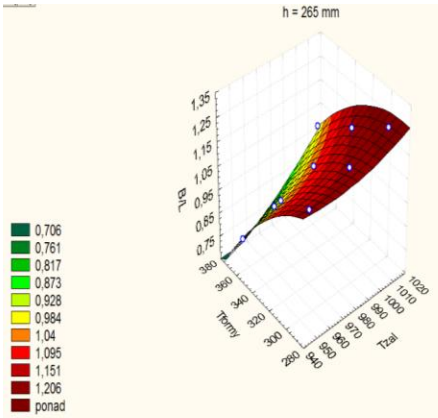

Fig 3. Relation of B/L factor and pouring temperature, temperature of mould, height of gating system 265 mm

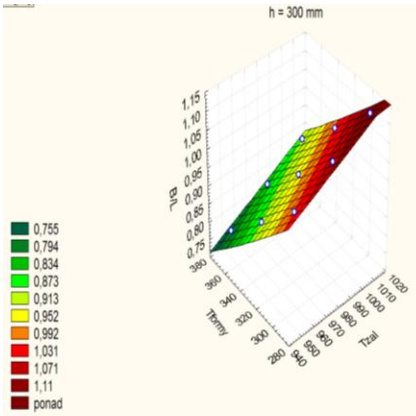

Fig. 4. Relation of B/L factor and pouring temperature, temperature of mould, height of gating system 300 mm

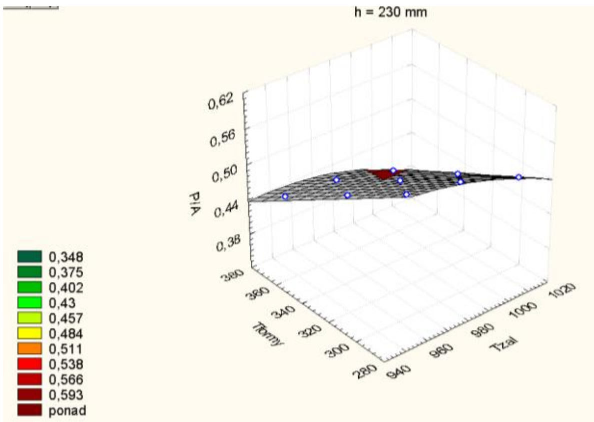

Fig. 5. Relation of P/A factor and pouring temperature, temperature of mould, height of gating system 230 mm

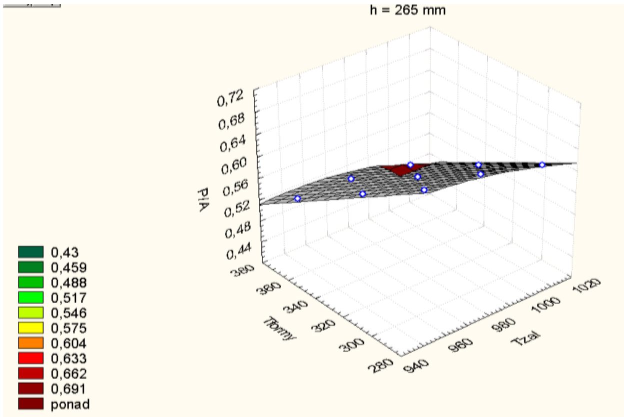

Fig. 6. Relation of P/A factor and pouring temperature, temperature of mould, height of gating system 265 mm

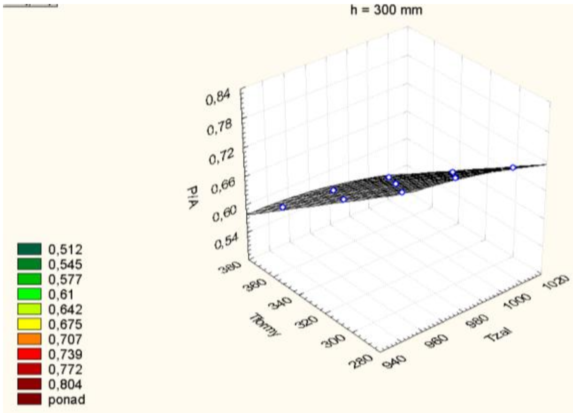

Fig. 7. Relation of P/A factor and pouring temperature, temperature of mould, height of gating system 300 mm

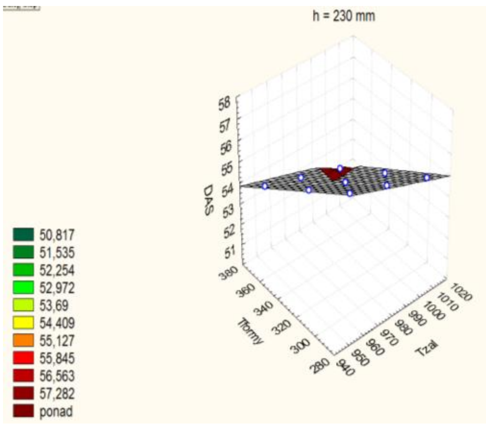

Fig. 8. Relation of secondary dendrite-arm spacing (DAS) and pouring temperature, temperature of mould, height of gating system 230 mm

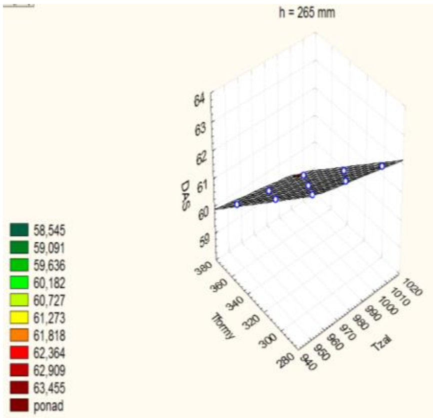

Fig. 9. Relation of secondary dendrite-arm spacing (DAS) and pouring temperature, temperature of mould, height of gating system 265 mm

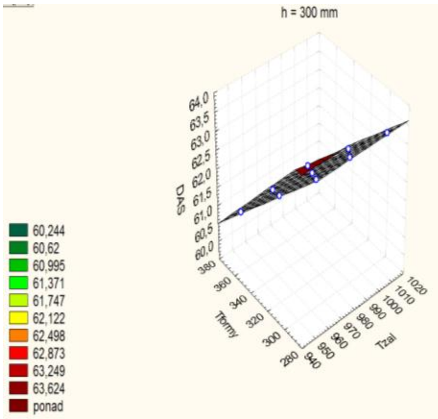

Fig. 10. Relation of secondary dendrite-arm spacing (DAS) and pouring temperature, temperature of mould, height of gating system 300 mm

On basis results of statistical analysis autors state that maximum of the function B/L = f(T_{pour}, T_{mould}, h) is for the technological parameters T_{pour} = 1013 K, T_{mould} = 293 K, h = 230 mm.

Minimum of the function DAS = f (T_{pour}, T_{mould}, h) is for the technological parameters T_{pour} = 1013 K, T_{mould} = 373 K, h = 230 mm.

Values of P/A factor for sample 5 (0,47 to 0,54 [1/μm]) authors considered the advantageous to obtain high strength [8, 9]. The sample was manufactured on technological condictions: T_{pour} = 1013 K, T_{mould} = 333 K, h = 265 mm. Graphs of the function P/A = f (T_{zal}, T_{formy}, h) authors were analyzed. Values of P/A factor (0,47 to 0,54 [1/μm]) for the pouring temperature (953 – 1013 K), temperature of mould (293 – 373 K) and height of gating system (230 – 265 mm) were obtained [4].

3. Summary

Secondary dendrite-arm spacing (DAS) authors considered to obtain least diversification of refinement degree of structure and least refinement of silicon crystals.

On basis research authors state that the best structural properties for technological parameters: T_{pour} = 1013 K, T_{fmould} = 373 K and h = 230 mm.

Optimization technological parameters is necessary to obtain the best structural properties (maximal refinement of structure and minimal structure diversification) and desirable values of the studied factors. Optimization studies must be conducted on basic of the results of research.

The results of statistical analysis are the prerequisite for optimization studies.

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