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Studies of structural and mechanical properties of aluminum skeleton castings

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Abstract

Skeleton castings were manufactured in accordance to elaborated production technology. The subject of the research was the microstructural analysis of non - monolithic castings. Analysis of metallographic specimens and quantitative analysis of silicon crystals and secondary dendrite-arm spacing analysis of solution α were performed. Studies were executed for typical regions of skeleton castings. The regions were diversified regarding the cooling rate.

The greatest value of compression strength were observed for casting manufactured according to technological conditions: pouring temperature T_{pour} 1013 K, temperature of the mould T_{mould} 333 K and height of the gating system h – 265 mm.

Technological conditions and modification treatment were determined on base of advantageous structural properties (high homogeneity and refinement). On basis of the research authors confirmed that in applied conditions of solidification advantageous structure of AlSi11 alloy was obtained.

The article showed the method of structure design of AlSi11 alloys skeleton castings, which was essential to obtain favorable operating properties of skeleton castings in future technical applications.

Keywords: Skeleton casting, Structure, Compression strength, AlSi alloy

1. Introduction

Skeleton castings belong to the modern group of constructions material and can find application for: pressure vessels for gaseous and liquid media for example hydrogen, ozone; zones of controlled absorption of kinetic energy in cars for example fenders, longerons, frames and bearing elements of transport agent, frames of machine tools, supporting structures of machines, military armors, elements of anti – radar shield.

These innovative castings manufactured on basis of heat-insulating and hydrophilic sand core with cristobalite and aluminosilicate matrices. Thermal properties of core material should be well-fitted. Besides obtaining the desirable geometry of the casting it is necessary to obtain the required microstructure of applied material. The basic problem is to obtain te highest possible homogeneity of microstructure in the entire volume of the casting.

The achievement of required mechanical properties requires designing the geometry of skeleton, which is closely connected with geometry of the core.

Methods of manufacturing of cores are: composing cores with single elements – profiles, which reproduce elementary cells; composing layers which reproduce the required number of cells; or direct execution of the whole core.

The aim of research was the description of technological parameters influence and modification treatment on structural properties of closed skeleton castings. The assumption was to obtain maximal refinement of the structure and the highest homogeneity.

2. Experimental procedure

Cores with aluminosilicate matrix (λ = 0,037 W/m·K) were used for experimental skeleton castings manufacturing. In comparison to traditional castings skeleton castings have large cooling surface, therefore heat-insulating materials were used. Properties and composition of aluminosilicate materials which were used for cores of skeleton castings were shown in table 1 [3].

Table 1.
Properties and composition aluminosilicate materials which were used on core of skeleton castings [3]

chemical composition	A	B
SiO_2	53 ÷ 55 %	46 ÷ 48 %
$Al_2O_3 + ZrO_2$	45 ÷ 47 %	52 ÷ 54 %
limit's temperature	1533 K	1703 K
specific heat 1173K	969 [J/ kg K]	

In every core set of channels with circular section (r = 2,5 mm) were made in all three perpendicular direction. Model of the core was shown in fig. 1.

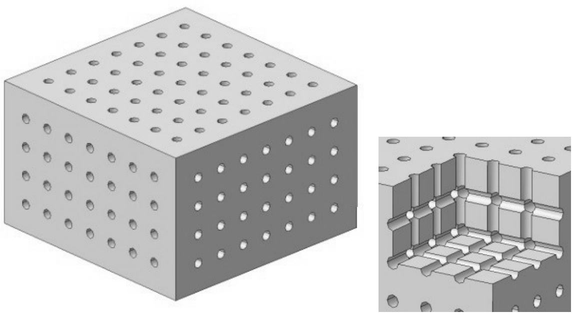


Fig. 1. Model of the core

The eutectic aluminum alloy AlSi11 with antimony was used for experimental casting manufacturing. This alloy crystallizes forming fine grained structure. Antimony belong to the group of the chemical elements which modify structure of Al-Si alloys. However, in presented research antimony was applied in order to decrease surface tension of liquid alloy to minimize production of Al_2O_3 oxides on stream front and to maximize the castability of the alloy.

Experimental castings were manufactured according to 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;
- radius of skeleton connector 2,5 mm;

During the studies the height of the gating system was constant and equal to h = 265 mm and variables were: the pouring temperature (T_{pour} = 983 and 1013 K) and mould temperature (T_{mould} = 293 K and 333K).

Closed aluminum skeleton casting was shown in fig 2.

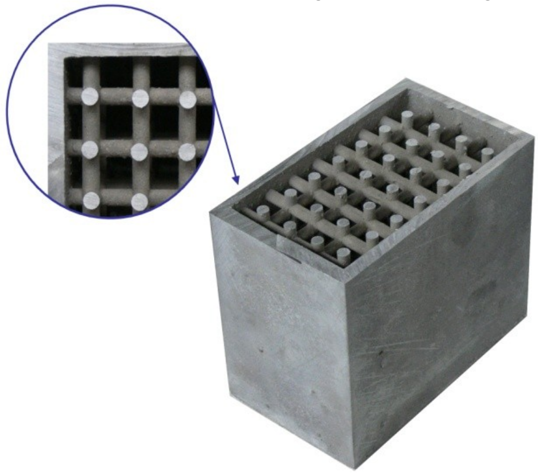


Fig. 2. Example of closed aluminum skeleton casting with eliminated external upper wall, modified AlSi alloy, 125x70x125 mm, T_{pour} 983 K, T_{mould} 293 K, h_c- 265 mm

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

Typical regions in which authors compared microstructure were shown in fig. 3.

a)

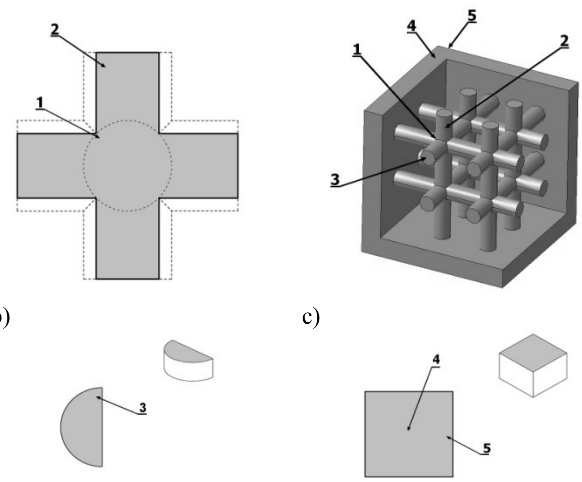
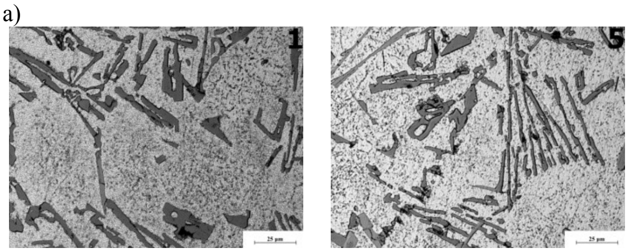


Fig. 3. Typical regions in which author compared microstructure: 1 - skeleton node corner; 2 - longitudinal section; 3 - cross-section; 4 - central elements of corner wall which closed the skeleton; 5 - external surface of corner wall which closed the skeleton [13]

Structural constituent of alloy is: α solution and eutectic crystals (α + Si) in interdendritic regions.
Microstructures in studied regions of consecutive skeleton castings were shown in fig. 4. Numerical designation in the right upper corner meets the description in fig. 3.

a)



b)

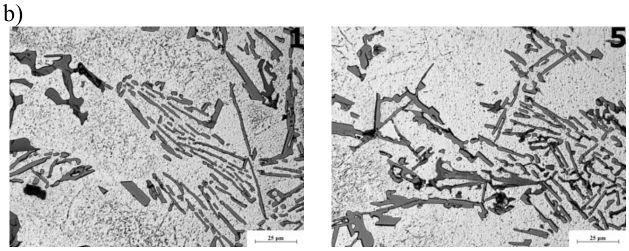


Fig. 4. Microstructure in studied regions of skeleton casting: a) AlSi11, T_{pour} 1013 K, T_{mould} 333 K, h – 265 mm; b) AlSi11, T_{pour} 983 K, T_{mould} 293 K, h – 265 mm for extreme regions: 1- corner of node; 5- external surface of wall which closed the skeleton; designation numerical (1;5) meet a description in fig. 3

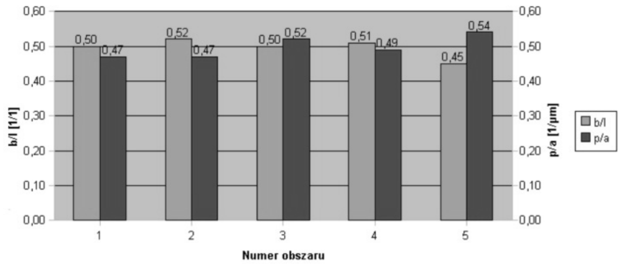
Metallographic photos of microstructure were analyzed. Variability of stereological parameters was studied: surface (P), perimeter (A), width (B) and length (L) of silicon crystals. Maximal and minimal and average values of stereological parameters for all analyzed regions research castings were determined. On basis on values of stereological parameters refinement degree was determined. Values of stereological parameters for selected sample were shown in table 3.

Table 2.
Values of measured and calculated stereological parameters of silicon crystals for research regions of consecutive castings – sample 5 (AlSi11, T_{pour} 1013K, T_{mould} 333K, h – 265 mm)

Region		A[µm²]	L [µm]	B[µm]	P[µm]	$\frac{B}{L}\left[\frac{1}{1}\right]$	$\frac{P}{A}\left[\frac{1}{\mu}\right]$
1	Average	**35,70**	**31,33**	**15,21**	**10,92**	**0,50**	**0,47**
	Max	3794,74	559,54	315,33	680,36	0,95	1,20
	Min	3,64	7,04	1,71	0,40	0,05	0,09
2	Average	**28,77**	**29,44**	**14,79**	**9,98**	**0,52**	**0,47**
	Max	961,44	377,85	204,94	299,41	1,00	1,19
	Min	3,71	7,29	1,71	1,93	0,10	0,14
3	Average	**23,31**	**25,07**	**12,43**	**8,64**	**0,50**	**0,52**
	Max	1788,55	350,72	260,76	344,61	0,96	1,29
	Min	1,02	3,08	0,85	0,67	0,06	0,18
4	Average	**28,96**	**27,75**	**13,73**	**9,56**	**0,51**	**0,49**
	Max	1735,61	483,33	162,71	451,50	0,97	1,14
	Min	3,64	7,04	1,71	1,91	0,06	0,11
5	Average	**19,61**	**26,10**	**11,08**	**7,99**	**0,45**	**0,54**
	Max	920,74	252,15	171,65	220,84	0,96	1,23
	Min	3,71	7,29	1,21	0,48	0,07	0,02

Diagrams of (B/L) factors and (P/A) factors values for typical regions of skeleton castings were shown in fig. 5. (numerical designation is the same as in fig. 3)

a)



b)

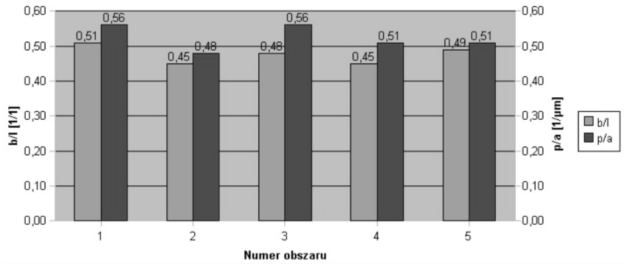


Fig. 5. Shape factor B/L and P/A for particular skeleton regions (1 ÷ 5): a) AlSi11, T_{pour} 1013K, T_{mould} 333K, h – 265 mm; b) AlSi11, T_{pour} 983K, T_{mould} 293K, h – 265 mm

Dendrite arm spacing of α solution was determined. Samples were polished and etched with use of 20% NaOH water solution.

Results of dendrite arm spacing for skeleton castings are shown in table 4.

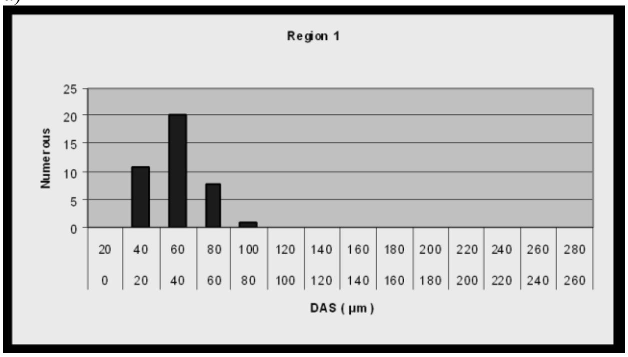
Table 3.
Dendrite arm spacing for select regions of skeleton castings

Sample	Measur. region	Dendrite arm spacing [µm]			
		min	maks	average	stand. dev.
T_{pour} 1013K, T_{mould} 333K, h – 265 mm	region 1	26,27	82,20	**49,14**	12,86
	region 5	22,52	86,06	**50,28**	13,88
T_{pour} 983K, T_{mould} 293K, h – 265 mm	region 1	22,97	82,20	**52,26**	14,94
	region 5	24,26	93,73	**52,68**	15,49

Based on these results the regions of extreme DAS values were indicated.

Distribution of the secondary dendrite-arm spacing diagrams for casting (T_{pour} 1013K, T_{mould} 333K, h – 265 mm) were presented in fig. 6.

a)



b)

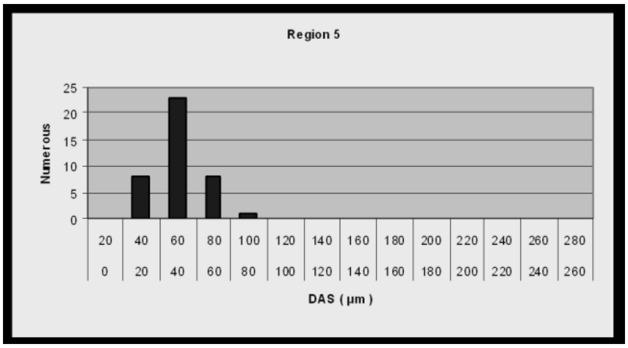


Fig. 6. Distribution of secondary dendrite-arm spacing for selected regions of casting – (AlSi11, T_{pour} 1013K, T_{mould} 333K, h – 265 mm)

Additionally, compression tests were performed for skeleton casting fragments (fig. 7).

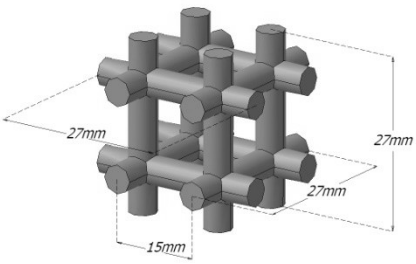
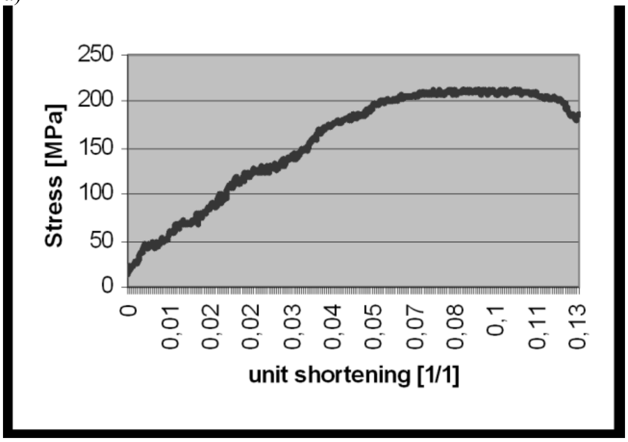


Fig. 7. Shape and diensions of specimen used for compression test

Six tests were carried out for every skeleton casting. Diagrams of deformation in function of compressing stress were shown in fig. 8.

In fig. 9 results obtained during the compression test were shown.

a)



b)

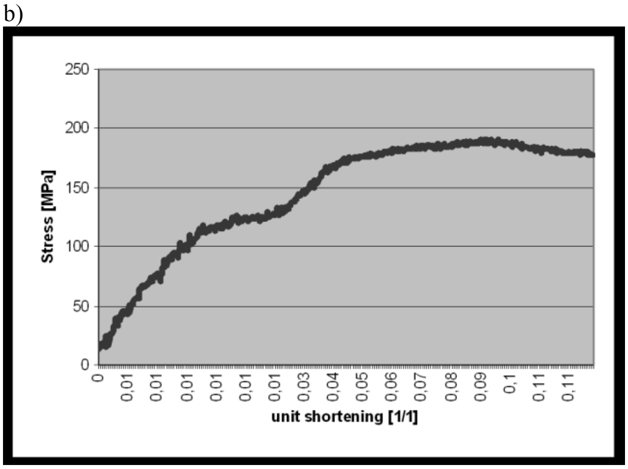


Fig. 8. Compressive stresses in function of unit shortening: a) AlSi11, T_{pour} 1013K, T_{mould} 333K, h – 265 mm; b) AlSi11, T_{pour} 983K, T_{mould} 293K, h – 265 mm

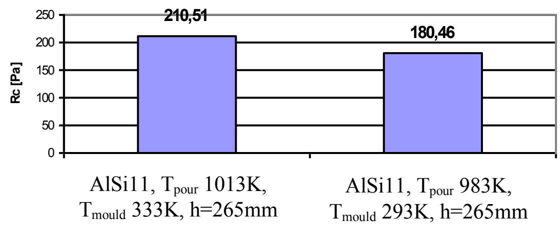


Fig. 9. Ultimate compressive strength of examined skeleton castings

3. Results and discussion

During crystallization of the casting diverse conditions of heat give up occurred. Structure of sections element connector of skeleton (fig. 3 a,b point 2,3) and in corner of a node (fig. 3 a point 1) and on wall which closed the skeleton (fig. 3 c point 4,5) were compared.

The highest averages of surface *A* of silicon crystals was in the region 1, (table 3), which confirmed that the least refinement of skeleton casting structure was on the corner of node. The lowest average of surface *A* of silicon crystals was in the region 5 for all skeleton castings, which can be connected with occurrence the least refined eutectic silicon and rapid heat give up.

B/L factor (table 3, fig. 5) determined the degree of extension of silicon crystals. The lower value of factor the more elongated silicon crystals were. Values of B/L factor were similar for all analyzed regions of all skeleton castings.

The P/A factor determine surface development of silicon crystals. For all analyzed regions P/A factor the greatest values were in region 5, next in region 4, which ca be connected with rapid heat give up in this region.

For research castings dendrite arm spacing the least values were registered in region 1. However DAS values in region 1 and 5 were similar (table 4).

Based on diagram of dendrite arm spacing distribution (fig. 9), numbers of DAS are similar in highest and lowest class of distribution for regions 1 and 5. It ca be connected with insignificant diversification of the structure in extreme regions of skeleton castings in respect of cooling rate.

Based on microstructural analysis results authors compared studied samples. The aim was to select samples with the most homogenous refinement of the structure and the smallest silicon crystals.

The lowest average overall surface of silicon crystals ($A_{śr}$ = 27,27 [μm^2]). was observed for castings, manufactured according to conditions: T_{pour} 1013K, T_{mould} 333K, h – 265 mm. B/L factor reached the highest values for this same casting, 0,45 to 0,52 for extreme regions of skeleton castings. Such values, indicate small elongation of silicon crystals in this sample.

Values of P/A factor for the same casting varied slightly for extreme regions (0,47 to 0,54). Also DAS values varied in limited range. Based on the research results authors stated, that the casting manufactured according to conditions: (AlSi11, T_{pour} 1013K, T_{mould} 333K, h – 265 mm) has more favorable structural properties than casting (AlSi11, T_{pour} 983K, T_{mould} 293K, h – 265 mm).

The skeleton connectors were subjected to buckling during the compression, what was the reason of difference in diagrams of compression tests for skeleton and monolithic castings (fig. 8).

Diagrams in fig. 8 showed nonlinear relation between the unit shortening and compressive stress.

The highest values of ultimate compressive strength were obtained for following technological conditions: T_{pour} 1013 K, T_{mould} 333 K, h – 265 mm.

4. Conclusions

1. Authors confirmed possibility of obtain of profitable structures of AlSi11 alloy in applied solidification conditions of skeleton.
2. Structural analysis confirmed influence of cooling rate on structure diversification for research skeleton castings, manufactured with modified hypo – eutectic and eutectic AlSi11 alloys. Whereas quantitative analysis confirmed quantitative refinement of structure of skeleton castings.
3. Casting at establishes thermal and geometrical parameters was investigated. It was obtained satisfactory filling the channels creating the skeleton shape and prepared in form of a core.
4. Based on microstructural studies it can be stated, that skeleton castings showed favorable structural properties (fine structure with high homogeneity).
5. The mechanism of profiles destruction under high loads and satisfactory values of ultimate compressive strength increase chances for future application of skeleton castings.

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