ARCHIVES of FOUNDRY ENGINEERING

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

ISSN (1897-3310)
Volume 12
Issue 2/2012

147 – 152

29/2

Structure of AlSi Skeleton Castings

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Received 25-05-2012; accepted in revised form 22-05-2012

Abstract

Skeleton castings macrostructure can be shaped in many ways, by choosing an appropriate material of cores and manufacturing technologies. Important factor, which puts foundry techniques over the other technologies of periodic cellular materials, is ability to adjust mechanical properties by changing the microstructure of an alloy from which the casting is made. The influence on the microstructure of the skeleton casting can be implemented by choosing the thermal properties, mainly thermal conductivity factor, of mould and core materials. Macro- and microstructure of skeleton castings with octahedron elementary cells was presented in this paper. The analysis concerns the differences in morphology of eutectic silicone depending on the location of measurements cross sections areas. The use of thermo-insulating material with appropriate properties assures correct fill of mould cavity and homogeneous microstructure on whole volume of skeleton casting. The selection of technological parameters of the casting process if very important as well.

Keywords: Skeleton Casting, Moulding Sand, Core, Microstructure Aluminum Alloy

1. Introduction

Mechanical, thermal acoustic properties of cellular metals assure them wide range of practical use. Technologies are making possible to manufacture ultralight constructions with good impact energy absorbing, heat conduction or dissipation [1]. Besides excellent thermo-mechanical properties, other aspects like for example production costs or technology accessibility are also very important.

Cellular materials like metallic foams are well known [2-4]. Development of such materials is enforced by progress in manufacturing techniques and better tools for designing and simulation of mechanical properties. Unfavorable aspect of cellular metals is random geometry and size of pores which preclude predicting mechanical properties of such material.

Periodic cellular materials such as skeleton castings, which are subject of this paper, are manufactured by several techniques. For example cellular metals are made with use of steel patters from trusses or hollow tubes. Assembled and joined together with soldering. Buckling tendency can be reduced by using slightly bigger hollow tubes instead of rods. It allows to reduce relative density as well [5].

Periodic cellular metals can be manufactures with plastic working. The core is formed from metal sheets on presses and next joined with outside walls by laser spot welding. Such sandwich panels have good strength and stiffness and are exploited in aerospace industry [6].

The skeleton castings have analogical features to the spatial microlattice structures [6-8]. Important advantage of skeleton castings compared to the elements used so far is among the other the technology [9-12]. With use of the classical foundry techniques it is possible to manufacture the skeleton castings with internal topology adjusted to specific application. The internal topology of skeleton castings can be obtained with different technology. Figure 1 shows 3D models of different skeleton castings. Design and all technological parameters was developed in Foundry Department of Silesian University of Technology [13-15].

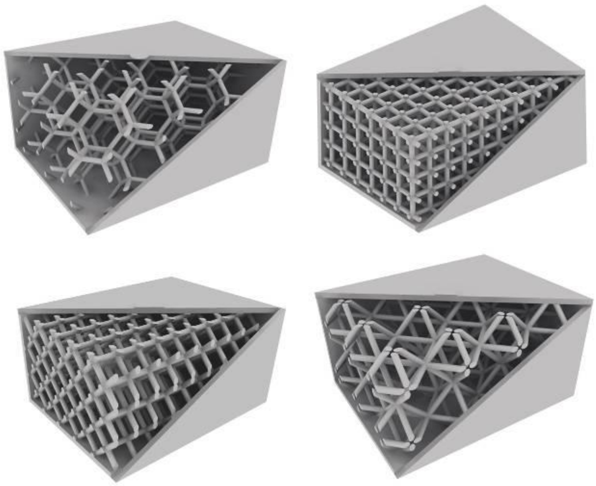


Fig. 1. Internal topologies of skeleton castings developed in Foundry Department

Skeleton castings are manufactured mostly without use of advanced technology. Classical and relatively cheap foundry techniques allow to manufacture skeleton castings with many different topologies and dimensions of ligaments and walls [12, 17]. Lost wax techniques are also used for periodic cellular metals and in connection with antigravity casting allow to obtain skeleton casting with diameter of ligaments about 1.5mm. Such castings are used in jet engines, and as framework or skin plane for aircrafts.

2. Aim and range of research

Skeleton casting macrostructure can be shaped in many ways by choosing an appropriate material of cores and manufacturing technologies. Important factor, that puts foundry techniques over the other technologies of periodic cellular materials is ability to select mechanical properties by changing the microstructure of an alloy from which the casting is made [14, 15, 19-23]. The influence on the microstructure of the skeleton casting can be implemented by choosing the thermal properties, mainly thermal conductivity factor, of mould and core materials [16]. The use of thermo-insulating material with appropriate properties assures correct fill of mould cavity and homogeneous microstructure on whole volume of skeleton casting. The selection of technological parameters of casting process is very important as well. Beside the metallurgical treatments like inoculation or refining are essential in skeleton castings technology because of its complexity of internal topology.

Presented research was carried out in purpose to investigate the influence of suggested moulding materials on heat dissipation and crystallization conditions. Also microstructure of skeleton casting with octahedron elementary cells was taken into account.

3. Methodology

In purpose of research three skeleton casting with octahedron elementary cells was chosen. The test castings with dimensions of (114x114x80) were made from near eutectic AlSi11 alloy in quartz mould with bentonite. As the core, porous, corundum shapes were chosen. Properties of shapes are shown in Table 1. In order to improve the castability of the liquid alloy the addition of the antimony in quantity of 0.4% wt was made.

Table 1.
Main physical properties of ceramic shapes

Thermal conductivity at 800°C [W/m·K]	0.40
Density [kg/m^3]	1020
Compressive Strength [MPa]	2.1
Cold Compressive Strength [MPa]	2.2
Specific Heat at 1000˚C [kJ/kg·K]	1.1
Chemical Composition [%]	
Al_2O_3	73.4
SiO_2	25.1
Fe_2O_3	0.5
$Na_2O + K_2O$	0.9
Other	0.1

The parameters of casting process were based on results of simulation of mould cavity filling processes:

- Pouring temperature: 963 K;
- Temperature of mould: 473 K;
- Height of feeding system: 211 mm;
- Height of casting in mould: 114 mm;
- Pouring speed: 0.5 kg/s.

For the microstructure analysis 5 key areas of skeleton castings were selected. Those areas are schematically presented in Figure 2. Outside closing walls was intentionally removed in purpose to show internal topology if skeleton casting. There were three photos taken of each area in each casting. Quantitative analysis of presented micrographs was carried out with use of computer image analysis system – NIS-Elements by Nikon. The distribution of average number of silicon crystals in each class of size, and averaged stereological parameters of silicon crystals in particular regions of skeleton castings were determined.

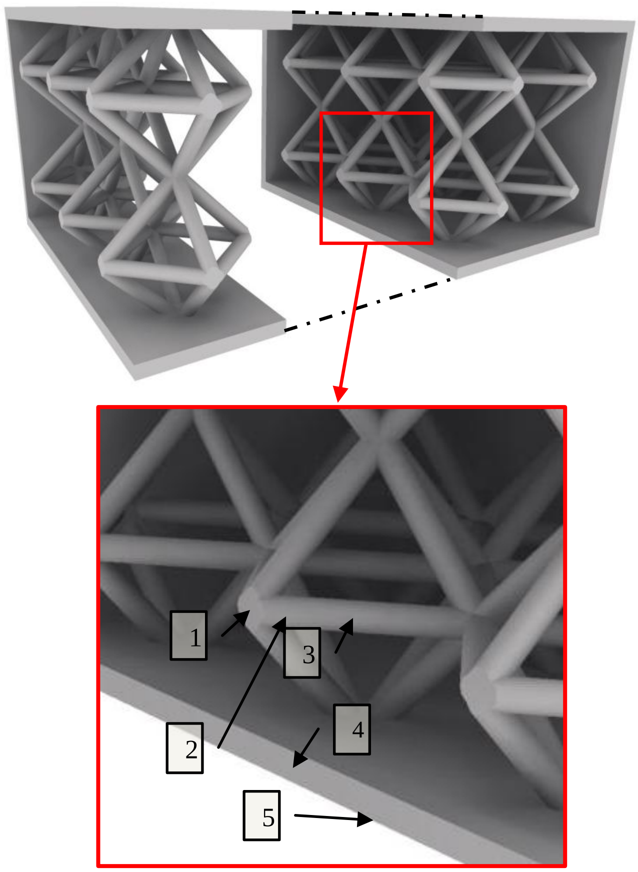
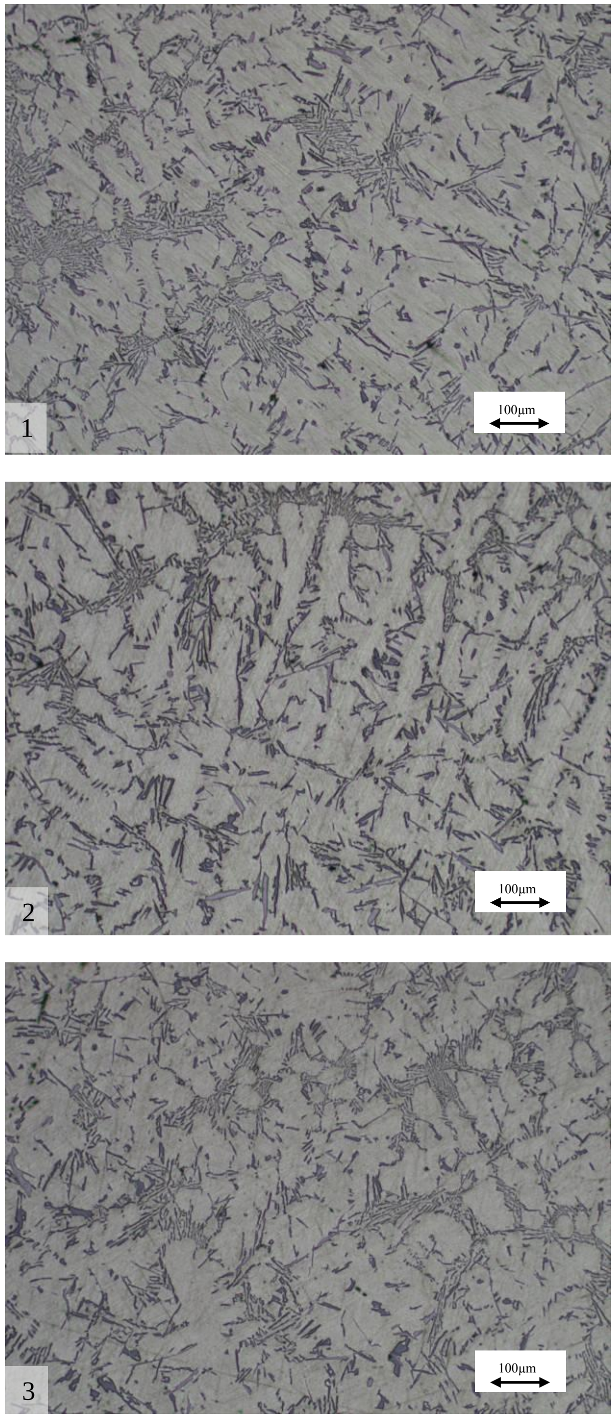
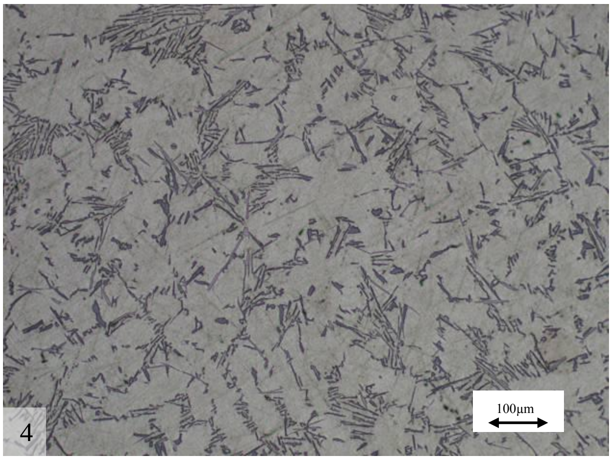


Fig. 2. Specified regions of microstructure investigation; 1 – node; 2 – near node cross-section; 3 – cross-section between the nodes; 4 – cross-section of closing wall; 5 – outside surface of closing wall



4. Results of research

Photographs of the microstructure of specimens representing particular regions of skeleton casting are shown in Figure 3. Alloy was inoculated with 0.4% wt antimony addition. The addition of antimony does not change lamellar morphology of silicone crystals, but reduces the interfacial distance of lamellar eutectic without changing it in the fibrous eutectic [24]. Additionally it must be noticed that the geometrical nodes of skeleton castings are natural hot spots, so those areas are especially vulnerable to the shrinkage porosity. The simulation carried out with taking into account thermal parameters of classical moulding materials predicted the presence of porosity near the nodes of skeleton casting. In real castings thanks to application of high thermo-insulating corundum shapes the porosity was not noticed.



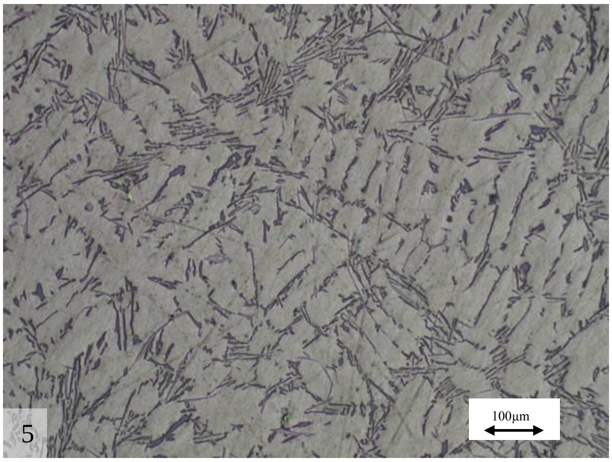


Fig. 3. AlSi11 alloy structure: 1 – node; 2 – near node cross-section; 3- cross-section between the nodes; 4- cross-section of closing wall; 5 – outside surface of closing wall

Table 2 is presenting average stereological parameters of particular regions of skeleton casting. Marks are corresponding with Figure 2. Figure 4 shows histograms describing the change of averaged parameters of shape of silicon crystals. It can be noticed, that the results of analysis of shape parameters are resemblance for all regions. Only perimeter to area ratio of specimen 3 (cross-section between the nodes) is higher. It suggests slightly more prolonged silicone crystals.

Histograms showed of Figure 4 (a-e) presents average distribution of silicon crystal in each class of size. In combination with shape parameters allows to describe the proper moulding material selection in terms of thermal properties. The distribution of size of silicone crystal is independent of region from which the specimen was taken.

Table 2.
Average stereological parameters of silicone crystals

Region	**Area $A[\mu m^2]$**	**Perimeter P[µm]**	**Length L[µm]**
1	27.35	24.43	9.83
2	36.61	28.23	11.35
3	23.97	22.15	8.97
4	32.25	26.62	10.8
5	27.75	23.17	9.15
Region	**Width B[µm]**	**Shape parameter B/L**	**Shape parameter P/A**
1	2.52	0.34	1.24
2	2.92	0.34	1.06
3	2.27	0.35	1.41
4	2.66	0.33	1.18
5	2.67	0.39	1.17

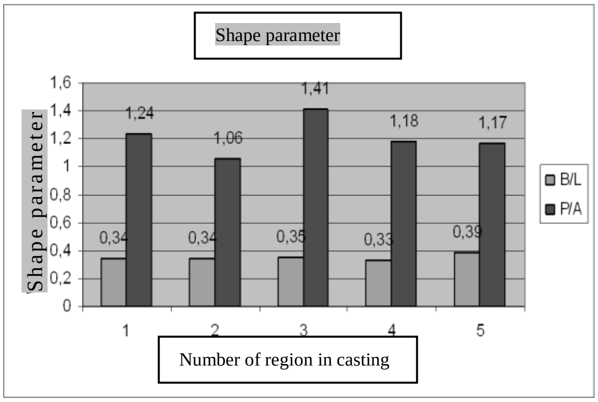
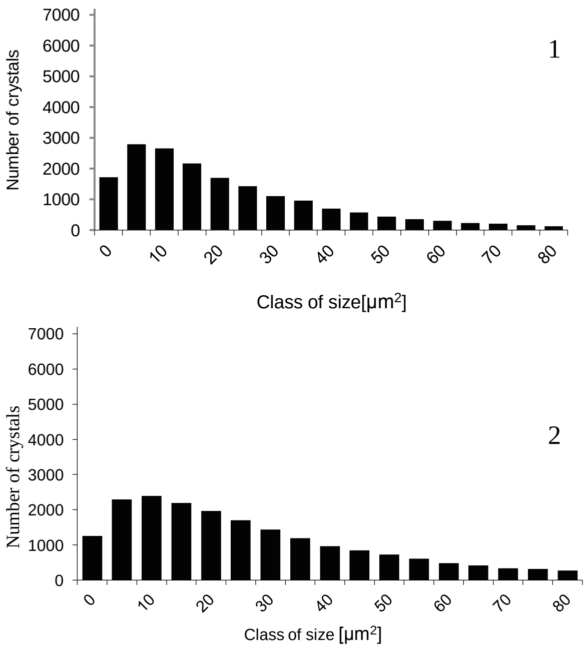


Fig. 4 Change of P/A and B/L shape parameters



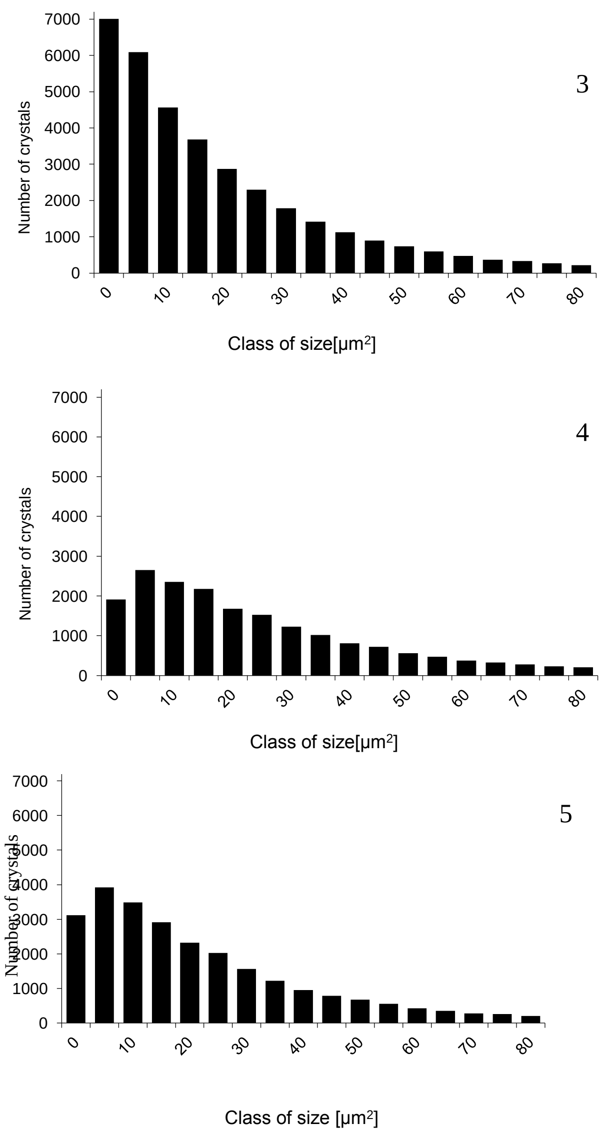


Fig. 5. Distribution of size of grain in each class of size: 1 – node; 2 – near node cross-section; 3 – cross-section between the nodes; 4 – cross-section of closing wall; 5 – outside surface of closing wall

The sample number 3 which was taken from cross-section between the nodes is exception. Microstructure is considerably finer. There is noticeable increase of number of silicone crystals in lowest class size under 5µm. The difference may be due to specific kinetic of heat transfer in area of ligaments. Because of good thermo-insulating properties of core and low diameter the ligaments crystallizes in whole volume assuring fine structure. Figure 6 shows the difference between each distribution of area of silicone crystals depending of region of casting.

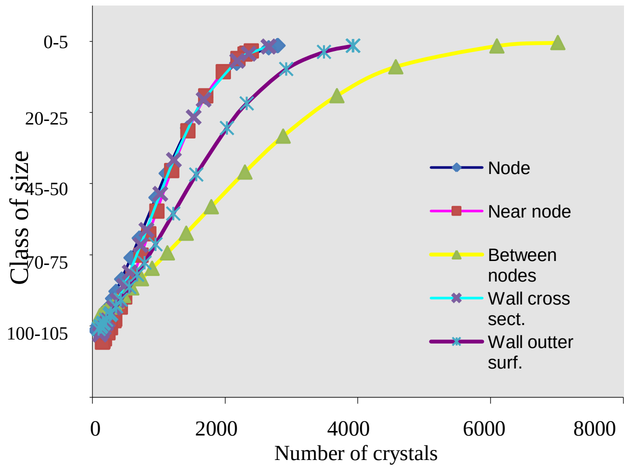


Fig. 6. Distribution of quantity of silicone crystals in each class of size

5. Conclusion

Analysis of size distribution of silicone crystals showed that the most of the silicone crystals are less than 20 µm. Depending on the area, from which the specimens were taken it can be noticed the similar degree of silicone crystals fragmentation. The greatest fragmentation of the structure occurs in the areas between the nodes. Silicone crystals are present in highest proportion in size up to 10 µm. The largest share of the silicone crystals in a class size of 5-20 microns are in wall cross section and the outer surface of the wall .In the case of the between the nodes areas it is possible necessity to repeat the metallographic examinations because of too large deviation from the mean result. It may be due to specific structures of the place of sampling, or improper processing of metallographic images.

- The study confirmed the structural correctness of the skeleton castings manufactured with proposed moulding materials.
- The addition of antimony did not cause a substantial modification to the structure but improved the degree of mold cavity filling by lowering the surface tension of liquid alloy and the influenced on the occurrence of fine dispersive eutectic.
- To determine the effect of microstructural properties on the strength of skeleton casting there is need to perform analysis of the distance between the secondary arms of dendrites of α phase (SDAS).
- Materials selected for molding ensure good fill of mold cavity and contribute to the reduction of shrinkage porosity in nodes of skeleton castings.

References

[1] Wadley H. N. G. (2006). Multifunctional periodic cellular metals. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*. *364*(1838), 31-68. DOI:10.1098/rsta.2005.1697.

[2] Davies G. J. & Zhen S. (1983). Review Metallic foams: their production, properties and applications. *Journal of Materials Science*. *18*, 1899-1911.

[3] Evans A. G., Hutchinson J. W. & Ashby M. F. (1999). Multifunctionality of cellular metal systems. *Progress in Materials Science*. *43*, 171-221.

[4] Ashby M. F. (1983). The Mechanical Properties of Cellular Solids. *Metallurgical Transactions*. *14*, 1755-1769.

[5] Queheillalt, D. T., & Wadley, H. N. G. (2005). Cellular metal lattices with hollow trusses. *Acta Materialia*, *53*(2), 303-313. DOI:10.1016/j.actamat.2004.09.024.

[6] Kooistra G. (2004). Compressive behavior of age hardenable tetrahedral lattice truss structures made from aluminium. *Acta Materialia*. *52*(14), 4229-4237. DOI:10.1016/j.actamat.2004.05.039.

[7] Norouzi Y., Rahmati S. & Hojjat Y. (2009). A novel lattice structure for SL investment casting patterns. *Rapid Prototyping Journal*. *15*(4), 255-263. DOI:10.1108/ 13552540910979776.

[8] Fan H., Yang W., Wang B., Yan Y., Fu Q., Fang D. & Zhuang Z. (2006). Design and Manufacturing of a Composite Lattice Structure Reinforced by Continuous Carbon Fibers. *Tsinghua Science & Technology*. *11*(5), 515-522. DOI:10.1016/S1007-0214(06)70228-0.

[9] Dziuba M. & Cholewa M. (2006). Rdzenie ceramicznie odlewu szkieletowego o komórkach otwartych. *Archives of Foundry Engineering*. *6*(22). 170-177.

[10] Dziuba M., Kondracki M. & Cholewa M. (2006). Warunki wytwarzania i postać geometryczna odlewów szkieletowych. *Archives of Foundry Engineering*. *6*(22).

[11] Kałuża M. D. (2008). *Wpływ czynników technologicznych wytwarzania na strukturę odlewów szkieletowych*. Politechnika Śląska.

[12] Cholewa M. Szuter T. & Dziuba M. (2011). Basic properties of 3D cast skeleton structures. *Archives of Materials Science and Engineering Processing*. *52*(2), 101-111.

[13] Cholewa M. & Szuter T. (2010). Geometrical and mechanical analysis of 3D casted skeleton structure. *Archives of Foundry Engineering*. *10*(2), 23-26.

[14] Cholewa M. & Dziuba-Kałuża M. (2009). Studies of structural and mechanical properties of aluminum skeleton castings. *Archives of Foundry Engineering*. *9*(3), 29-34.

[15] Cholewa M. & Dziuba-Kałuża M. (2008). Structural analysis of aluminum skeleton castings. *Archives of Foundry Engineering*. *8*(3), 29-36.

[16] Cholewa, M, & Szuter, T. (2011). Heat-insulating moulding sand with the glycol addition. *Archives of Foundry*. *11*(3), 61-64.

[17] Cholewa M., Tenerowicz S. & Wróbel T. (2008). Quality of the joint between cast steel and cast iron in bimetallic castings. *Archives of Foundry Engineering*. *8*(3), 37-40.

[18] Wallach J. C., & Gibson L. J. (2001). Mechanical behavior of a three-dimensional truss material. *International Journal of Solids and Structures*. *38*(40-41), 7181-7196. DOI:10.1016/S0020-7683(00)00400-5.

[19] Cholewa M. & Dziuba-Kałuża M. (2008). Microstructure quantitative analysis of aluminum skeleton castings. *Archives of Foundry Engineering*. *8*(4), 241-250.

[20] Szajnar J. & Wróbel T. (2007). Inoculation of primary structure of pure aluminium. *Journal of Achievements in Materials and Manufacturing Engineering*. *20*, 283-286.

[21] Szajnar J., Stawarz M., Wróbel T. & Sebzda W. (2009). Influence of electromagnetic field on pure metals and alloys structure. *Journal of Achievements in Materials and Manufacturing Engineering*. *34*(1), 95-102.

[22] Szajnar J. & Wróbel T. (2008). Inoculation of pure aluminium aided by electromagnetic field. *Archives of Foundry Engineering*. *8*(1), 123-132.

[23] Szajnar, J. (2009). *The influence of selected physical factors on the crystallization process and castings structures*. – Gliwice: Polish Academy of Science.

[24] Pietrowski, S. (2001). *Silumins.* Łódź. Technical University Editorial. (in Polish).