ARCHIVES

of

FOUNDRY ENGINEERING

Porosity of Castings Produced by the Vacuum Assisted Pressure Die Casting Method

A. Zyska*, Z. Konopka, M. Łągiewka, M. Nadolski
Department of Foundry, Częstochowa University of Technology,
Armii Krajowej 19, 42-200 Częstochowa, Poland
*Corresponding author. E-mail address: zyska@wip.pcz.pl

Abstract

The paper presents the results of investigations concerning the influence of negative (relative) pressure in the die cavity of high pressure die casting machine on the porosity of castings made of AlSi9Cu3 alloy. Examinations were carried out for the VertaCast cold chamber vertical pressure die casting machine equipped with a vacuum system. Experiments were performed for three values of the applied gauge pressure: -0.3 bar, -0.5 bar, and -0.7 bar, at constant values of other technological parameters, selected during the formerly carried initial experiments. Porosity of castings was assessed on the basis of microstructure observation and the density measurements performed by the method of hydrostatic weighing. The performed investigation allowed to find out that – for the examined pressure range – the porosity of castings decreases linearly with an increase in the absolute value of negative pressure applied to the die cavity. The negative pressure value of -0.7 bar allows to produce castings exhibiting porosity value less than 1%. Large blowholes arisen probably by occlusion of gaseous phase during the injection of metal into the die cavity, were found in castings produced at the negative pressure value of -0.3 bar. These blowholes are placed mostly in regions of local thermal centres and often accompanied by the discontinuities in the form of interdendritic shrinkage micro-porosity. It was concluded that the high quality AlSi9Cu3 alloy castings able to work in elevated temperatures can be achieved for the absolute value of the negative pressure applied to the die cavity greater than 0.5 bar at the applied set of other parameters of pressure die casting machine work.

Keywords: Innovative foundry technologies, Aluminium alloys, Vacuum assisted high pressure die casting, Defects in pressure die castings, Porosity

1. Introduction

The high pressure die casting (HPDC) technology is counted among these modern methods of production of aluminium, magnesium, and the low-melting alloy castings, which provide good quality of products, i.e. their high surface smoothness and excellent dimensional and shape accuracy, accompanied by the relatively low production costs. The advantages of these methods include also the refined structure of castings, defect-free surfaces, small machining allowances, the possibility of obtaining the intricate thin-walled castings, and the high productivity of the process [1-4]. The main defect affecting the pressure castings is their gas porosity, and for castings of intricate geometry – both the shrinkage and the gas porosity. The presence of blowholes in castings is related to the character of liquid metal flow during the first and the second stages of filling the pressure die. During the first stage, an occlusion of gaseous phase present in the injection

sleeve takes place, while during the second phase the air trapped in the die cavity is absorbed. The airtight walls of the metal die along with a very short injection time result in the minimal effectiveness of cavity venting. Moreover, the high plunger velocity in the second phase of injection causes the turbulent flow of metal and the compression of the gaseous phase in the die cavity [4-6]. As a result, the solidified casting contain a large amount of tiny blowholes [4, 6, 7]. This main defect of pressure castings not only prevents them from being applied under the conditions of elevated temperature, but also precludes their thermal treatment and restricts the possibility of their machining to a very narrow range. Various solutions are used in order to limit the porosity of pressure castings: there can be applied the multi-phase injection systems, which allow to control both the plunger velocity and the intensification pressure by means of modern digital systems [8, 9], or the atmosphere of active gases can be generated in the die cavity [1, 2, 6]. One of such solutions is the application of lowered pressure to the die cavity while it is filled with molten alloy [1, 2, 7-13]. This method can be employed for production of the high-quality castings from magnesium, zinc, and copper alloys. Its broad perspectives of application are suggested by the results of several works [7, 10, 11, 14-16]. Application of the negative (relative) pressure in the die cavity causes that both the porosity level of castings become comparable with the respective results obtained for squeeze casting technology [15]. The presented method, as compared with the conventional HPDC process, requires some changes in construction of the metal mould and some adjustments in working parameters of the injection system [7, 11-13]. Their optimisation gives definite economic profits due to the reduction of casting wall thickness, the improvement in the process stability, the prolonged pressure die life, the reduced quantity or even total elimination of overflows, the reduced values of injection velocity and pressure, the possibility of achieving pressuretight and weldable castings, which can work in elevated temperature without the risk of surface deformation because of the expansion of gases contained in voids [7, 12-14, 16].

The work presents the results of initial studies concerning the influence of negative pressure in the mould cavity on the porosity of pressure castings.

2. Methods and results of investigation

Experiments were performed for the standardized AlSi9Cu3 alloy (EN AB 46000 or DIN 226). Castings were produced by means of the cold chamber vertical pressure die casting machine VertaCast 400. The characteristic feature of the machine is the arrangement of elements and units of the hydraulic drive upon its upper part and taking advantage of the weight of the movable platen in order to speed up its movement during clamping. A modified injection system was used, and the machine was also equipped with a vacuum system consisting of a vacuum pump and vacuum valves, in order to remove the air contained in the mould cavity and the injection sleeve. The vacuum system was connected to the venting system in a way preventing the flow of metal into the vacuum system. The system construction allowed to control both the pressure in the die cavity and the rate of filling the die with molten alloy.

The VertaCast machine was equipped with the horizontally parted two-cavity pressure die designed for casting soleplates of clothes iron (Fig. 1). The selected type of castings should meet the requirements adequate for items working within the range of elevated temperature, exceeding 100°C. The good quality of castings, and particularly their low gas porosity, is the main criterion of their acceptance.

Nine injection sequences were carried out in order to determine the influence of negative pressure in the die cavity on the porosity of castings, a series of castings being produced during each of them. The negative pressure value for a sequence was set either to - 0.3, or - 0.5, or - 0.7 bar. The examinations were performed at the following constant technological parameters: injection temperature - 640°C, die temperature of 150°C, total volume of castings (two soleplates) along with overruns and the gating system equal to $V_0 = 373$ cm^3, plunger diameter $d_k = 58$ mm, plunger velocity during the first stage of injection – 0.3 m/s, plunger velocity during the second stage of injection – 4 m/s, degree of filling of the injection sleeve – 60%, machine clamping force $N_z = 2000$ kN, total cross-section of gates for both cast soleplates $\Sigma f_w = 2 \times 75$ mm $\times$ 1.5 mm = 225 mm^2, average casting wall thickness $d = 5$ mm. These values were set on the basis of the former initial experiments.
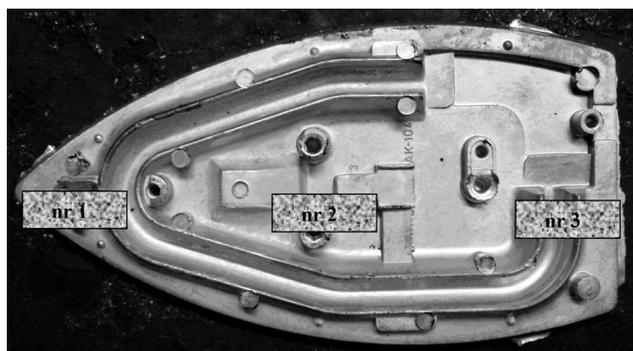
Fig. 1. The examined cast soleplate of clothes iron with marked regions from which the specimens for metallographic examination were taken

Porosity of castings were assessed according to the Standard BN-75/4051-10. Hydrostatic weighing was carried out for 45 soleplate castings, 15 measurements corresponding to each value of negative pressure being taken. The examined casting were randomly selected, five items from each series of castings. All specimens were weighted in air and in water, then their densities were determined according to the formula:

$$\rho_P = \frac{m_1}{m_1 - m_2} \cdot \rho_W \qquad (1)$$

where: ρ_P – density of the specimen, m_1 – mass of the specimen in air; m_2 – mass of the specimen in water; ρ_W – density of water.

Next the porosity of the examined specimens was calculated from the relationship:

$$P = (1 - \frac{\rho_P}{\rho_{WZ}}) \cdot 100\% \qquad (2)$$

where: ρ_{WZ} – true density, equal to 2 760 kg/m^3 for the EN AB 46000 alloy in accord with EN 1706.

The results of measurements are detailed in Table 1 and the averages presented in Fig. 2.

Table 1.
The results of porosity measurements of castings

Negative pressure in the die cavity, bar					
− 0.3		− 0.5		− 0.7	
Density g/cm^3	Porosity %	Density g/cm^3	Porosity %	Density g/cm^3	Porosity %
2.680	2.913	2.698	2.252	2.730	1.084
2.649	4.037	2.701	2.155	2.746	0.498
2.647	4.093	2.707	1.904	2.730	1.097
2.682	2.821	2.692	2.449	2.725	1.256
2.680	2.890	2.702	2.108	2.739	0.777
2.659	3.642	2.681	2.878	2.738	0.780
2.687	2.649	2.717	1.566	2.724	1.296
2.673	3.149	2.699	2.223	2.747	0.455
2.687	2.654	2.708	1.896	2.745	0.550
2.672	3.203	2.701	2.122	2.734	0.948
2.671	3.229	2.707	1.921	2.733	0.979
2.695	2.352	2.713	1.692	2.730	1.084
2.689	2.574	2.686	2.667	2.724	1.310
2.666	3.418	2.710	1.818	2.736	0.885
2.658	3.698	2.714	1.668	2.740	0.714
Average porosity P, %					
3.155		**2.088**		**0.914**	
Standard deviation σ(P), %					
0.534		**0.370**		**0.281**	

The performed examinations indicate that the porosity of castings decreases in a linear manner with an increase of the absolute value of the negative pressure applied to the die cavity and the injection sleeve. The lowest porosity value of about 1% occurs for soleplate castings produced at the negative pressure of -0.7 bar. Comparing the extreme values of negative pressure one can find that the reduction of pressure by -0.4 bar results in the significant decrease in the porosity of castings, exceeding 2%.

Observations of microstructures were carried out by means of the computer image analyser CSS SCAN – MULTISCAN Y 8.08 coupled with the NIKON EPIPHOT optical microscope. Metallographic specimens were prepared from the material taken out of the three places along the soleplate length. These places are indicated in Figure 1. The figures below present microstructures and representative defects of castings produced under the negative pressure of -0.3 bar (Fig.3), -0.5 bar (Fig. 4), or -0.7 bar (Fig. 5).

a) area N° 1

b) area N° 2

Fig. 2. The influence of negative pressure in the die cavity on the porosity of castings made of EN AB 46000 alloy
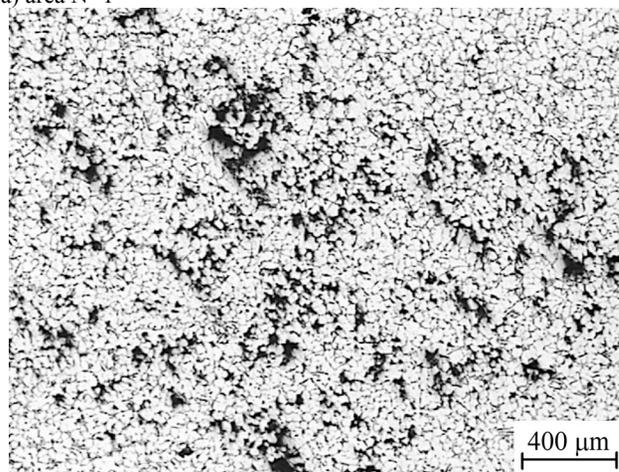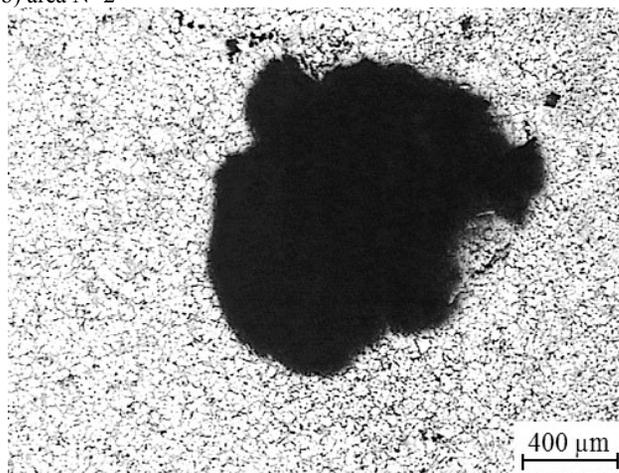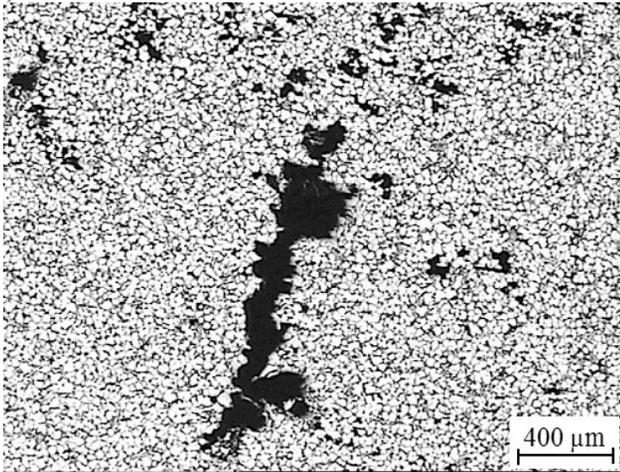
c) area Nᵒ 3

c) area Nᵒ 3

Fig. 3. Representative shrinkage and gas porosity occurring in castings produced under the negative pressure value of -0.3 bar
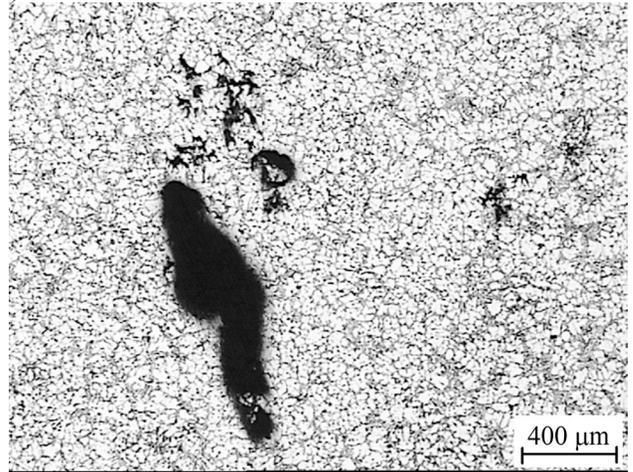
Fig. 4. Representative shrinkage and gas porosity occurring in castings produced under the negative pressure value of -0.5 bar

a) area Nᵒ 1
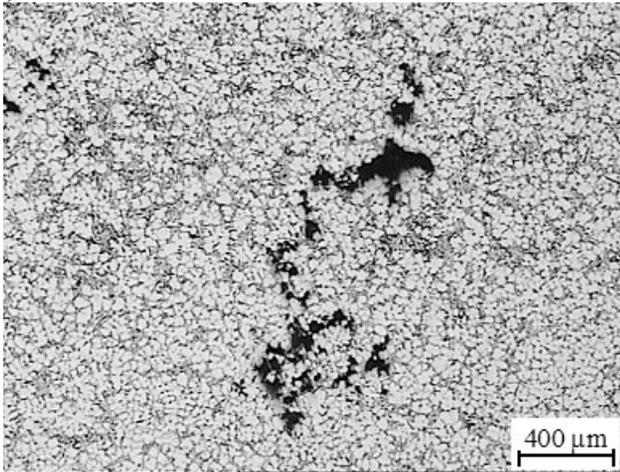
a) area Nᵒ 1
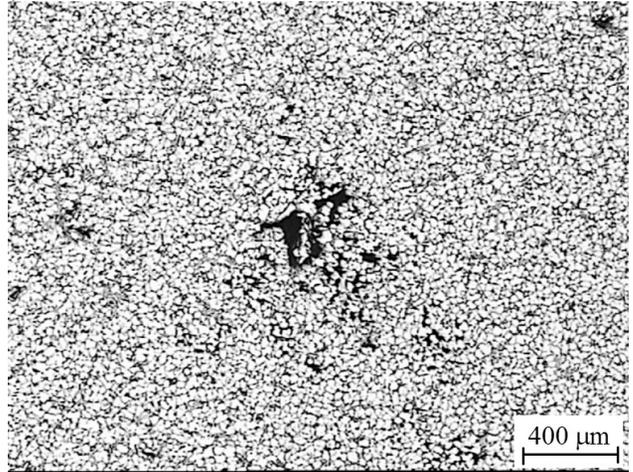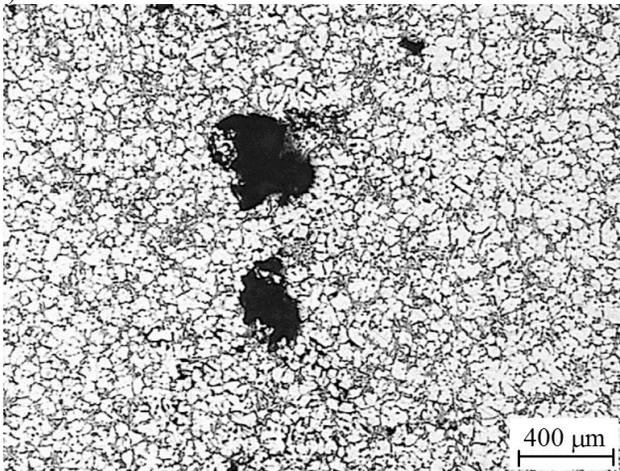
b) area Nᵒ 2

b) area Nᵒ 2
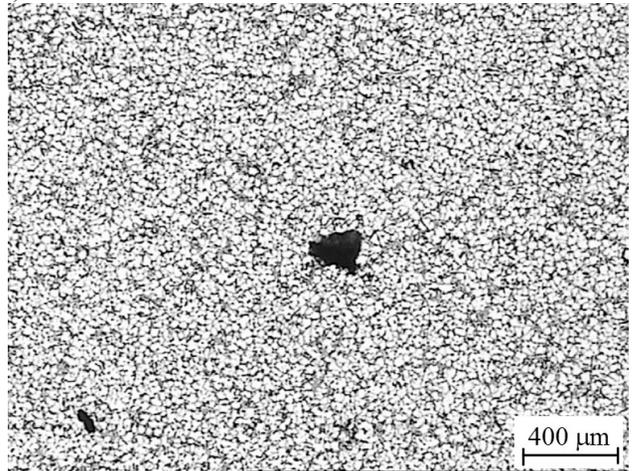
c) area N° 3
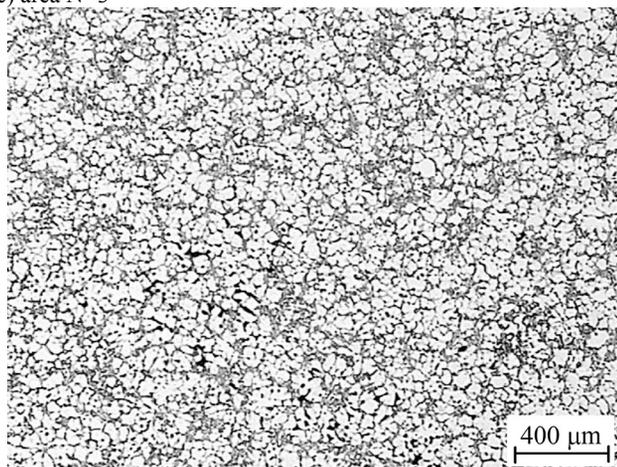
Fig. 5. Representative shrinkage and gas porosity occurring in castings produced under the negative pressure value of -0.7 bar

The main defect occurring in castings produced under the negative pressure of -0.3 bar is gas porosity. It is found in a form of large voids of regular shape and results from the occlusion of gaseous phase during the filling of the die cavity. Also the dispersed interdendritic shrinkage porosity was observed in the microstructure of the alloy in thermal centres of the castings. The indicative feature of this defect is the irregular, sometimes elongated shape of the voids and significantly less dimensions. Desorption of gases dissolved in metal to the empty shrinkage voids sometimes makes impossible to classify the actual, i.e. the primary source of these discontinuities. Some configurations of microstructure can be described generally as the combined shrinkage and gas porosity. Gas porosity occurs also when the negative pressure is equal to -0.5 bar, but both the number and the size of voids are significantly reduced. Further lowering the pressure value to -0.7 bar restricts the generation of gas voids even more. Their presence in the analysed regions is only occasional, and their dimensions are limited to several micrometres. The images of microstructure of castings produced under the negative pressure of -0.7 bar confirm that the casting parameters set on during the initial examinations provide for the correct filling of the die cavity, and the metallurgical quality of the molten silumin was high. If the liquid alloy had been excessively gassy, the discontinuity defects would be still present. The shrinkage microporosity is another problem, always to be found in the discussed castings, irrespective of the selected technological parameters. Its source is the geometry of the irregular side of the clothes iron soleplate, with its changes in the wall thickness which are, in turn, responsible for the presence of local thermal centres. This, however, results from the imposed construction solution of the final product.

The microstructure of the examined silumin consists of the primary dendrites of α phase and the $\alpha + Si + Al_2Cu$ eutectics (Fig. 6b). These constituents are arranged over the microsection surfaces in a way characteristic for pressure castings. The surface layer exhibits the fine-grained microstructure and the enrichment in alloying elements, but the degree of microstructure refinement and the quantity of eutectic phase changes towards the middle of the casting wall (Fig. 6a – 6b). The influence of negative pressure applied within the die cavity on the microstructure of castings produced of the EN AB 46000 alloy was not observed in the examined pressure range.

3. Final conclusions

1. The high pressure die casting with the application of negative pressure in the die cavity during the first and the second phases of injection (the so-called vacuum-assisted HPDC) allows to produce the high quality EN AB 46000 alloy castings. Properly selected technological parameters of the process provide for minimal gas-and-shrinkage porosity of castings.
2. Porosity of castings changes in a linear manner with the change in the negative pressure applied to the die cavity. The change in the negative pressure by -0.2 bar results in the reduction of porosity by 1%. The minimum porosity, less than 1 %, is obtained at the value of negative pressure in the die cavity at the level of -0.7 bar.

a)

b)
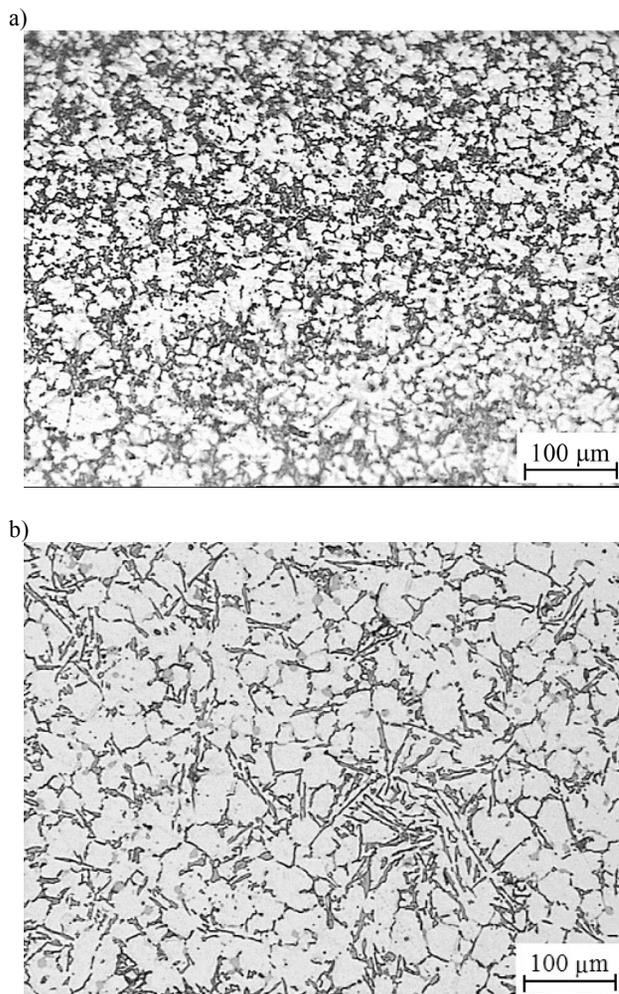
Fig. 6. Microstructure of the EN AB 46000 alloy casting: a) close to the surface of the casting wall, b) in the middle of the wall

3. Taking into account the shape, the size, and the arrangement of voids within a casting, as well as the possibility of momentary oscillations in the negative pressure level during the working cycle of the pressure die casting machine, it can be assumed that the minimum absolute value of negative pressure, at which the sound clothes iron soleplate castings are achieved, is equal to -0.5 bar.

4. Castings produced at the negative pressure value of -0.3 bar clearly indicate the phenomenon of air entrapment occurring during the injection. Large blowholes can be found locally, in the regions of heat centres, so that there is a danger of deformation of the working surfaces of such castings at the elevated working temperature.

References

[1] Perzyk, M., Waszkiewicz, S., Kaczorowski, M., Jopkiewicz, A. (2000). *Foundry*. Warsaw. WNT. (in Polish).

[2] Górny, Z., Sobczak, J. (2005). *Non-ferrous metals based novel materials in foundry practice*. Krakow: Za-pis. (in Polish)

[3] Bonderek, Z. Chromik, S. (2006). *Pressure die casting of metals and injection molding of plastics*. WN Akapit. (in Polish).

[4] Białobrzeski, A. (1992). *Pressure die casting*. Machinery, equipment and technology. Warszawa WNT. (in Polish).

[5] Dańko, J., Dańko, R. & Stojek, J. (2008). Cognisable effects of model investigations of die casting processes. *Archives of Foundry Engineering*. 8, 57-62.

[6] Białobrzeski, A. (2002). *Special die casting technologies*. Foundry Research Institute. Krakow. (in Polish).

[7] Niu, X.P., Hua, B.H., Pinwilla, I. & Lib, H. (2000). Vacuum assisted high pressure die casting of aluminium alloys. *Journal of Materials Processing Technology*. 105, 119-127

[8] Bielecka, A., Konopka, Z., Zyska, A. & Łągiewka, M. (2007). Investigation of pressure die casting of the aluminium alloy matrix composites with SiC particles. *Archives of Metallurgy and Materials*. 52, 497-502.

[9] Białobrzeski, A., Słowik, P., Wojtarowicz, A. (1984). Research determining the desirability of Vacuum assisted high pressure die casting. Work program, order 7087/I, II. Foundry Research Institute. Krakow. (in Polish).

[10] Valette. A. & Fac, T. (2002). The "Full Sleeve". An innovation technology for pressure casting of aluminium (1). *Fonderie. Fondeur d'aujourd'hui*. 212 5-10 (in French).

[11] Konopka, Z., Zyska, A., Łągiewka, M., Bielecka, A. & Nocuń, S. (2008). The „full sleeve" application in the horizontal cold-chamber machine for pressure die casting of aluminium alloys. *Archives of Foundry Engineering*. 8, 65-71.

[12] Jin, Ch. & Kang, Ch. (2011). Fabrication process analysis and experimental verification for aluminum bipolar plates in fuel cells by vacuum die-casting. *Journal of Power Sources*. 196, 8241– 8249.

[13] Jin, C. & Kang, C. (2012). Fabrication by vacuum die casting and simulation of aluminum bipolar plates with micro-channels on both sides for proton exchange membrane (PEM) fuel cells, *International Journal of Hydrogen Energy*. 37, 1661-1676.

[14] Wan, L., Hu, Z., Wu, S. & Liu, X. (2013). Mechanical properties and fatigue behavior of vacuum-assist die cast AlMgSiMn alloy. *Materials Science and Engineering*. A576, 252–258.

[15] Hébert, G., Dubé, D. & Tremblay, R. (2012). Tensile and fatigue behaviour of thin-walled cast A383.0 components. *Materials Science and Engineering*. A552, 89– 96.

[16] Kim, E.S., Lee, K.H. & Moon, Y.H. (2000). A feasibility study of the partial squeeze and vacuum die casting process. *Journal of Materials Processing Technology*. 105, 42-48.