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POLSKA AKADEMIA NAUK

ARCHIVES of FOUNDRY ENGINEERING

DOI: 10.2478/afe-2014-0030

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

DE GRUYTER OPEN

ISSN (2299-2944)
Volume 14
Issue 2/2014

23 – 26

The Effect of Vacuum Assistance on the Quality of Castings Produced by High Pressure Die Casting Method

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Received 03.03.2014; accepted in revised form 30.03.2014

Abstract

The presented work is aimed to deal with the influence of changes in the value of negative (relative) pressure maintained in the die cavity of pressure die casting machine on the surface quality of pressure castings. The examinations were held by means of the modified Vertacast pressure die casting machine equipped with a vacuum system. Castings were produced for the parameters selected on the basis of previous experiments, i.e. for the plunger velocity in the second stage of injection at the level of 4 m/s, the pouring temperature of the alloy equal to 640°C, and the die temperature of 150°C. The examinations were carried on for three selected values of negative gauge pressure: - 0.03, - 0.05, and - 0.07 MPa. The quality of casting was evaluated by comparing the results of the surface roughness measurements performed for randomly selected castings. The surface roughness was measured by means of Hommel Tester T1000. After a series of measurements it was found that the smoothest surface is exhibited by castings produced at negative gauge pressure value of - 0.07 MPa.

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

1. Introduction

The basic technological problem in high pressure die casting (HPDC) is to remove completely the gaseous phase from the die cavity at the time of an injection. The problem arises due to total gas impermeability of the die and the very short time of filling it with the liquid metal. Changes in the plunger velocity result in generation of gaseous occlusions in the shot sleeve of pressure die casting machine. Then both the high velocity of metal which induces its turbulent flow and the difficulties in air escaping from the die cavity contribute to the great porosity of castings produced by the HPDC process [1, 2]. Common pressure castings are not pressure-tight, they cannot work in elevated temperature range, cannot undergo the heat treatment, and can be machined only in a very limited range. There exist methods which allow for reduction of porosity in castings made by pressure die casting processes, including the pore-free die casting method which consists in filling the die in the atmosphere of active gases. These methods, however, demand for special casting conditions to make possible using oxygen in the presence of hydrocarbons. Castings produced according to this technology exhibit significantly reduced porosity, but their surface quality gets notably worse. Many solutions were also proposed in the construction field in order to reduce porosity generation [3]. Formation of air occlusion in the shot sleeve is mostly influenced by the accuracy and repeatability of dispensing the liquid alloy dose to the shot sleeve.

Therefore castings of better quality are produced when automatic dosing systems are employed [4].

On the other hand, the high cooling rate and low temperature gradients allow for achieving great uniformity and significant refinement of the structure, comparable with those achieved in gravity castings after modifying treatment. Consequently, the pressure die castings exhibit high mechanical properties as compared with castings produced by other casting methods [5].

Currently, Polish foundries produce pressure die castings by conventional methods using hot and cold chamber pressure die casting machines. New solutions, which can improve surface quality and make possible production of pore-free castings, should be developed in order to widen the range of produced elements. The special pressure die casting methods become nowadays more and more significant, answering the demand for reduced porosity and optimization of casting parameters with respect to the process of the die filling. Attempts of reducing the gas porosity in pressure die castings led to the application of multiphase injection systems which allow to control the plunger velocity and the intensification pressure by means of new digital systems [6, 7]. Other solutions try to generate special physical and chemical conditions within the die cavity, e. g. the lowered pressure [8-12].

One of such solutions, capable of reducing the porosity of castings, is applying the negative relative pressure, which would facilitate the evacuation of air from inside the die cavity. The development of the so-called vacuum-assisted pressure die casting technology would allow for the production of high quality aluminium, zinc, or copper castings free of pores in the subsurface layer. This would involve significant economic advantages with respect to the reduction of discards, possibility of achieving thinner walls (reduced volume), improvement of the process stability, increased lifetime of the pressure die, diminution or even elimination of overflows, possibility of applying lower pressure and injection speed, possibility of achieving weldable castings, possibility of applying heat treatment without the occurrence of surface defects, possibility of galvanizing, anodizing, or teflon coating of the castings.

2. Methods and results of investigation

The main purpose of the presented work was to determine the influence of negative gauge pressure in the die cavity on the quality of pressure castings. An innovative stand for vacuum assisted high pressure die casting was assembled in order to achieve it. The stand used the Vertacast cold chamber HPDC machine, which is a universal machine for production of intricate castings made of aluminium, manganese, zinc, and other metal alloys. The characteristic feature of Vertacast 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. A modified injection system was used in the machine employed during the experiment. The machine was also equipped with a vacuum system consisting of a vacuum pump and vacuum valves. The vacuum system was connected to the air venting system in such a way that the flow of metal into the vacuum system was prevented. The vacuum system was aimed to reduce the amount of gases – which otherwise would be entrapped in metal during the injection – by sucking the air out of the shot sleeve and the die cavity.

After the vacuum system had been designed and assembled, the initial test series of castings was produced to verify the work of the system. Then some adjustments, which allowed to achieve castings without casting defects and exhibiting the reduced porosity, were made.

Castings made of AlSi9Cu3 alloy (DIN226) were produced at the previously determined optimum casting parameters, for which a combination of good mechanical properties and the minimum porosity had been previously achieved, namely: the plunger speed in the second phase of injection equal to 4 m/s, the metal injection temperature of 640°C, and the die temperature of 150°C.

After a series of castings had been produced, the quality of randomly selected castings was examined. The quality of castings can be evaluated mainly with respect to their surface quality, the achieved dimensional accuracy or the values of their strength properties. The present work deals with the analysis of surface quality which is characterised by surface roughness parameters. The surface roughness examination for the selected castings were performed by means of the Hommel Tester T1000. The surface roughness measurements taken for the pressure castings produced by the vacuum-assisted HPDC method included such parameters as Ra (arithmetical mean roughness value), Rmax (maximum peak-to-valley height within a single sampling length), Rz (average maximum height of the assessed profile), Rt (total height of the profile), Rpm (average maximum profile peak height), Rp (maximum profile peak height), Rq (root mean square roughness), Wt (total height of the waviness profile), D (peak count), Rsm (mean width of the profile elements). The bearing properties of the surface were also characterised by determining the material ratio at the upper and the lower limit of the roughness core area (Mr1, Mr2).

Examinations were performed for several dozen of castings produced at the above mentioned values of casting parameters and at the assistance of negative gauge pressure equal either to - 0.03, or - 0.05, or - 0.07 MPa. The roughness measurements for each of the selected castings were taken at five different places over the examined surface. Examples of profilograms achieved for surfaces of pressure castings produced at the above stated parameters are presented in Figures 1, 2, and 3.

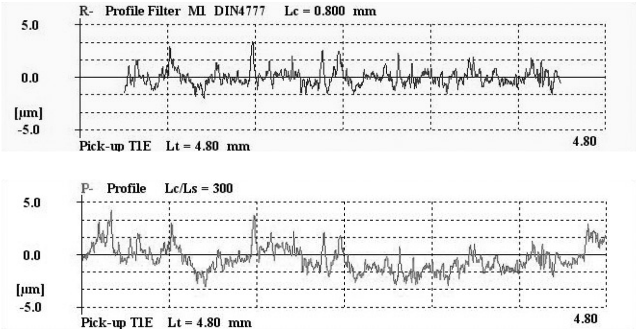

Fig. 1. Profilogram of the surface of a casting produced at the assumed pressure casting parameters and the value of negative gauge pressure at the level of - 0.03 MPa

The multiple data coming from the roughness measurements were averaged and gathered in tables. An exemplary tables containing the average results for the selected castings are presented in the right-side column.

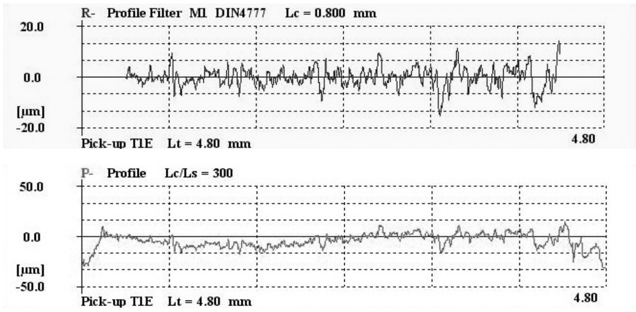

Fig. 2. Profilogram of the surface of a casting produced at the assumed pressure casting parameters and the value of negative gauge pressure at the level of - 0.05 MPa

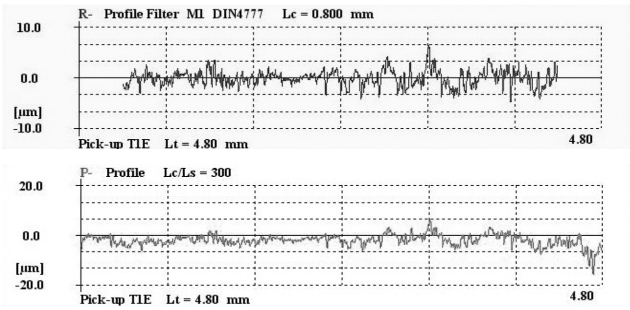

Fig. 3. Profilogram of the surface of a casting produced at the assumed pressure casting parameters and the value of negative gauge pressure at the level of - 0.07 MPa

Table 1.
Data achieved from roughness measurements of a casting produced at the negative gauge pressure of - 0.03 MPa

Area of measurement / Parameter	Casting N^o 6 (- 0.03 MPa)				
	1	2	3	4	5
Ra	3.43	2.52	1.46	0.82	0.71
Rz	25.09	17.97	7.92	4.66	4.63
Rp	18	21.44	7.70	5.41	4.67
Rmax	44.05	41.39	13.82	7.98	5.96
Rt	44.05	41.39	13.82	7.48	6.54
Rpm	10.21	8.17	4.53	3.02	3.16
Rpm/Rz	0.40	0.45	0.57	0.65	0.68
Rq	5.23	3.99	2.29	1.18	0.96
Wt	16.47	8.48	30.87	9.14	9.0
D	49	70	13.82	71	66
Rsm	0.0816	0.0571	0.0741	0.0563	0.0606
Mr1	10.6	8.7	16.2	18.8	16.4
Mr2	79	81.9	82.7	85.5	92.7

Table 2.
Data achieved from roughness measurements of a casting produced at the negative gauge pressure of - 0.05 MPa

Area of measurement / Parameter	Casting N^o 4 (- 0.05 MPa)				
	1	2	3	4	5
Ra	0.73	2.35	0.72	2.43	0.58
Rz	5.40	13.51	6.83	12.71	5.12
Rp	5.85	18.05	5.06	19.31	4.34
Rmax	7.79	28.41	9.61	31.48	5.96
Rt	7.98	28.11	11.88	31.48	7.26
Rpm	3.65	7.60	2.84	7.37	3.20
Rpm/Rz	0.67	0.56	0.415	0.58	0.625
Rq	0.98	3.6	1.1	4.11	0.79
Wt	5.79	57.33	9.06	27.23	6.74
D	61	40	95	36	85
Rsm	0.0656	0.1000	0.0421	0.1111	0.0471
Mr1	14.4	14.9	12	11.1	15.5
Mr2	92.6	83.6	86.7	83.5	92.2

Table 3.
Data achieved from roughness measurements of a casting produced at the negative gauge pressure of - 0.07 MPa

Area of measurement / Parameter	Casting N^o 1 (- 0.07 MPa)				
	1	2	3	4	5
Ra	0.66	0.57	0.57	0.71	0.68
Rz	4.75	4.34	3.51	5.51	6.09
Rp	2.72	3.60	2.76	5.83	7.93
Rmax	5.57	6.67	4.13	7.48	9.61
Rt	5.93	6.67	4.66	7.53	10.26
Rpm	2.34	2.16	2.08	3.41	4.15
Rpm/Rz	0.49	0.49	0.59	0.61	0.68
Rq	0.85	0.79	0.71	0.96	1.02
Wt	2.77	4.08	3.43	6.68	4.42
D	66	121	69	58	87
Rsm	0.0606	0.0331	0.0580	0.0690	0.0460
Mr1	12.2	12.4	11.2	14.9	12.3
Mr2	91.7	85.7	95.1	94.3	86.8

3. Analysis of results and conclusion

Previous Polish Standard established 14 classes of roughness. Each of them is characterised by the corresponding range of Ra or Rz roughness parameter. Castings produced at the pressure casting parameters previously found as optimum ones and with the assistance of negative gauge pressure equal to - 0.07 MPa exhibited the average value of Ra parameter (arithmetical mean deviation of the profile) equal to 0.68 µm, which is compatible with the roughness of a surface after the rough grinding. The average Ra for negative gauge pressure value equal to - 0.05 MPa was at the level of about 1.4 µm, and for the value of - 0.03 MPa was equal to about 1.8 µm, thus approaching the roughness characteristic for machined surfaces. The Rz parameter (average maximum height of the roughness profile) for the negative gauge pressure of - 0.03 MPa takes the value of about 12 µm and decreases with an increase of the absolute value of negative gauge pressure, dropping to about 5 µm for the negative gauge pressure of - 0.07 MPa. It should be also noticed that the values of both considered parameters for castings made at the negative gauge pressure of - 0.07 MPa are similar at each measuring area, while for castings produced at the negative gauge pressure of - 0.03 MPa they vary significantly from place to place, e.g. one can notice the Ra value of 3.43 µm, or the Rz value risen to almost 25 µm in Table 1. The Rmax parameter (maximum peak-to-valley height) behaves in a similar way: it is almost constant and varies from 4 to 10 µm for castings made at the high negative gauge pressure (- 0.07 MPa), while for castings made at the negative gauge pressure of - 0.03 MPa one can find the values of Rmax reaching almost 45 µm.

It is worth mentioning that the average valued of roughness parameters reported for the precision casting technology (investment casting) are at the level of Ra = 2.5 µm, Rz = 15 µm, so – as far as Ra and Rz are concerned – the vacuum assisted HPDC process produces castings with much better surface characteristics than other technologies regarded as quality-compatible ones, even if the lowest examined value of negative gauge pressure equal to - 0.03 MPa is applied. Similar conclusion can be drawn while comparing such parameters as Rp (maximum profile peak height) and Rpm (mean maximum profile peak height). The Rpm parameter is useful for assessing the bearing properties of the surface, since if the surface is to exhibit good bearing properties, the larger part of the profile height should correspond to valleys than to peaks. Considering the Rpm/Rz (mean peak height to mean peak-to-valley height) value, it was found that the applied value of negative gauge pressure does not really affect the shape of the roughness profile (Rpm/Rz < 0.5 indicates a plateau-like profile, Rpm/Rz > 0.5 signals a sharp ridge one). Among the measured bearing parameters, the material ratio at the lower limit of the roughness core (Mr2) proved to be the pressure-sensitive value, rising from an average value of 80-85% for castings produced at the negative gauge pressure of - 0.03 MPa to the value of 90-95% for the ones cast at the negative gauge pressure of - 0.07 MPA. The total waviness height (Wt) for castings produced at the negative gauge pressure of - 0.07 MPa was equal to 3-5 µm as an average, and was similar at all examined areas of castings, while for castings produced at the negative gauge pressure of - 0.03 MPa it varied from 8 µm to even 37 µm.

The application of innovative technologies of vacuum assisted high pressure die casting offers a possibility to achieve the high-quality castings made of Al, Zn, Mg, Cu, and other alloys, free of gaseous porosity and exhibiting high surface smoothness. There are also expected the advantageous changes in microstructure, which finally will influence favourably the strength and the plastic properties of castings.

The above presented results of examinations concerning the quality of pressure casting produced with the assistance of negative gauge pressure indicate that the properly selected working parameters of pressure die casting machine, the adequate temperature of metal and the die, and most of all the additional application of negative gauge pressure in the die would allow for achieving the high quality castings.

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