COMPARISON OF POROSITY OF CASTS PRODUCED BY HPDC AND VPDC TECHNOLOGIES

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The die casting technology enables the production of complex casts with good mechanical properties and high repeatability of the production within narrow tolerance limits. However, the casts are showing signs of porosity to some extent, which may reduce their mechanical and qualitative properties. The presented article solves the problem of reducing the porosity f the high pressure die casts by vacuuming the mold. Under constants technological parameters of casting, series of casts are being casted using the HPDC and VPDC technology. The indirect method of verifying the density and volume of individual samples is used to analyze the porosity of casts. At the same time, a macroscopic examination of the homogeneity of the casts is performed on selected samples. Macroscopic examination showed a detectable decrease in pore size and distribution in the casts. Based on the measurements, i tis proved that by using the vacuum pressure die casting process while maintaining the constant settings of the technological parameters of casting, a reduction in the porosity of the casts by an average of 24.4 % was achieved.

KEYWORDS

Vacuum Pressure Die Casting (VPDC), High Pressure Die Casting (HPDC), Porosity, Gas Entrapment, Zinc Alloys

1 INTRODUCTION

High pressure die casting (HPDC) is a process that enables the production of high-quality casts with narrow dimensional tolerances. Due to their flexibility and high productivity, HPDC casts are increasingly used in the automotive industry [Szalva 2020a]. Due to their low weight, complete recyclability, excellent processability and high corrosion resistance, Al-Si based alloys occupy leading positions in the automotive industry [Szalva 2019]. Depending on the use and location of the cast parts, the complexity of their geometry and at the same time the strength requirements increase [Krenicky 2012 and 2015]. The strength of casts and the associated mechanical properties are closely correlated with the internal homogeneity, which is most often represented by porosity [Szalva 2020b].

The porosity of the casts is related to the gas entrapment by the melt as it passes through the gating system. During the transition of the melt through then cross-sections and complex shapes of the cast, more significant mixing of gases and vapors with melt occurs [Cao 2019]. One of the possibilities to prevent mixing of the melt with gases is a suitable design of the gating system, starting with the correct design of the runners, through the design of the ingates to the correct design of the ventilation system [Meethum 2017, Otsuka 2014].

Another possibility of elimination of the porosity in casts is the correct setting of technological parameters of the casting cycle [Pasko 2014]. The HPDC process generally consists of melt dosing into the filling chamber of the machine, the slow pressing phase, the fast injection phase and the solidification under increased pressure [Li 2016]. The gas entrapment by the melt takes place, except for the phase of elevated, in all the above-mentioned phases. By reducing the pressing speed, we can favorably influence the melt flow through the gating system. On the other hand, the reduction of the pressing speed leads to a more pronounced subcooling of the melt, and thus to the formation of externally solidified crystals (ESC), which disrupt the structure of casts and initiate fractures and cracklings [Cao 2020, Kuppusamy 2017].

In the solidification phase under increased pressure, it is possible to favorably influence the size and distribution of the pores in the cast by higher values of the pressure. On the other hand, high pressure values support faster wearing off the mold and increased demands on design and quality of the mold material [Nova 2012, Ruzbarsky 2014].

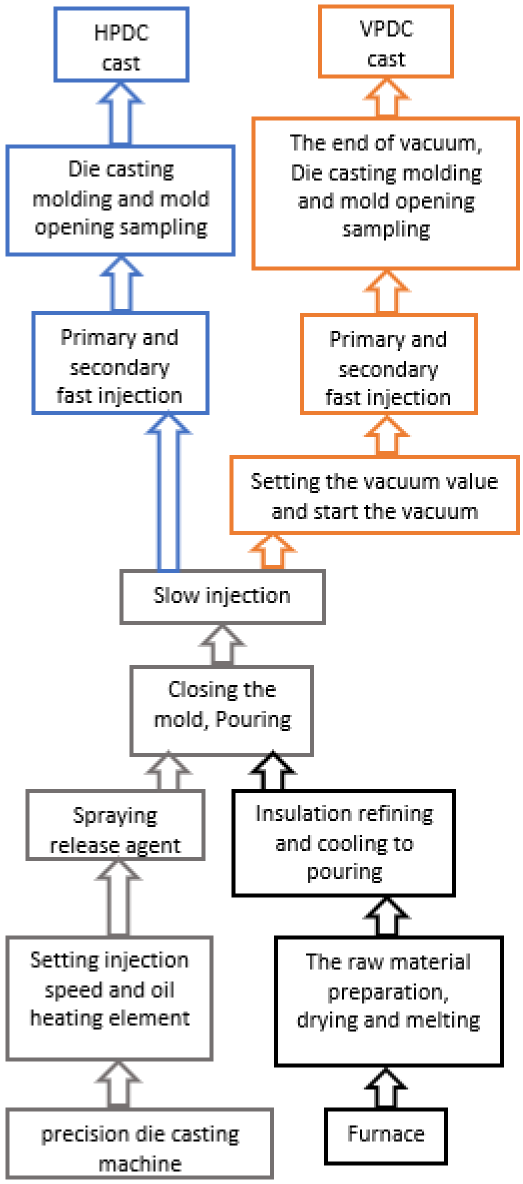

Figure 1. Flow chart of the HPDC and VPDC casting technologies [Le 2020]

In conventional HPDC technology i tis necessary to find a compromise between the design of the gating system and the setting of technological parameters of casting with respect to the melt flow regime through the runners and perfect discharge of the gases from mold cavity in front of the advancing melt stream [Liu 2018].

A progressive development of the HPDC is the incorporation of a vacuum device into the process to extract gases and vapors from the mold cavity in front of the advancing melt stream. Vacuum pressure die casting (VPDC) is a term for die casting technology assisted by vacuuming the mold [Iwata 2012]. The porosity of casts casted by VPDC technology is significantly reduced and the density of the casts is higher. This makes it possible, among other things, to achieve the possibility of additional heat treatment of the casts in order to eliminate internal stresses, and thus the prediction of defect caused by them [Le 2020].

The principle of VPDC consists in connecting the suction device via vacuum valve to the mold, which function is in pumping out the air and gases from the mold cavity within a few milliseconds during the casting process. Suction persists throughout the cycle until the mold cavity is completely filled [Yang 2019]. Almost all air, gases and other vapors are evacuated from the mold. The low pressure in the mold cavity allows the molten metal to flow even through the blind recesses and the designed chamfers of the cast. Sufficient vacuum allows the melt flow face to proceed freely through the gating system without creating vortices and thus entrap the gases in its volume [Liu 2019, Szalva 2019]. The fundamental differences in HPDC and VPDC technology are shown on Fig. 1.

The presented contribution is devoted to the analysis of the effect of vacuum die casting on the porosity of the casts. With a constant setting of the technological parameters of casting, series of casts were produced by the HPDC method and after the inclusion of the vacuum die casting also by the VPDC method. The evaluation of the cast porosity produced by different technologies was carried out by an indirect method by determining the weight and volume of the cast immersed in water. To compare the size and distribution of pores in the casts, metallographic sections of randomly selected samples from the series of casts were performed. It has been shown that the incorporation of the vacuum die casting into the casting process has a favorable effect on the porosity values of the casts, the size and distribution of the pores. The measured porosity values of casts made with the HPDC and VPDC technology show that the inclusion of vacuum achieved a reduction in porosity of 24.4 % on average compared to the casts made with the standard HPDC technology.

2 MATERIALS AND MEHTODS

Experiments were performed on the casts (Figure 2) intended for the automotive industry, which were cast in the eight-fold mold.

Figure 1. Zinc cast K210

The FRECH DAW125F die casting machine was used for the experiments. I tis a pressure casting machine with a warm, vertically arranged chamber. A FONDAREX vacuum device was used to evacuate the die. The basic technical parameters of the vacuum device are given in Table 1.

Electricity required	120 – 575 V
Operational capacity	2 kW
Air supply	6 bar (0.6 MPa)
Vacuum ports	2
Control voltage	24 V
Vacuum regulation	Yes
Measurement (vacuum/pollution)	simultaneously

Table 1. Technical parameters of the FONDAREX vacuum device

The casts are made from zinc alloy ZnAl14Cu1, the chemical composition of which is given in Table 2 and is in accordance with the standard STN EN 1774.

Element	Prescribed volume in %		
		Min.	Max.
Al	3.900	3.800	4.200
Cu	0.800	0.700	1.100
Mg	0.045	0.035	0.060
Cr	----	----	----
Ti	----	----	----
Pb	0.001	----	0.003
Cb	0.002	----	0.003
Sn	0.001	----	0.001
Fe	0.015	----	0.020
Ni	0.001	----	0.001
Si	0.010	----	0.020
Zn	95.225	residue	

Table 2. Chemical composition of the alloy according to STN EN 1774

During the casting cycle by the HPDC and VPDC methods, the constant technological parameters of the casting, presented in Table 3, were abode.

Parameter	Value
Holding pressure duration, s	1.5
Holding pressure, MPa	16
Piston velocity in 1st phase, $m.s^{-1}$	0.12
Piston velocity in 2nd phase, $m.s^{-1}$	1.2
Melt temperature, °C	434
Mold temperature, °C	145

Table 3. Technological parameters of casting cycle

The porosity analysis was performed by an indirect method by verifying the density and volume of the samples used. A METTLER TOLEDO PG203-S scales were used for this analysis. The volume of the casts was subtracted from the immersion in the measuring cylinder. From the measured values, the density of the cast was calculated according to the formula:

$$\rho = \frac{m}{V} \quad (1)$$

Where :
ρ – density of the cast, kg.m^{-3},
m – weight of the cast, kg,
V – volume of the cast, m^3.

Subsequently, according to the calculated density of the cast, the percentage porosity of analyzed samples was determined according to the formula:

$$porosity = \frac{alloy\ density - casting\ density}{alloy\ density} * 100 \quad (2)$$

Macroscopic analysis of samples taken from the casts made with HPDC and VPDC technologies was performed using an OLYMPUS GX51 microscope.

3 RESULTS

The comparison of the casts´ porosity was carried out on the basis of examination of porosity by indirect method and subsequently on the basis of macroscopic comparison of metallographic grindings of randomly selected samples from the series of casts.

3.1 *The evaluation of casts porosity by indirect method*

Table 4 shows the measured weight and volume characteristics of casts and the calculated porosity values according to the formula (2) for the casts produced by using the HPDC technology.

Sample No.	Weight, g	Density, kg/dm^3	Porosity, %
HPDC 1	23.776	6.458	3.612
HPDC 2	23.726	6.467	3.478
HPDC 3	23.948	6.463	3.537
HPDC 4	23.901	6.498	3.015
HPDC 5	23.801	6.497	3.030
HPDC 6	23.830	6.485	3.209
HPDC 7	23.842	6.494	3.075
HPDC 8	23.937	6.484	3.224
HPDC 9	23.782	6.477	3.328
HPDC 10	23.837	6.496	3.045
HPDC 11	23.874	6.504	2.925
HPDC 12	23.816	6.481	3.269
HPDC 13	23.806	6.486	3.194
HPDC 14	23.784	6.487	3.179
HPDC 15	23.854	6.478	3.313
HPDC 16	23.914	6.501	2.970
Minimum	23.726	6.458	2.925
Maximum	23.948	6.504	3.612
Average	23.839	6.484	3.218

Table 4. Measured weight and volume characteristics + calculated porosity for HPDC casts

Table 5 shows the measured weight and volume characteristics of the casts and calculated porosity according to the formula (2) for the casts produced by using VPDC technology.

Sample No.	Weight, g	Density, kg/dm^3	Porosity, %
VPDC 1	23.918	6.531	2.522
VPDC 2	23.939	6.543	2.343
VPDC 3	23.991	6.559	2.104
VPDC 4	23.951	6.560	2.090
VPDC 5	23.948	6.542	2.358
VPDC 6	23.942	6.555	2.164
VPDC 7	23.931	6.534	2.478
VPDC 8	24.060	6.535	2.463
VPDC 9	23.981	6.523	2.642
VPDC 10	23.958	6.547	2.284
VPDC 11	23.947	6.521	2.672
VPDC 12	23.910	6.525	2.612
VPDC 13	23.935	6.535	2.463
VPDC 14	23.925	6.522	2.657
VPDC 15	23.952	6.527	2.582
VPDC 16	23.973	6.524	2.627
Minimum	23.910	6.521	2.090
Maximum	24.060	6.560	2.672
Average	23.957	6.536	2.434

Table 5. Measured weight and volume characteristics + calculated porosity for VPDC casts

Based on the values given in Table 4 and Table 5, the graphs shown on Figure 2 were constructed.

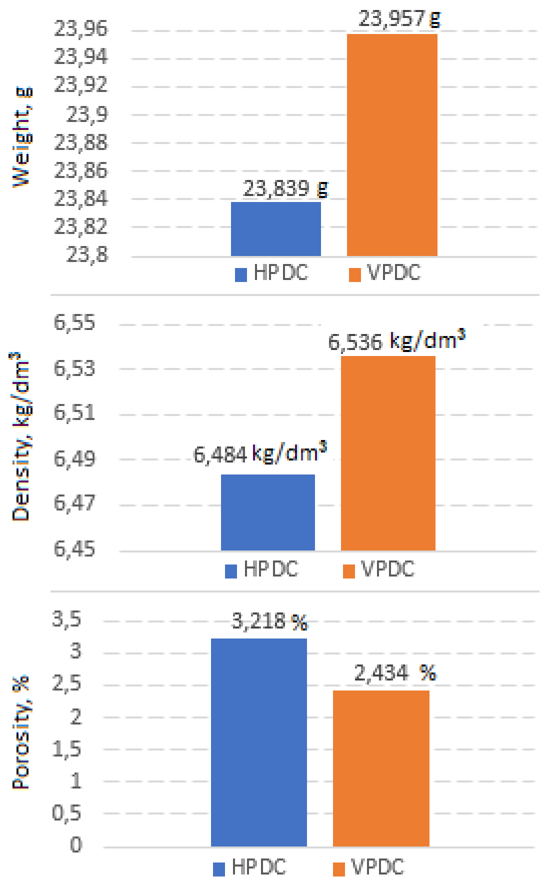

Figure 2. Comparison of average values of weight, density and porosity of the casts produced by HPDC and VPDC technology

As Figure 2 shows, the difference between HPDC and VPDC technologies in terms of cast porosity is significant. It is possible to predict an increased proportion of porosity in casts produced by HPDC technology by comparing the weight and density of casts produced by HPDC and VPDC technologies. The reduced weight and density of HPDC casts predict the occurrence of increased porosity, which is subsequently confirmed.

3.2 Comparison of metallographic grindings of HPDC and VPDC samples

From the series of casts subjected to the examination of porosity by indirect method, casts were selected, on which the comparison of the macrostructure in the area of the cast near its surface was performed. Metallographic optical analysis was performed with an OLYMPUS GX51 microscope at 100x magnification. Samples were prepared for the metallographic analysis by mechanical grinding and diamond paste polishing.

Figure 3 documents representative macroscopic images of metallographic grindings of casts made with HPDC and VPDC technology. The pores are visible in the metallographic grinding as black stains (arrows refer to them).

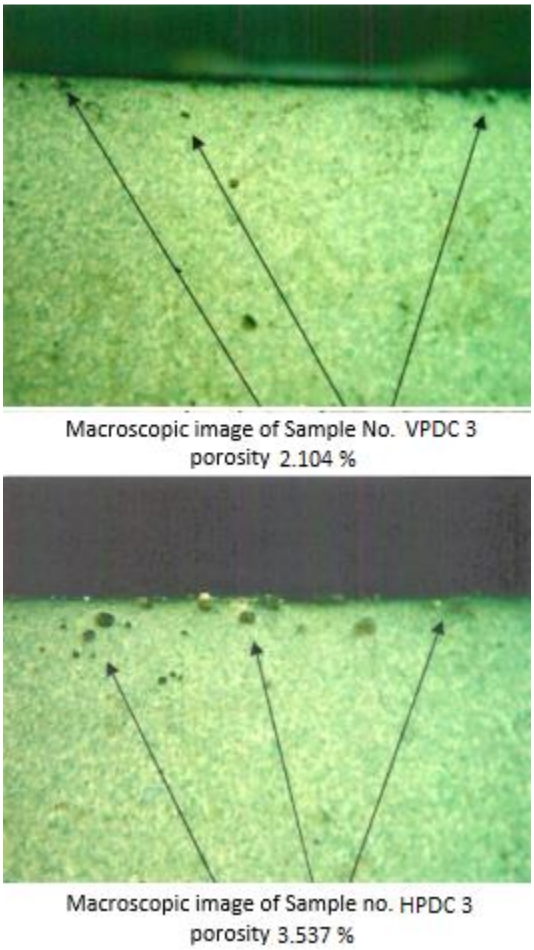

Figure 3. Comparison of internal macrostructure of HPDC and VPDC casts

As can be observed from Figure 3, the pore size and distribution are higher in HPDC casts than in VPDC casts. Although vacuuming of the mold does not completely eliminate the formation of pores in the cast volume, it has been shown that their size and distribution is lower compared to cast without vacuum.

4 DISCUSSION

The contribution is focused on the comparison of porosity of casts produced by HPDC and VPDC technology. In order to verify the results obtained and to determine the differences in porosity values between casts made without and with vacuum, a total of 32 casts were made, of which 16 casts using the VPDC technology and 16 casts using the HPDC technology.

Based on the set of weight and volume measurements of all analyzed samples using METTLER TOLEDO PG203-S scales, individual values of density and subsequent porosity of analyzed samples were determined based on formulas (1) and (2). The data obtained is recorded in Table 4 and Table 5. A graphical representation of the difference between the average values of the measured quantities and the subsequently calculated porosity of the casts made in vacuum and without vacuum is documented in Figure 2.

Based on the achieved results, it is possible to state unequivocally the positive effect of the vacuuming of the mold on the elimination of the porosity of the casts. Figure 2 shows that the average porosity of all analyzed samples cast without vacuum is 3.218 %. The application of the vacuum subsequently recorded a decrease in the porosity values to 2.434 %.

Based on the data in Table 4 and Table 5, it can be further stated that by applying a vacuum, lower porosity values were achieved in all analyzed samples cast in vacuum.

The influence of the vacuum die on the porosity of the casts can also be concluded on the basis of the analysis of metallographic grindings of selected samples. Figure 3 documents the macroscopic samples of vacuum and non-vacuum made casts, where black stains on the grinding represent pores in the wall of the cast. Based on the analysis of metallographic grindings, the evaluation of the size and distribution of cavities in the cross-section of the cast wall, the determined porosity values can be related by indirect method of weight and volume determination with these parameters.

The distribution of the total pore volume in the cross-section of the cast is conditioned by the filling conditions of the mold cavity. The turbulence of the melt entrains the air and gases from the lubricants and the mold gating system, they are not sufficient to be discharged by the mold ventilation system and are thus subsequently entrapped in the walls of the cast. By applying the vacuum to the die casting mold, the air and gases from filling system, the runners and the mold cavity are discharged by vacuum into the tank of the vacuum device with a positive effect on minimizing the porosity of casts.

5 CONCLUSIONS

Results presented in the contribution clearly confirm the positive effect of the vacuum die casting on the porosity of casts.

It has been shown that the inclusion of a vacuum device in the casting process increase the homogeneity of the casts by an average of 24 %. The beneficial effect of mold vacuuming is also noticeable in metallographic sample grindings. The inclusion of vacuum has a beneficial effect on reducing the size of the pores and their location and distribution in the cast.

Recognition of the dependences between the process of application of vacuum into the molds and porosity of the casts, verification of achieved results and determination of differences in porosity values between casts produced by HPDC and VPDC technologies is an important attribute influencing the final quality properties of casts with positive response to product failure, which effectively affects the results in economic area.

Further research directions in the field of VPDC will be oriented in two lines. In the first, the influence of the inclusion of mold vacuuming on the mechanical properties of the casts will be investigated. In the second direction, the main part of the research will be focused on the comparison of HPDC and VPDC technology with regard to the effectiveness in reducing the porosity of casts of different weight and material categories.

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