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ARCHIVES of FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 19
Issue 4/2019

33 – 38

10.24425/afe.2019.129626

5/4

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

Influence of Runner Geometry on the Gas Entrapment in Volume of Pressure Die Cast

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Received 09.07.2019; accepted in revised form 06.09.2019

Abstract

The high pressure die casting technology allows the production of complex casts with good mechanical properties, with high production repeatability within narrow tolerance limits. However, the casts are somewhat porous, which may reduce their mechanical properties. There are several recommendations for reducing the porosity of casts, which are aimed at setting the technological parameters of the casting cycle. One of the primary and important ways to reduce the porosity and air entrapment in the melt is a suitable gating system design. Submitted contribution is devoted to assessing the influence of the runner branching geometry on the air entrapment within the cast volume during the filling phase of the casting cycle. Four variants of the gating system for a particular cast are compared with different design of main runner branching. The initial design is based on a real gating system where the secondary runner is connected to the main runner at an angle of 90 °. The modified designs are provided with a continuous transition of the main runner into the secondary ones, with the change in the branching runner radius r_1 = 15 mm, r_2 = 25 mm and r_3 = 35 mm. The air entrapment in the melt is assessed within the cast volume behind the cores, which have been evaluated as a critical points with respect to further mechanical treatment. When designing the structural modification of geometry it was assumed that by branch changing using the radius value r_3 = 35 mm, the melt flows fluently, and thus the value of the entrapped air in the volume of the cast will be the lowest. This assumption was disproved. The lowest values of entrapped air in the melt were found in the casts with runner transition designed with radius r_1 = 15 mm. The conclusion of the contribution explains the causes of this phenomenon and from a designing point of view it presents proposal for measures to reduce the entrapment of the air in casts.

Keywords: HPDC, Air entrapment, Product development, Runner dimensions, Melt flow

1. Introduction

High pressure die casting allows the production of thin-walled casts with high geometrical accuracy, good mechanical properties and low price. However, defects such as the porosity, which is primarily caused by the air entrapment of melt in the filling phase, affect the cast quality [1]. The reduced quality caused by air entrapment in the cast volume is manifested mainly by a reduction in its mechanical properties and machinability. In addition to these resulting problems, the air entrapment leads to oxygen reactions with chemical components in the melt during the filling phase, where then the oxide inclusions are being formed that can be distributed to the cast volume. In aluminum casts the metal passes through the free surface turbulences, initially oxidized skin comes into contact with the melt and other oxides and can form a double oxide films – so called bi-films that can ultimately manifest as notches and reduce the cast resistance to mechanical stress [2][3].

In general, casts made by high pressure die casting technology contain a plurality of pores in order to trap the air or gas in the molten metal during the die filling phase due to the high velocity and high pressure when filling the die. Currently most discussed factor affecting the reduction and compression of the pores is the specific pressure. It has been shown that increased values of holding pressure favorably affect the distribution, size and volume of pores and tightness of cast. After the solidification of the gate, the volume of pores is slightly increased due to the shrinkage of the melt during solidification. On the other hand, excessive increasing of the holding pressure reduces the die life [4][5]. By holding pressure it is possible to reduce the porosity in the final phase of the casting cycle, but it does not prevent the air entrapment by the melt during its transition through the runners and die cavity.

From the technological aspect it is possible to reduce the air and gas entrapment in the melt by suitable adjusting of the input parameters of the casting cycle, which affect the size and distribution of the pores in the cast volume and the filling mode of the die cavity. The filling mode is dependent on the melt flow rate when transiting through the gate. It is directly proportional to the pressing piston velocity in the filling chamber. In various scientific works, the correlation of the pressing velocity and the porosity of the casts, respectively air entrapment in the filling phase has been demonstrated. Higher pressing velocity changes the character of the melt flow in runner from laminar-planar to the turbulent-non-planar causing a mismatch in the melt flow. Through the reduction of the pressing velocity, it is possible to achieve calming of the melt flow. In this way, a continuous and regular melt flow face is achieved over the entire cross-section of the runner which does not entrap the air and gas in its volume. On the other hand, it is assumed that the elongation of the casting cycle at a low pressing velocity leads to a decrease in the melt temperature due to the long casting cycle time, which leads to other casting errors such as cave-ins and cold joints [2][6][7].

Regardless of the technological parameters, the key factor which is affecting the air entrapment in the melt volume is the proper gating and ventilation system design. Ventilation channels should be placed on the cast respecting the die cavity filling mode, so that the air contained in the die cavity had a sufficient time to leak and would not remain entrapped in the cast volume [1][3]. Liquid metal is required to flow through the straight paths without sudden changes in the flow direction as far as possible. It has been observed that the angle between the main and secondary runner affects the specific pressure, filling time, residual stresses and resulting porosity[8]. The casting process can be adjusted and the occurrence of defects reduced by changing the gating and ventilation system design according to observed die melt flow [9][10].

Regarding to the air entrapment, it is extremely important to observe the filling process and predict the air entrapment in the melt. Simulation programs for supporting the foundry processes are an effective tool in this respect. In recent years, the CAE-based computer simulation has made a rapid progress in high pressure die casting technology. CAE technologies are dealing with very important and urgent issues related to defining the design of casts, gating systems and the actual casting process, thus increasing the efficiency, improving the quality, function and saving time, which is related to economic indicators. It is proved that the use of CAE support in a foundry to simulate the high pressure die casting processes save 40% of the time required to cast design, 30% of the time required to verify the results in laboratories and provide a 25% increase in overall process yield [3][11].

A method for reducing the air entrapment in the melt and for predicting of the porosity origins in the casts has been described above. As presented, the use of increased values of holding pressure can only be used in the last phase of the casting cycle. We achieve the reduction of the distribution and volume of pores, but do not prevent the air entrapment during the die filling while reducing the die life. Although the reduction in pressing velocity eliminates the air entrapment when filling the die, there is a risk of surface defect such as cold joints and cave-ins. The presented contribution is focused on the design of the runners. It has been hypothesized that the gating system needs to be designed such way to obtain the least possible vortex formation which leads to the gas entrapment within the cast. Turbulent melt flow in runners and gas entrapment is avoided by rounding the transitions in the constrictions and subdivisions of the runner. Thus, the equation of the direct proportionality should be applied: the smoother the transition of the main runner into secondary one, the lower the proportion of the air entrapment in the melt and cast volume. Therefore, the influence of the runner branching geometry on the air entrapment in the cast volume is investigated. The percentage of the air entrapment is evaluated at the time just before the start of the holding pressure phase, when the die cavity is filled to 100%. This time period of the casting cycle was chosen with regard to the fact that the holding pressure significantly reduces the air entrapment and porosity. Measurement and observations of the melt flow in runners were made using the Magmasoft simulation program. Since the hypothesis was not confirmed, the reasons for its disproval and the proposed measures for reduction of air entrapment in the casts are explained in the conclusion of this contribution.

2. Experimental procedure

The numerical simulation of the air entrapment is the cast volume is carried out on the cast of the electric motor flange. Air entrapment measurement is performed at locations where further mechanical machining of the casts occurs (Figure 1). At these locations, the circumfluence of the cores forming the structural apertures in cast arise during the die cavity filling. While circumfluencing of the cores, two melt streams join into one and the assumption of air entrapment in the cast volume arises. The monitoring points are 3mm behind the core and 2mm from the cast surface to its volume (C1a – C4e).

The air entrapment has been investigated on casts attached to four different gating system designs. Figure 1 shows a design based on the real gating system, where the secondary runner is connected to the main runner at an angle of 90° (hereinafter referred to as GS – a90°). Modified designs are provided with a continuous transition of the main runner into the secondary one, with a change in the radius of runner branching r_1 = 15 mm, r_2 = 25 mm a r_3 = 35 mm, as shown on the Figure 2 (these values of branching were chosen empirically, based on discussions with technologists in die foundries). Cross-section of runners are for all gating system design solutions constant.

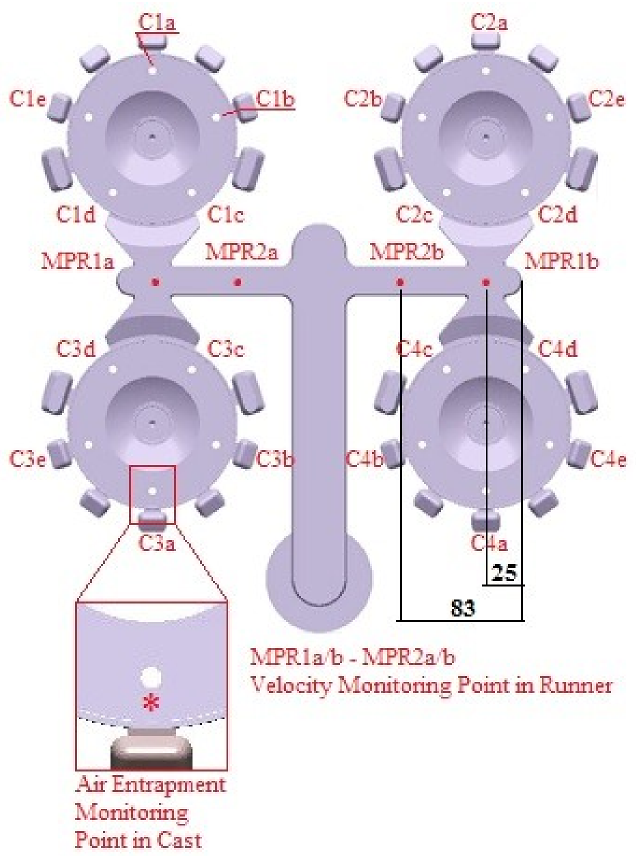

Fig. 1. Location of monitoring points

Fig. 2. Modified main runner branching solutions

The melt velocity in the secondary runner is assessed in the middle of the runner, on the middle pipe diameter (Figure 1). Monitoring points MPR1a/b are placed opposite to the gates. The location of the MPR2a//b monitoring points is at the same distance from the end of the gate in all variants of the gating systems. The distance of 83mm is chosen with regard on the ensuring of the relevance of the melt flow velocity assessment. It is therefore desirable to measure the velocity in the locations where the melt flows in linear paths. The distance of the monitoring points MPR2 is determined according to the runner branching design MGS – r35. In the design of MGS – r35 the circular melt path while transition through the branching is being changed into linear 2mm before the monitoring point MPR2a/b.

Measurements were carried out using the Magmasoft MAGMA 5 simulation program – HPDC module. The cast is made of EN AC 47100 alloy. The choice of machine and the setting of input technological parameters in the simulation is identical with the conditions in real production. It is presented by the Table 1.

Table 1.
Technological parameters of the casting cycle

Parameter	Value
Melt temperature in filling chamber, °C	617
Die temperature, °C	200
Temperature of the tempering medium, °C	190
Piston velocity, $m.s^{-1}$	2.9
Holding pressure, MPa	25
Die cavity filling time, s	0.016

3. Description of achieved results

Using the MAGMA5 – HPDC module the values of air entrapment in monitoring points were found in the section Result/Air Entrapment. Measurement is performed at the time when the entire gating system including the overflows is filled at 100% of the volume, just before the start of a holding pressure phase. The filling time of the die cavity is 546.9 ms. Table 2 presents the average values of air entrapment in casts for the assessed gating systems designs.

Table 2.
Values of Air Entrapment in Castings

Gating System	Air Entrapment, %
GS – a90°	6.006
MGS – r15	3.516
MGS – r25	4.549
MGS – r35	5.343

As shown is Table 2, the lowest percentage of the air entrapment in the cast volume is achieved in the gating system designated as MGS – r15, where the radius of the secondary runner curvature is r_1 = 15mm. Thus, the hypothesis: The smoother the transition of the main runner into secondary one, the lower the proportion of the air entrapment in the melt and cast volume, has been disproved. It was assumed that in the initial gating system GS – a90°, the vortices that assist the air entrapment in the melt will be arising at the branching point, and thus the air entrapment values in the cast will reach the highest values. Conversely, the gating system MGS – r35 provides the direct melt flow where the flow direction change is continuous and most direct from all of the selected variations of the gating system modification. The question is now, what is the cause of this condition?

The first step to solve the problem was to assess the melt flow at the main runner branching point and in the transition through the secondary runner. In MAGMA5 – HPDC module, the Result/Flow Tracer section was used to visualize the flow. Figure 3 presents the melt flow in individual gating system design variants shortly before the end of the filling phase at 546 ms.

As anticipated, in the GS – a90° gating system, vortices occur at the branching point, which are observable throughout the filling phase. The flow in modified gating systems MGS is fluent and has the same character in all designs. Local swirling occurs at the end of the secondary runner, which serves as a buffer and its role is to calm the melt flow before entering the gate. Although the melt flow monitoring by trace parts confirms the presumption of vortex formation in the GS – a90°gating system, it does not clarify the increase in air entrapment in the melt depending on the increasing radius of runner curvature.

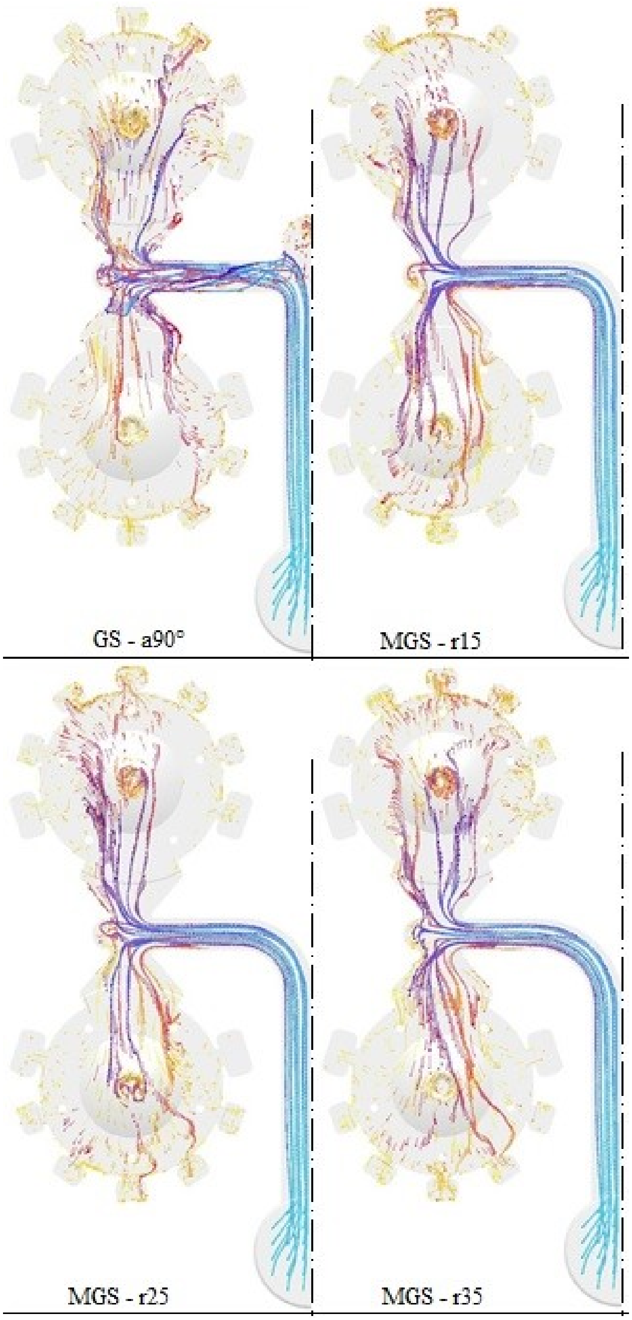

Fig. 3. Melt flow in runners

Since the melt flow assessment in the gating system did not provide the desired explanation, the issue was oriented on the secondary runner melt flow velocity monitoring. The distribution of monitoring points was constant for all the gating system design variants (Figure 1). Table 3 presents the average velocity values at the monitoring points. The elocity values that were measured when the melt fully filled the cross-section of a runner were considered relevant.

Table 3.
Melt flow velocity in runner

Gating system	Velocity, ms^{-1}	MPR1	MPR2
GS – a90°	average	9.95	19.54
	max.	11.10	21.56
MGS – r15	average	8.90	23.13
	max.	10.99	24.54
MGS – r25	average	10.90	23.18
	max.	12.31	24.50
MGS – r35	average	11.64	23.22
	max.	12.70	25.16

Table 3 implies that the MGS – r15 gating system achieves the lowest melt flow velocity at the monitoring points. Referring to the publications cited in the introduction [2][5][6][7], the cause of the refutation of the initial hypothesis is explained. Obviously, the air entrapment and melt flow velocity values in modified gating systems correlate with each other.

Adjusting of the pressure piston velocity is constant for all gating system variations. According to the hydrodynamic fundamentals, referring to the Bernoulli equation, the melt velocity in the secondary runners should remain constant. However, the measured values show that with increasing curvature radius of the secondary runner, the melt flow velocity increases. This phenomenon is explained with the reference to the dissipation of the melt flow mechanical energy. To put it simply, the kinetic energy of the melt flow is converted into other forms of energy. With smaller curvature radius, the melt fiber filaments are locally densified on the inner arc, increasing their internal friction which is converted into thermal energy and decreases the melt flow velocity behind the curvature[12].

Runner velocity is also influenced by the gate velocity. The gate velocity determines the die cavity filling mode. For this reason, the gate melt velocity was also observed. The monitoring point was located in the middle of the gate, according to Figure 4. Only the values of the melt velocity subtracted when the gate was completely filled were considered relevant. Table 4 presents the gate melt velocity values.

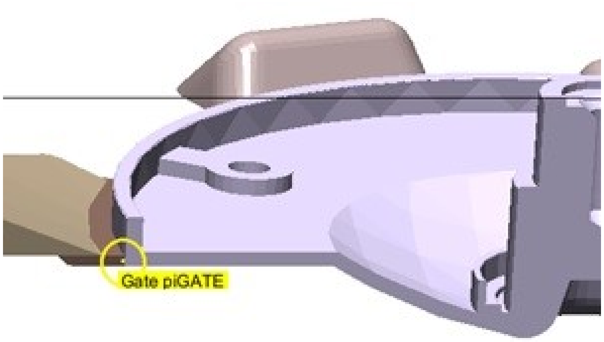

Fig. 4. Monitoring Point in the Gate

Table 4.
The gate melt flow velocity

Casting system	Velocity, ms^{-1}	
	max.	average
GS – a90°	40.68	37.58
MGS – r15	39.92	35.48
MGS – r25	40.11	37.83
MGS – r35	40.75	38.40

The maximum gate velocity value is relatively constant for all gating system modifications. Variations can be observed at average velocity values. Upon observing the melt flow through the die cavity, the formation of discontinuity of melt flow behind the cores was noticeable at higher melt flow velocities. At higher velocities, the melt breaks out, allowing gases to enter the melt volume. It can be stated that the gate velocity and formation of the melt flow when transiting through the die cavity have a significant influence on the gas entrapment proportion in casts.

4. Conclusions

In presented contribution, the influence of the main runner branching geometry on the air entrapment within the pressure die cast volume has been investigated. Measurements were carried out using the Magmasoft simulation program. Based on the measurements, the direct effect of main runner branching geometry on the values of air entrapment has been demonstrated.

It was assumed that the smoother the transition of the main runner into secondary one, the lower is the proportion of the air entrapment in the melt and cast volume. Although the fluent transition is desired, the above statement does not apply. The reasons for refuting this fact can be outlined into following points:

a) The theoretical melt flow velocity of runners can be determined based on the Bernoulli equation. However, the mechanical energy dissipation of the flow which affects the flow velocity is not counted with. Higher values of curvature radii eliminate the dissipation, thereby increasing the runner melt flow velocity. Higher value of the melt velocity during the transition through runner changes the character of the melt flow from laminar to turbulent, allowing easier air entrapment by the melt and its distribution to the cast volume.

b) As demonstrated, the higher runner curvature radius imparts the melt higher velocity during the transition through the secondary runner. This also influences the gate melt velocity under influence of which the melt flow during the transition through the die cavity and die filling mode are formed. When colliding the obstructions in the flow direction, such as cores or various protrusions on the cast, melt breaks behind these obstructions, thereby supporting the further air entrapment by the melt.

Based on the simulations and measurements, general recommendations for the gating system designs with the aim of air entrapment reduction can be outlined:

1) it is desirable to select fluent transitions between the main and secondary runners and to avoid the sharp angles when changing the melt flow direction,
2) when designing the runners, to find a suitable proportion between runner curvature radius and the melt velocity behind this curvature,
3) if possible, to guide the melt flow so that it does not collide with obstructions such as cores, ribs and protrusions during the transition through the die cavity,
4) 5-) It is advantageous to use CAE support, which enables to analyze the gating system design and discover hidden issues and their solutions.

Modified gating system variants on which the presented measurements were carried out are designed with a constant location of the casts in die. Thereby, the location of the cores and ejectors and thus the die design are not impaired. This measure was chosen with consideration of further research, where it is a prerequisite to produce the shape insertions corresponding to the modified gating systems and to cast sets of casts in order to monitor the development of porosity depending on the gating system design and on the change of input technological parameters of casting cycle.

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