INFLUENCE OF RUNNER CROSS-SECTION ON AIR ENTRAPMENT IN PRESSURE DIE CASTS VOLUME

STEFAN GASPAR[1], JAN MAJERNIK[2], TOMAS CORANIC[1], JAN PASKO[1]

[1] Technical University of Kosice, Faculty of Manufacturing Technologies with seat in Presov

[2] Institute of Technology and Business in Ceske Budejovice

DOI: 10.17973/MMSJ.2021_6_2021020

stefan.gaspar@tuke.sk

Technology of metal die casting is characterized by production of casts complicated as to shape yet with positive mechanical properties and with high repeatability of production. However, casts are porous to a certain extent which eventually reduces their mechanical properties. One of the significant methods of porosity reduction of casts rests in correct design of a gating system. The submitted paper studies the influence of cross-section area of a runner on air entrapped in the cast volume. Seven alternatives of runners with the identical structural organization and variable cross-section area were compared. In case of a gating system design there was an assumption made that the runner with the largest cross section would deliver the lowest possible velocity to the melt before reaching the runner which would result in the lowest possible values of air entrapment. The air entrapment in the cast volume is evaluated behind the cores which were evaluated as critical points with regards to further processing. The results reached during examination of the melt flowing through runners proved the aforementioned assumption, yet the values of air entrapment in die casts volume did not show remarkable differences. In its final part, the paper clarifies the reached results and recommendations which should be taken into consideration when designing the gating system structure.

KEYWORDS

HPDC, air entrapment, runner dimensions

1 INTRODUCTION

Die casting allows production of thin-walled casts with high geometric precision, positive mechanical properties and low price. However, defects such as porosity, which is primarily caused by air entrapment by the melt during filling phase, influence cast quality [Zhao 2018, Cao 2019]. Porosity of casts is visible in decrease of mechanical properties and machinability. Air entrapment in melt volume results in reactions of oxygen with chemical components in the melt leading thus to oxidic inclusions which can be distributed to the volume of cast. In case of aluminium casts the melt passes through free surface turbulences and primarily oxidized skin gets into contact with the melt and with other oxides and can create double oxidic films – bifilms which have form of channels and decrease resistance of casts against mechanical stress [Majidi 2019].

Air entrapment in the melt volume is conditioned by mould geometry. Complicated geometry leads to heavy three dimensional melt flow with significant fragmentation of free surface and spatters [Cleary 2014]. Alleviation of free surface fragmentation can be achieved either by suitable adjustment of input parameters of casting process or by adequate structure of the gating system [Majernik 2019].

From the technological point of view entrapment of air and gasses in the melt can be decreased by suitable adjustment of input parameters of casting process which influence both the size and distribution of pores in the volume of a cast as well as filling mode of a shaping mould cavity [Qin 2019]. Filling mode depends on velocity of the melt flowing through the ingate. It is directly proportional to velocity of a plunger in the filling chamber. Several scientific theses proved correlation of pressing velocity and porosity of casts or air entrapment during filling phase. Higher pressing velocity changes the character of the melt flow in the runner from laminar-planar to turbulent - non-planar which causes discontinuous melt flow. Reducing the pressing velocity can lead to deceleration of the melt flow by means of which a continuous and regular melt front may be reached along the entire cross section of the runner not entrapping the gas and air in its volume. On the other hand, it is assumed that prolongation of a casting cycle at low pressing velocity results in drop of melt temperature due to long duration of casting cycle which leads to defects such as cold laps and cold joints [Majidi 2019, Majernik 2019a, Iwata 2013].

Regardless of technological parameters the key factor influencing air entrapment in the melt volume is correct structure of both gating and venting system of the mould. Venting channels should be attached to the cast with regards to the filling mode of mould shaping cavity to provide the air occurring in the mould cavity with enough time to escape and to remain closed in the cast volume [Zhao 2018, Cao 2019]. Liquid metal is required to flow along straight trajectories without abrupt changes of the flow direction [Saga 2014]. It could be observed that the angle between lateral and main runner influences specific pressure, filling period, annealing stress and final porosity [Kanazawa 2016]. Casting process can be adjusted and occurrence of defects can be decreased by change of gating and venting systems on the level of structural design of mould according to the melt flow observed in the mould [Murcinkova 2013, Cao 2019, Majernik 2019b, Trytek 2016]. It is evident that porosity values and amount of entrapped gas in the melt volume are influenced by correlation of several structural nodes in the gating system such as correct design of ingate, runners, flow holes and venting channels. Therefore, it is useful to eliminate air entrapment in the first design of runner geometry [Meethum 2017].

According to the aforementioned facts the amount of air entrapment in the cast volume can be influenced by selection of technological parameters [Turtelli 2006, Kanazawa 2016, Trytek 2016, Meethum 2017]. The publication [Majernik 2019c] proved correlation of technological parameters (such as melt temperature prior to entering the mould shaping cavity), velocity of meld flow in the ingate and filling period of mould shaping cavity with the cross section of the main and lateral runner. The submitted paper is devoted to assessment of cross section of the runner on air entrapment in the cast volume. The publication [Majernik 2019b] proved that the increasing cross section of runner leads to decrease of melt flow velocity prior to entering the ingate. It presupposes more compact melt flow after passing through the ingate and smoother filling mode of mould shaping cavity [Majernik 2019b]. A hypothesis was made: if spattering of liquid metal and fragmentation of melt flow after passing through the ingate has to be avoided, it will be inevitable to select cross section of the runner so that compact and smooth melt flow is assured prior to entering the ingate. At the same time lower velocity should be assured as well.

If the input technological parameters remain constant, especially plunger velocity, the following dependence must be applicable with the Bernoulli Equation being in force: the larger the ingate cross section is, the lower the melt flow velocity is. The aforementioned fact thus determines smoother transfer of melt through the ingate and lower values of air entrapment in the melt volume. Therefore, the study revolves around influence of the ingate cross section on air entrapment in the cast volume. Percentage of air entrapped in casts is evaluated during the period right before holding pressure phase is triggered in case of which the mould cavity is 100% filled. This period of casting cycle was selected with regards to the fact that holding pressure considerably reduces entrapment of air and porosity. [Gaspar 2016] Measurement and monitoring of the melt flow in runners were realized by simulation programme Magmasoft. The presupposed hypothesis was proved only partially, i.e. the melt flow reaches lower velocity right before the ingate yet values of air entrapment in the melt remained without noticeable changes. It is clear that excessive increase of cross sections of runners is undesirable in practice therefore the final part of the paper is devoted to designs of precautions regarding the factors which must be taken into consideration in case of selection of suitable ingate structure.

The results presented in this paper were collected during designing the solution of gating system for innovative production of thrust face of gear pumps.

2 EXPERIMENTAL PROCEDURE

Numerical simulation of air entrapment in the cast volume is realized with the cast of thrust face of a gear pump. Since pressure loss is unacceptable in case of the gear pump, the porosity value of casts must range within the values below 1%. Measurement of air entrapment was realized in the areas behind structural holes of the cast which are designed for placement of friction bearings. In case of selected areas, the confluence of melt flows around the cores can be observed and thus there exists the highest probability of air entrapment in the cast volume (Figure 1).

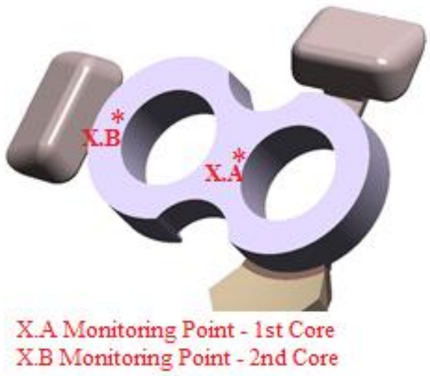

Figure 1. Location of monitoring points

In bearings a cyclic dynamic stress occurs and thus possible gas cavities in their proximity can act like a notch therefore they must be eliminated to the lowest possible value. Monitoring areas were located in the middle of cast height h = 10.15 mm and 1 mm behind the core.

Air entrapment was examined in case of casts attached to seven alternatives of gating system. Figure 2 shows basic shape of primarily designed gating system. Table 1 presents basic geometric characteristics of the examined modified alternatives of the runners.

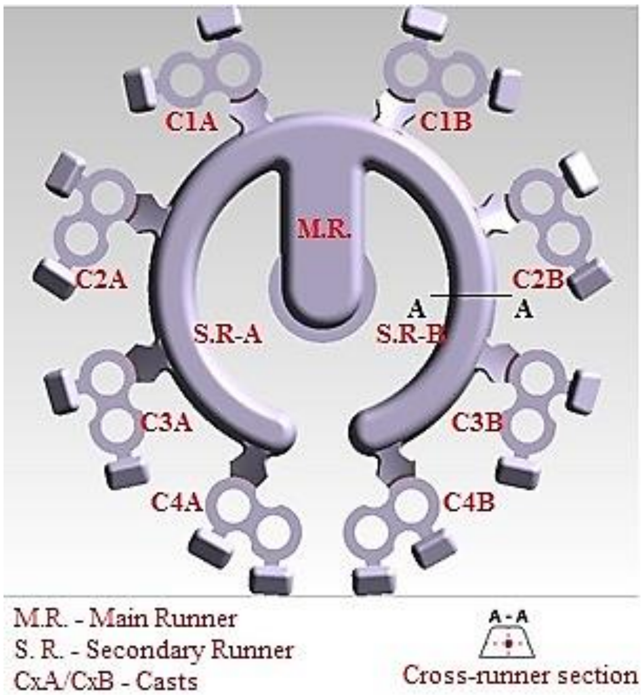

Figure 2. Scheme of ingate system

Table 1. Reviewed parameters of gating systems

Dimensions of runners				
	Sectional [mm²]	Area S	Channel Width [mm]	Channel Height [mm]
S.R. 440 computing	S.R.	440.098	31.88	15.94
	M.R.	831.9	56.46	15.94
S.R. 420	S.R.	420	30.62	15.94
	M.R.	792.45	53.98	15.94
S.R. 400	S.R.	400	29.36	15.94
	M.R.	754.72	51.62	15.94
S.R. 380	S.R.	380	28.10	15.94
	M.R.	716.98	49.24	15.94
S.R. 360	S.R.	360	26.84	15.94
	M.R.	679.25	46.88	15.94
S.R. 340	S.R.	340	25.58	15.94
	M.R.	641.51	44.52	15.94
S.R. 320	S.R.	320	24.35	15.94
	M.R.	603.77	42.15	15.94

Measurements were carried out with the use of the programme Magmasoft MAGMA 5 – HPDC module. The cast is made of alloy EN AC 47100. Setting-up of input technological parameters which is constant for all variations of structural design of ingate system is given in Table 2.

Table 2. Technological parameters of the casting cycle

Parameter	Value
Melt temperature in filling chamber, °C	610
Die temperature. °C	200
Temperature of the tempering medium, °C	190
Final piston velocity/1.st phase, $m.s^{-1}$	0.9
Final piston velocity/2.nd phase, $m.s^{-1}$	3.6
Piston velocity after decelerating, $m.s^{-1}$	1.5
Holding pressure, MPa	25
Die cavity filling time, s	0.0226

The velocity of piston during the first phase of filling is required not to be high which prevents melt from being splashed in the filling chamber and air from being entrapped in the melt volume. It is useful to select velocity switching between the first and the second phase at the moment when the melt flow approaches the gate [13]. Figure 3 shows development of velocity of plunger in relation to its position in the filling chamber.

Figure 3. Development of pressing speed velocity

3 DESCRIPTION OF ACHIEVED RESULTS

The values of air entrapment in the measurement points were detected with the use of the programme MAGMA 5 – HPDC module, in section Result/Air Entrapment. The measurement was carried out during time when gating system along with spews were 100% filled right before the holding pressure phase was triggered. Table 3 and Table 4 present average values of air entrapment in the casts behind the cores in the reviewed areas. Table 5 presents final average values o fair entrapment in the casts on the basis of measured values in the individual measuring points. entrapment in the casts behind the cores in the reviewed areas. Table 5 presents final average values o fair entrapment in the casts on the basis of measured values in the individual measuring points.

Primary assumption that increasing cross-section area of the runner leads to lower value of air entrapment in the cast volume proved to be true. However, considerable differences among individual structural solutions of gating systems were not detected and values of air entrapment in case of all alternatives ranged within the scope of required values which was below 1%. The aforementioned facts lead to the conclusion that the area of the runner does not considerably influence the values of air entrapment in the melt volume.

It is inevitable to be cautious about increasing values of air entrapment in the cast volume between measuring points X.A and X.B, i.e. behind the first and behind the second core. In case of all casts the increase of air entrapment in the area behind the second core could be observed. The cause of such phenomenon could be searched for in the filling mode of the mould shaping cavity and melt flowing around the cores (Figure 3).

Table 3. Values of air entrapment behind the first core

Average values of air entrapment in the points X.A, %					
Cross section of runner	Cast/point				
	C1/1A	C2/2A	C3/3A	C4/4A	Average
S.R. 440	0.180	0.231	0.448	0.759	0.405
S.R. 420	0.232	0.259	0.452	0.702	0.411
S.R. 400	0.259	0.243	0.513	0.776	0.448
S.R. 380	0.221	0.366	0.643	0.788	0.505
S.R. 360	0.315	0.521	0.660	0.811	0.577
S.R. 340	0.398	0.552	0.692	0.894	0.634
S.R. 320	0.403	0.533	0.723	0.917	0.644

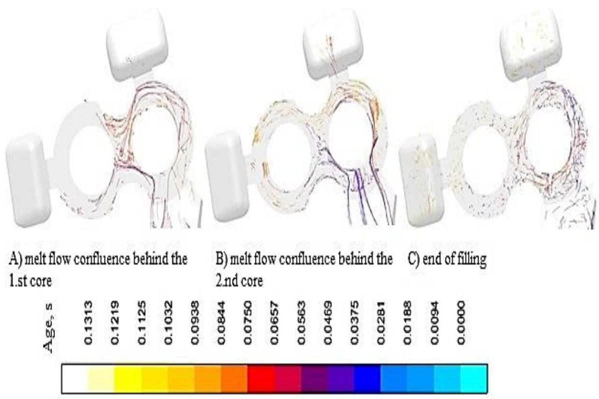

Figure 4. Melt flowing around cores

Table 4. Values of air entrapment behind the second core

Average values of air entrapment in the points X.B, %					
Cross section of runner / Cast/point	C1/1B	C2/2B	C3/3B	C4/4B	Average
S.R. 440	0.335	0.325	0.513	0.807	0.495
S.R. 420	0.321	0.318	0.729	0.819	0.547
S.R. 400	0.381	0.362	0.766	0.828	0.584
S.R. 380	0.396	0.477	0.769	0.890	0.633
S.R. 360	0.395	0.575	0.769	0.871	0.653
S.R. 340	0.405	0.635	0.735	0.925	0.675
S.R. 320	0.543	0.637	0.795	0.965	0.735

Table 5. Final average values of air entrapment in the volume

P Average values of air entrapment in the casts %	
Cross section of runner	
S.R. 440	0.450
S.R. 420	0.497
S.R. 400	0.516
S.R. 380	0.596
S.R. 360	0.615
S.R. 340	0.655
S.R. 320	0.690

Filling of the mould shaping cavity was carried out by MAGAMA 5 – HPDC module in the section Result/Tracer. The module allows monitoring the flowlines of liquid metal which present the filling mode and graphically determined the length of activity of particles in the gating system. Figure 4 A shows confluence of melt flows behind the first core. It is clear that in case of confluence of flows the melt gets blended which is accompanied by whirling. Consequently, the melt is poured into the point behind the second core (Figure 4B) in case of which further confluence of divided flow and blending of melt occurs. At the end of filling (Figure 4C) the melt flow behind the cores is massive and major part of the melt which passed through double whirling is transferred to deaerating basins. Right the double confluence of the melt flow is the cause of increasing entrapment of air behind the second core.

Step increase of air entrapment in the melt can be observed in all alternative of gating systems in case of casts C4. The reason of increase of air entrapment is position of deaerating basin which is situated behind the cast. The structure of gating system did not allow positioning of deaerating basin in the direction of flow, i.e. in the cast axis. Offset of deaerating basin results in change of direct melt flow through the cast leading to backward melt flowing around the core which does not allow full transfer of the melt to the basin. It supports air entrapment in the cast volume.

4 CONCLUSIONS

The submitted paper is devoted to review of influence of cross-section area of the runner on the values of air entrapment in the cast volume. As it has been proved the cross-section area of the runner does not considerably influence the values air entrapment in the cast volume. The increase of air entrapment in the cast volume was detected in case of casts between the first and the second core. The influence on air entrapment in cast was proved also in case of change of position of deaerating basin. On the basis of results presented in the paper the following conclusions can be drawn:

a) The change of area of the runner does not remarkably influence the values of air entrapment in the cast volume. Therefore, excessive enlargement of the area of cross section in order to reduce the melt velocity in the runner and in order to sedate the flow has no relevant significance in practice.

b) The values of air entrapment in the cast volume are influenced by the position of deaerating basins. The basins must be positioned so that direct melt flow through the cast is allowed. Thus, backward flow of melt in the mould shaping cavity is avoided. The melt containing air after flow blending behind the cores is directly drained to deaerating basins.

c) In case of production of quality casts with high requirements for tightness it is adequate to select the volume of deaerating basins so that their volume corresponds to the volume of melt flowing through the cast. The same is applicable especially in case when the filling of the mould shaping cavity is accompanied by bypassing of several cores placed in successive order. Thus, multiple whirling and blending of the melt can be observed during flow confluence in the area behind the cores. Therefore, it is desired to have the melt volume, which contains the air entrapped during pressing, drained to the deaerating basin and to have the cast made from continuous melt flow freshly delivered.

d) Evaluation of the porosity of casts cannot be considered as the average of the detected values. As it is shown Table 3, Table 4, Table 5 the average value of air entrapment in cast is lower than the values detected in the individual points behind the second core. Therefore, in case of evaluation of the air entrapment it is inevitable to relate the entrapment values or porosity value to the particular points in the cast.

On the basis of the performed measurements and with references mentioned in the beginning of the paper [Mascenik 2019] it is possible to define basic factors influencing the air entrapment in the cast volume:

1) The cross section of the runner designed by calculation can be structurally modified by use of simulations. Cross-section area does not considerably influence the porosity

values. When assessing the optimal solution, it is useful to focus on the temperature and flow velocity of the melt before entering the runner.

2) If the main and lateral runners must be branched, the branching must be performed with smooth transfer without sharp changes of the flow direction.
3) The melt flow must be directed to avoid hitting the cores and lugs when passing through the mould shaping cavity. If hitting the cores cannot be avoided, the deaerating basins must be positioned in the axis of the melt flow and their volume must be enlarged adequately.
4) It is useful to use the CAE support during technological preparation of production which allows analysing the structural design of the gating system and revealing the hidden problems along with their solutions.

ACKNOWLEDGMENTS

This article has been prepared within the project VEGA 1/0116/20.

REFERENCES

[Cao 2019] Cao, H., et al. Direct observation of filling process and porosity prediction in high pressure die casting. Materials, 2019, Vol. 12, No. 7. ISSN 1996-1944.

[Cleary 2014] Cleary, P.W., Savage, G., Ha, J. Prakash, M. Flow analysis and validation of numerical modelling for a thin walled high pressure die casting using SPH. Computational Particle Mechanics, 2014, Vol. 1, No. 3, pp. 229-243. ISSN 2196-4378.

[Gaspar 2016] Gaspar, S., Pasko, J. Pressing Speed, Specific Pressure and Mechanical Properties of Aluminium Cast. Archives of Foundry Engineering, 2016, Vol. 16, No. 2, pp. 45-50. ISSN 1897-3310.

[Iwata 2013] Iwata, Y. et al. Effects of solidification behavior during filling on surface defects of aluminum alloy die casting. Materials Transactions, 2013, Vol. 54, No. 10, pp. 1944-1950. ISSN 1347-5320.

[Kanazawa 2016] Kanazawa, K., Yano, K., Kawatani, R., Ogura, J., Nemoto, Y. Optimization of gating system design for high pressure die casting to reduce air entrapment defects. 72nd World Foundry Congress, 2016, pp. 303-304. ISBN 9781510833128.

[Majernik 2019a] Majernik, J., Podaril, M. Influence of runner geometry on the gas entrapment in volume of pressure die cast. Archives of Foundry Engineering, 2019, Vol. 19, No. 3, pp. 33-38. ISSN 2299-2944.

[Majernik 2019b] Majernik, J. et al. Optimization of the runner numerical design dimensions using the simulation program. Manufacturing Technology, 2019, Vol. 19, No. 2, pp. 273-279. ISSN 1662-9795.

[Majernik 2019c] Majernik, J. et al. The influence of the gate geometry on selected process parameters in the high pressure die casting technology. Manufacturing Technology, 2019, Vol. 19, No. 1, pp. 101-106. ISSN 1662-9795.

[Majidi 2019] Majidi, S.H., Beckermann, C. Effect of Pouring Conditions and Gating System Design on Air Entrainment During Mold Filling. International Journal of Metalcasting, 2019, Vol. 13, No. 2, pp. 255-272. ISSN 1939-5981.

[Mascenik 2019] Mascenik, J., Pavlenko, S. Innovative broad - Spectrum testing and monitoring of belt transmissions. MM Science Journal, 2018, Vol. November, No. 5, pp. 2706-2709. ISSN 1803-1269.

[Meethum 2017] Meethum, P., Suvanjumrat, C. Evaluate of Chill Vent Performance for High Pressure Die-Casting Production and Simulation of Motorcycle Fuel Caps. International Conference on Mechatronics and Mechanical Engineering, 2017, pp. 21-23. ISBN 9781510858756.

[Murcinkova 2013] Murcinkova, Z., Krenicky, T. Applications utilizing the damping of composite microstructures for mechanisms of production machines and manipulator devices. In: SGEM 2013: 13th Int. Multidisciplinary Sci. Geoconf. Vol. 1: 16-22 June, 2013, Albena, Bulgaria. Sofia: STEF92 Technology, 2013. pp. 23-30. ISBN 978-954-91818-9-0.

[Qin 2019] Qin, X.-Y. et al. Finite element analysis for die casting parameters in high-pressure die casting process. China Foundry, 2019, Vol. 16., No. 4, pp. 272-276. ISSN 1672-6421.

[Saga 2014] Saga, M., Vasko, M., Pechac, P. Chosen numerical algorithms for interval finite element analysis. Modelling of Mechanical and Mechatronic Systems 2014, Procedia Engineering, Vol. 96, pp. 400-409.

[Trytek 2016] Trytek, A. et al. The Effect of a Thin-Wall Casting Mould Cavity Filling Conditions on the Casting Surface Quality. Archives of Foundry Engineering, 2016, Vol. 16, No. 4, pp. 222-226. ISSN 2299-2944.

[Turtelli 2006] Turtelli, R.S, Krenicky, T., et al. Magnetic and structural characterization of as-cast and annealed melt- spun Fe80-xSi20Crx. Journal of Magnetism and Magnetic Materials, 2006, Vol. 304, No. 2, pp. E687-E689.

[Zhao 2018] Zhao, X., et al. Gating system optimization of high pressure die casting thin-wall AlSi10MnMg longitudinal loadbearing beam based on numerical simulation. China Foundry, 2018, Vol. 15, No. 6, pp. 436-442. ISSN 1672-6421.

CONTACT

Stefan Gaspar
Technical University of Kosice, Faculty of Manufacturing Technologies with seat in Presov
Sturova 31, 080 01 Presov
stefan.gaspar@tuke.sk