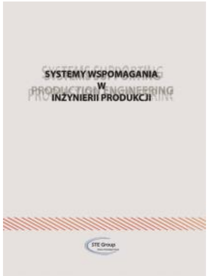
Options for Solutions of the Inlet System Into the Mold

Data wpłynięcia do Redakcji: 06/2023
Data akceptacji przez Redakcję do publikacji: 07/2023

2023, volume 12, issue 2, pp. 57-70



Juraj Ružbarský, Tibor Krenický,
Jozef Maščeník, Tomáš Coranič
Technical University of Kosice, **Slovakia**

Abstract: The presented contribution points out the possibilities of solving the inlet system, as one of the important factors influencing the final quality of the castings. Due to its design and function, the sprue system influences the process of filling the mold cavity. With the correct design of the sprue system, we achieve the continuity of filling the mold cavity and the elimination of qualitative and quantitative errors caused by non-observance of basic principles in the design of sprue systems. When conducting the experiments, we monitored the mold inlet system, modeling the process of filling the mold cavity and the speed of the liquid metal in the notch and the mold cavity. The results of the experiments show that the speed of the liquid metal when filling the mold is approximately half of the calculated theoretical value.

Keywords: pressure casting, mold construction, inlet system, pressure

INTRODUCTION

The design of the mold is of decisive importance for the production and quality of pressure-cast castings. The proper structure of the die-casting mold represents one of the main factors for producing proper castings as to shape and size without defects. The optimum structural design of a mold, including the correct setting of technological and metallurgical parameters, presupposes producing high-quality molds. A mold's Structure defects are difficult to rectify, and possible interventions (for instance, welding of ingates) might be performed at the expense of a mold service life decline. The die-casting mold represents a complex system of high-quality tool steel [1, 2].

In case of the alloys with lower melting points (for instance, zinc) a mold should prove failure strength values ranging from 700 to 1100 MPa, and in case of the alloys with higher melting points the range should be from 1200 to 160 MPa [3].

The method of mold production depends on complexity as well as on the required precision of the cast products. Milling, grinding, or electro-erosive machining are the most common operations in mold production. These production methods are rather demanding. Thus, the price of some of the die-casting molds reaches ten thousand or even a hundred thousand euros due to the economic reasons their utilization is suitable solely for bulk production [4, 5].

Contact address: juraj.ruzbarsky@tuke.sk

A properly cast product is conditioned by the appropriately designed casting and mold structure therefore mold production primarily stems from the drawing documentation of a component that is the most frequently modelled by applying one of the CAD systems. Consequently, the 3D model is enlarged by the value of metal shrinkage due to the linear expansion of the casting metal, and the gating system distributing the liquid metal inside a mold is modeled. The part of the gating system is also represented by venting holes designed for the removal of gas produced in the casting process [6, 7].

The quality and productivity of die-castings are closely linked with the final structural design of the die-casting mold which depends on the abilities and communication of the design engineers of castings and a mold as well as of the technologists of a die-casting plant. The structure and service life of a die-casting mold influences mold quality and the economic efficiency of the production of castings to a high degree. The die-casting molds are stressed by high temperature and pressure, sudden temperature changes, and the melt erosive effect. The mentioned factors determine the basic requirements for mold material as follows [8, 9]:

- chemical durability against the casting alloy,
- retention of mechanical properties at high temperatures,
- sufficient resistance against thermal shocks,
- good machinability,
- reasonable price.

The presented requirements are met most by the steel alloyed by vanadium, chromium, molybdenum, and cobalt after heat treatment. To increase a mold service life chemical treatment is used. The effective mold protection is nitridation with diffusion annealing. An increase in a mold service life is possible to be achieved by the application of the following measures [9, 10]:

- mold temperature regulation,
- adequate mold lubricant application (endothermic),
- utilization of material for mold production with the lowest thermal,
- expansion, the lowest modulus of elasticity, and the highest thermal conductivity casting technology with crystallization under pressure and treatment of semisolid metal.

A die-casting mold usually consists of fixed and moving parts. The properly designed gating and venting systems determining the basic characteristics of a die-casting mold by their design are of primary significance for the economical production of sound castings. The selection of shape and type of the systems depends on the experience of design engineers and simulation tools intended for the proposal and evaluation of arisen faults based on input conditions of die-casting and underdetermination of the individual systems [11, 12].

The inseparable part is a cooling and tempering system used in mold cooling during the series casting and, vice versa, in case of its heating to reach operating temperature before the casting process. To achieve the utmost productivity in casting the product's smaller shape, multiple molds might be used in which several castings are possible to be cast at a time during a single working cycle [13, 14, 15].

Mold material for pressure casting

Molds for pressure casting are stressed by high temperatures and pressures, sudden temperature changes, and the erosive effect of the melt. The following factors determine the basic requirements for the mold material [16, 17]:

- chemical stability to the cast alloy,
- preservation of mechanical properties at high temperatures,
- sufficient resistance against thermal shocks,
- good machinability,
- accessible price.

Steels that are alloyed with vanadium, chromium, molybdenum, tungsten, cobalt, and other elements after heat treatment best meet the stated requirements. To increase the service life, the mold is chemically processed. Effective mold protection is nitriding with diffusion annealing. By nitriding the mold to a depth of about 0.3 mm, the hardness of the surface increases while maintaining the toughness of the core [18].

An increase in durability can be achieved using the following measures [18, 19, 20]:

- mold temperature regulation,
- use of suitable e.g., of endothermic grease for the mold,
- use of materials to produce molds with the lowest expansion temperature, the lowest modulus of elasticity, and the highest thermal conductivity,
- casting technology with crystallization under pressure and semi-solid metal processing.

The lifetime of the mold depends mainly on the type of cast alloy. Before casting, various protective, or dividing means, which, in addition to protecting the mold, enable easier release of the casting from the mold. When choosing a protective separation agent, one must consider its gas-forming ability [21, 22, 23].

Filling Mode in a Mold Cavity

In general, the liquid flowing is classified as laminar flow (Fig. 1) in case the liquid is flowing without mixing of partial flows and turbulent flows (Fig. 2) in case mixing of partial flows occurs.

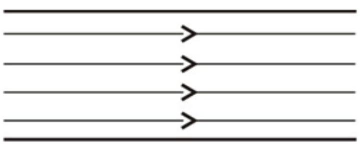


Fig. 1 Laminar flow

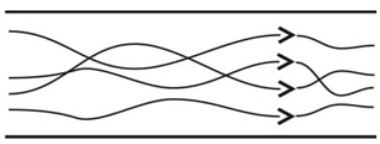


Fig. 2 Turbulent flow

Source: [22]

In characterizing by the Reynolds number Re:

$$R_e = \frac{v.d}{v_k} \qquad [-] \qquad (1)$$

with:
v – liquid flow speed [m/s],
d – diameter of piping with flowing liquid [m],
υ_k – kinematic viscosity [m^2/s].
The range is defined by the critical Reynolds number $R_{ecrit.}$ = 2320.
Consequently:

laminar flow is defined by $R_e < R_{ecrit.} = 2320$, (2)

turbulent flow is defined by $R_e > R_{ecrit.} = 2320$. (3)

During a mold cavity filling not only does the flowing character matter but the flowing face of the liquid metal as well. From the perspective of the face, three types of flows are distinguished – planar flow (Fig. 3) with the continual flow face being regular along the entire mold cavity width not entrapping the air bubbles during a mold cavity filling at low speed, and non-planar flow (Fig. 4) with the discontinuous flow face in the narrower extent comparing to a mold cavity width entrapping the air bubbles during a mold cavity filling at higher speed and disperse flow (Fig. 5) forming in a mold cavity filling the dispersed mixture of liquid metal and air [24, 25].

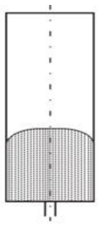


Fig. 3 Planar flow

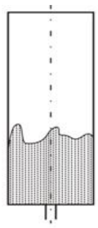


Fig. 4 Non-planar flow

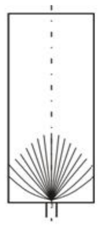


Fig. 5 Disperse flow

Source: [7]

A more up-to-date method of determination of mode or metal flowing faces in a mold cavity compared to the critical value of the Reynolds number, which does not consider disperse flow, is the explicit ratio of the Reynolds and Ohnesorge numbers shown in Fig. 6.

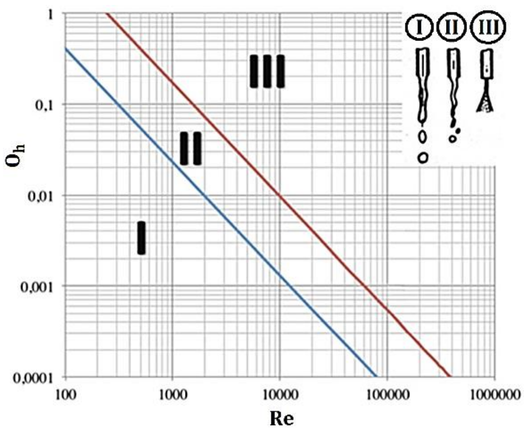


Fig. 6 Dividing of the flow faces by the Reynolds and Ohnesorge numbers
I – planar flow, II – non-planar flow, III – disperse flow

Source: [18]

The Ohnesorge number O_h relates viscous forces to inertial and surface tension forces of metal [6, 26].

$$O_h = \frac{\eta}{\sqrt{\rho.\sigma.d}} \qquad [-] \qquad (4)$$

with:
η – dynamic viscosity [Pa.s],
ρ – metal density [kg/m^3],
σ – surface tension [N/m],
d – diameter of piping with flowing liquid [m].
Concerning the expansion of the metal flowing surface during the formation of metal flow faces the energy is directly proportional to surface tension characterized by the Ohnesorge number. The energy required for the formation of the metal flow faces is possible to be supplied by the pressing mechanism of the die-casting machine through the ingate or by the shearing forces acting upon the metal flow. The extent of the formation of metal flow faces is determined by the Reynolds and Ohnesorge numbers that classify the types of the face flows as planar one, non-planar, and dispersed [27, 28, 29].

MATERIALS AND METHODS

We used the AlSi9Cu3 alloy in our experiment. In Fig. 7 shows a specific pressure casting used in the automotive industry, where during pressure casting, we monitored different modes of metal flow into the mold and the speed of the melt in the notch of the mold's inlet system.

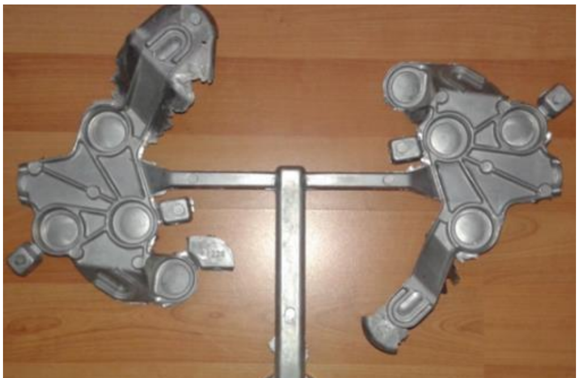


Fig. 7 Unprocessed pressure casting together with the inlet system

In the automotive industry, it is a dominant hypoeutectic alloy of the Al-Si-Cu type, which is used to produce castings, such as engine blocks, gearboxes, and others. The Cu component improves machinability and enables self-hardening after rapid cooling in water. This alloy also contains a certain amount of Mg, which forms a hardenable phase to improve the mechanical properties of the casting. We carried out our experiments on a pressure casting machine marked CLV 250, where the maximum closing force is 600 t and the maximum injection force is 65 t.

Setting technological parameters for the casting

We set the speed of the alloy flow when filling the chamber and the inlet system in the interval from 17 to 90 m/s, and the pressure of the alloy was constant at 125 MPa. The values of melt temperature (660°C) and mold temperature were set to constant temperatures in the process of experiments. The casting solidification time from filling the mold to its opening is set to 30 seconds.

The process of filling the mold cavity

The German researchers Frommer and Brandt developed the theory of the process of filling the mold cavity with alloy during pressure casting [5]. The filling mode of the mold cavity depends on the pressing speed and pressure. According to Frommer, Barton, Vejnik, and other researchers, the pressing pressure on the metal can be expressed as a function of the speed of the pressing piston, the cross-sectional area of the inlet, the temperature of the mold, and other variables [5]. In principle, we distinguish two options for filling the mold cavity, which is determined by the ratio of the cross-section of the inlet notch to the cross-section of the casting:

$$\text{a)} \quad \frac{S_f}{S_F} > 0.25 \tag{5}$$

$$\text{b)} \quad \frac{S_f}{S_F} < 0.25 \tag{6}$$

with:

S_f – ingate cross-section area [m^2],

S_F – an area of mold cavity cross-section [m^2].

Cavity filling takes place according to Brandt (Fig. 8.)

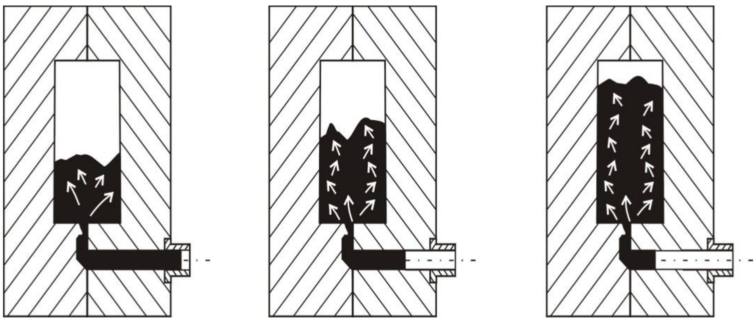


Fig. 8 Process of filling the mold cavity according to Brandt

Source: [18]

Fig. 9 shows the filling of the mold cavity at the ratio Sf/SF < 0.25, which we also call the filling of the cavity according to Frommer.

Water colored with hyper manganese was used as a model liquid. The transparent form was made of plexiglass. We used a speed camera with a cadence of 1000 to 2000 frames per second to process the filling of the mold. To optimize the values of castings from the used aluminum alloy, we subsequently determined:

- filling time of the mold cavity depends on the thickness of the casting wall,

- speed in the notch depends on the maximum distance of the mold cavity from the inlet notch and the thickness of the casting wall.

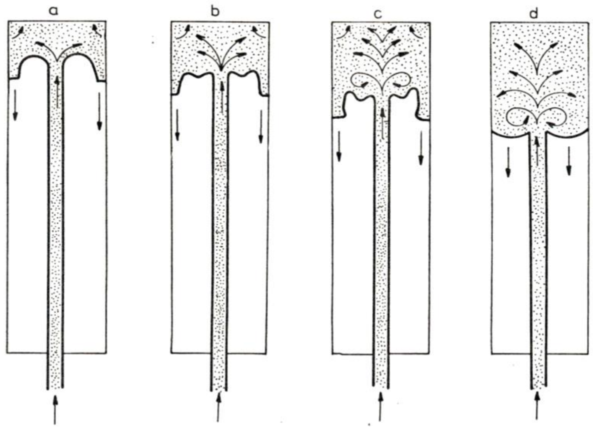


Fig. 9 The process of filling the mold cavity according to Frommer

Source: [18]

To determine the mechanical properties, the tensile test performed on cast round bars with a diameter of 6.3 mm is most often used, from which we determine the tensile strength limit according to the relevant standards. As a test device for the tensile test, we used the TIRAtest universal testing machine.

RESULTS

Design of a Mold Gating System

The task of the gating system is to fill a mold cavity at such speed and place to assure the directed solidification and to provide limitation of oxidation, dragging of the air and gases, and non-metal inclusions inside the casting. Apart from this, the improperly designed gating system can lead to leakage, contractions, dry joints, and unsatisfactory surface quality of castings. The influence of an improperly designed gating system upon the occurrence of air bubbles in the casting is documented in Fig. 10.

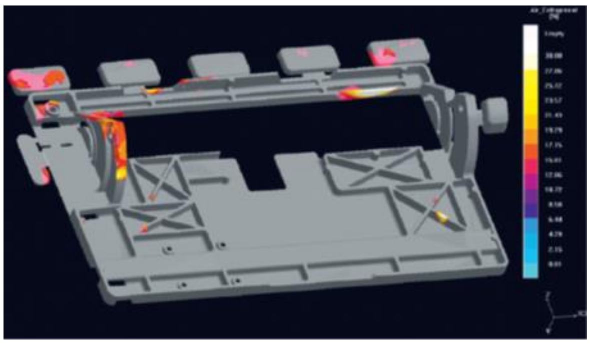


Fig. 10 Improperly designed gating system

Figure 11 shows an acceptable design of the gating system without the necessary change of the casting structure concerning the formation of bubbles stressing the most problematic area of the casting.

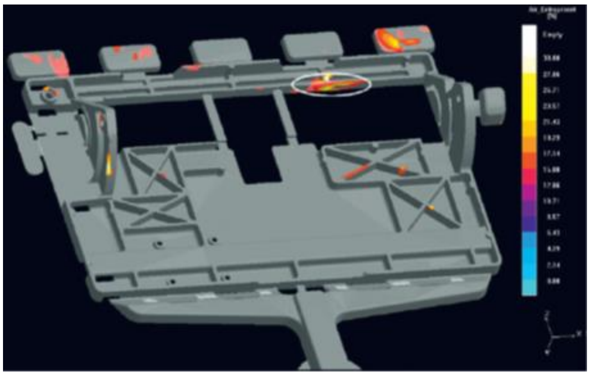


Fig. 11 Properly designed gating system

The indicator in the case of Fig. 10 and Fig. 13 is a color scale expressing in percentage the air bubbliness rate of casting. The metal must be transferred into a mold cavity without whirling and splashing yet rather fast so that the hot metal manages to fill a mold cavity faultlessly.

The instance of the structural and design solution of the gating system of the multi-cavity mold is shown in Fig. 12.

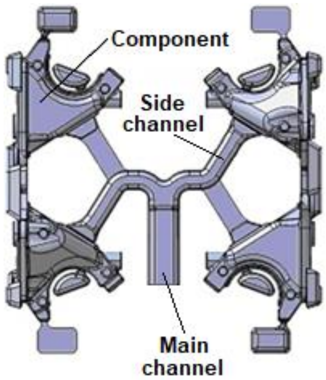


Fig. 12 Structural and design solution of the gating system

The main channel of the gating system connects the filling chamber with the ingate. The diameter of the main feed channel is to decrease evenly along with the direction from the filling chamber towards the ingate to provide an even increase of the melting speed in the course of the passing through the main channel. Not before the last quarter of the direction close to the ingate, the cross-section starts decreasing faster which means an increase in the melting speed which reduction in the difference between the optimal melt speed inside the ingate and the speed of the last part of the main channel is achieved. Sudden enlargement of the cross-section of the main channel and consequent diminishing to the original one results in the enclosure of the bubbles in the liquid metal and their transfer to a mold cavity which is tried to be prevented in practice.

Filling Process in a Mold Cavity

The most frequently occurring metal flowing modes in a mold cavity during filling are dispersed and turbulent flows. On the other hand, it must be accepted that a mold cavity filling is considerably complicated by structural elements such as brackets, bends, etc. By generalizing the modes consisting of turbulent and dispersed flows the final flowing in a mold cavity is obtained in the case of the majority types of structurally more complicated castings. Even with a simple casting type, it is difficult to foresee and analyze the flowing mode type in a mold cavity.

The British researcher Barton proved that at lower speed the alloy flow injected into a mold cavity generated "primarily formed crust "(Fig. 13).

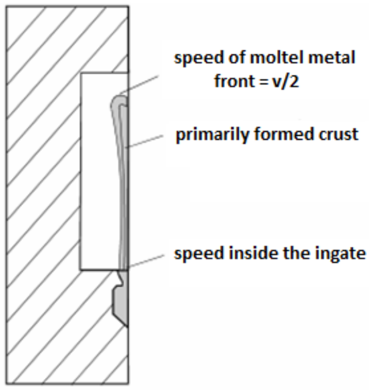


Fig. 13 Primarily formed crust

In the cross-section of the melt flow the heat and speed gradient is generated which means that in the proximity of a mold face the alloy with lower temperature and higher viscosity occurs, i.e., less movable one (almost solidified). With the increasing direction from a mold face, the melt moves at a higher speed as it possesses a higher temperature and lower viscosity. The layers of the rapidly moving upper zone reach the front face. The front is dragged by the rotary center and simultaneously swept by the flow and its movement transfers into the rotating one as during a mold cavity filling the viscose shear occurs between the adjacent layers inside the surface crust, in the surface layer speed gradient ranges from zero to v and on the internal surface of the "primarily formed crust" of the proceeding crust head v/2 as a similarity to an unfolding carpet. This results in a collision with a mold cavity area with high kinetic energy, the head possesses a big momentum constituent perpendicular to the progress direction being pacified. This causes the expansion of the stream of alloy with a circular cross-section after leaving the tube when the friction stops and therefore the alloy filling the mold cavity is forced by the perpendicular component of momentum to directly contact the surface of the mold cavity according to Fig. 14. The outcome rests in precise copying of the working cavity of the casting mold which is a significant merit of the die-casting technology.

Fig. 14 Perpendicular component of momentum casing the filling of the segmented mold cavity shapes

The results of the experiments show that the speed of the liquid metal when filling the mold is approximately half of the calculated theoretical value. The lost energy is converted into heat and the temperature of the alloy should rise before it leaves the notch. The process of filling the mold was captured by a speed camera with a cadence of 1000 to 2000 frames per second. With the camera, we recorded the actual flow speed for different shapes of the mold cavity. In Fig. 15 shows the beginning of the discharge from the notch when the friction stops and there is a tendency to increase the flow cross-section, which experimentally confirms the theoretically derived process according to Fig. 14.

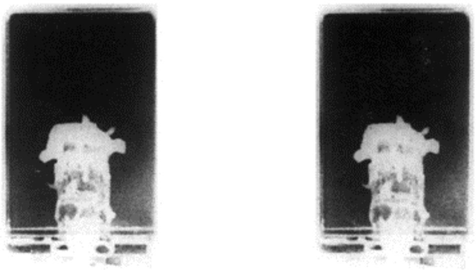


Fig. 15 The beginning of a widening outflow from the notch

Images taken with a high-speed camera made it possible to compare the effect of the notch thickness on the emergence of laminar and turbulent flow based on the Reynolds number and thus confirm the assumed viscosity.

CONCLUSIONS

The properly designed gating system determining the basic characteristics of a die-casting mold by their design is of primary significance for the economical production of sound castings. The selection of shape and type of the systems depends on the experience of design engineers and also on simulation tools intended for the proposal and evaluation of arisen faults based on input conditions of die-casting. Due to its design and function, the sprue system influences the process of filling the mold cavity. By harmonizing and properly designing the sprue system, we achieve continuity of filling the mold cavity and elimination of qualitative and quantitative errors caused by non-observance of basic principles in the design of sprue systems. The inlet system must be designed in such a way as to achieve:

- correct filling of the mold cavity,
- such a direction of metal flow in the mold cavity that its walls do not wear out prematurely,
- limiting the local increase in temperature, which would lead to excessive wear and deterioration of the surface cleanliness of the casting,
- the smallest possible formation of eddies in the melt stream, which leads to the entrapment of gases in the volume of the casting,
- required shape and surface quality of the casting.

The sprue system determines the basic characteristics of the mold by its solution. In this solution, we have to start by filling the cavity of the mold with liquid metal. The individual phases of filling the mold cavity are as follows:

- filling the chamber with the required amount of liquid metal,
- filling the cavity of the mold with a stream of liquid metal, while the kinetic energy of the stream of metal is partly converted into heat by friction in the notch,
- precise filling of the mold cavity by the hydrodynamic pressure of the flowing liquid metal,
- after the mold cavity is filled in the entire volume, hydrostatic pressure acts during the solidification of the liquid metal,
- plastic deformation due to pressure in some cases, for example, when casting steel under pressure.

ACKNOWLEDGMENTS

The authors would like to thank the KEGA grant agency for supporting project 015TUKE-4/2022.

REFERENCES

[1] Hopmann, C. – Schneppe, T. – Theunissen, M. Et Al.: Investigation on the Transferability of Algorithms for the Numerical Optimization of Cooling Channel Design in Injection Molding on Metal Gravity Die-Casting – 2017. In: *Materialwissenschaft Und Werkstofftechnik*, Volume: 48, Issue: 12, Pages: 1220-1225, ISSN: 0933-5137

[2] Gaspar, S. – Coranic, T. – Majernik, J. – Husar, J. – Knapcikova, L. – Gojdan, D. – Pasko, J.: Influence of Gating System Parameters of Die-Cast Molds on Properties of Al-Si Castings – 2021. In: *Materials*, Volume 14, Issue 13, eISSN1996-1944

[3] Silmbroth, M. – Bozorgi, S. – Bozorgi, S.: Analysis of the Mechanical Properties of Secondary Alznmg(Cu) Die-Cast Alloys – 2020. In: *International Journal of Metalcasting*, ISSN: 1939-5981

[4] Kang, Hj. – Yoon, Ph. – Lee, Gh. Et Al.: Evaluation of the Gas Porosity and Mechanical Properties of Vacuum Assisted Pore-Free Die-Cast Al-Si-Cu Alloy – 2021. In: *Vacuum* – 2021. Volume: 184. ISSN: 0042-207x

[5] Cai, Q. – Mendis, Cl. – Chang, It.H. Et Al.: Microstructure and Mechanical Properties of New Die-Cast Quaternary Al-Cu-Si-Mg Alloys – 2021. In: *Materials Science and*

Engineering A-Structural Materials Properties Microstructure And Processing, Volume: 800, ISSN: 0921-5093

[6] Raffaeli, R. – Favi, C. – Mandorli, F.: Virtual Prototyping in the Design Process of Optimized Mold Gating System for High Pressure Die-Casting – 2015. In: *Engineering Computations*, Volume 32, Issue 1, Page 102-128, ISSN 0264-4401

[7] Ružbarský, J. - Paško, J. - Gašpár, Š.: Techniques of Die-Casting. Lüdenscheid: Ram-Verlag - 2014. - 199 P. - ISBN 978-3-942303-29-3

[8] Muenstermann, S. – Kuethe, F. – Buenck, M. Et Al.: Near-Net Shaping of the Geometrically Complex Diving Knife by Semisolid Steel Casting Using Ceramic Mold System – 2011. In: *International Journal of Cast Metals Research*, Volume: 24, Issue: 1, Pages: 6-12, ISSN: 1364-0461

[9] Ragan, E. At Al.: Liatie Kovov Pod tlakom. 1. Prešov, 2007, 392 S., ISBN 978-80-8073-979-9.

[10] Stein, S. – Wedler, J. – Rhein, S. Et Al.: A Process Chain for Integrating Piezoelectric Transducers Into Aluminum Die-Castings To Generate Smart Lightweight Structures – 2017. In: *Results in Physics*, Volume: 7, Pages: 2534-2539, ISSN: 2211-3797

[11] Gašpar, Š. – Paško, J.: Pressing Speed, Specific Pressure and Mechanical Properties of Aluminium Cast – 2016. In: *Archives of Foundry Engineering*, Volume: 16, Issue: 2, Pages: 45-50, ISSN: 1897-3310

[12] Szymczak, T. – Gumienny, G. – Klimek, L. Et Al.: Characteristics of Al-Si Alloys With High Melting Point Elements for High Pressure Die-Casting – 2020. In: *Materials*, Volume: 13, Issue: 21, ISSN 1996-1944

[13] Ružbarský, J. - Majerník, R.: Theoretical Regulation of Delimitation of Metal Level Decrease in the Furnace in Case of Pneumatic Dosing Device of Metal - 2017. In: *Manufacturing Technology*. Vol. 17, No. 1 (2017), P. 84-86. - ISSN 1213-2489

[14] Maidin, S. – Yi, Tm. – Hambali, A. – Akmal, S. – Hambali, Rh. – Abdullah, Z.: Investigation of Optimum Gating System Design of Fused Deposition Modelling Pattern For Sand Casting – 2017. In: *Journal of Mechanical Engineering and Sciences*, Volume 11, Issue 3, Page 2801-2814, ISSN 2289-4659

[15] Gašpar, Š. – Paško, J.: Technological Parameters Of Die-Casting and Quality of Casting from En Ac46500 Alloy – 2016. In: *Metalurgija*, Volume: 55, Issue: 3, Pages: 391-394, ISSN: 0543-5846

[16] Chang, Q. – Schwam, D. – Chen, C. – Xiong, J. – Wallace, Jf.: Mold Filling Process Control of Molten Aluminum in Permanent Molds With a Web Gating System – 2008. In: Materials Science Forum Book Series Materials Science Forum, Volume 575-578, Page 63-+, Part 1-2, ISSN 0255-5476

[17] Ružbarský, J.: Al–Si Alloy Casts by die-Casting a Case Study - 1. Vyd. - Cham : Springer Nature - 2019. - 71 S. - ISBN 978-3-030-25149-9

[18] Ružbarský, J. – Sitko, J.: Possibilities Of Pressure Die-Casting Of Iron Alloys - 2019. In: *Management Systems In Production Engineering* – 2019. Vol. 27, No. 4 (2019), S. 199-204, ISSN 2299-0461

[19] Stachovec, I. – Horacek, M. – Zemcik, L. – Kolda, V. – Horensky, J.: Gating Systems for Sizeable Castings From al Alloys Cast Into Ceramic Molds – 2012. In: *Archives of Foundry Engineering*, Volume 12, Issue 2, Page 65-68, ISSN 1897-3310

[20] Lee, Ks. – Lin, Jc.: Design of the Runner and Gating System Parameters For a Multi-Cavity Injection Mold Using Fem and Neural Network – 2006. In: *International Journal of Advanced Manufacturing Technology*, Volume 27, Issue11-12, Page1089-1096, ISSN 0268-3768

[21] Majidi, Sh. – Beckermann, C.: Effect of Pouring Conditions and Gating System Design on Air Entrainment During Mold Filling – 2019. In: International Journal of Metalcasting, Volume 13, Issue 2, Page 255-272, ISSN 1939-5981

[22] Ragan, E. - Ružbarský, J.: Parameters Stating in the Die Cavity – 2006. In: *Materiálové Inžinierstvo*, Vol. 13, No. 3, P. 21-22, - ISSN 1335-0803

[23] Yuan, Ly. – Han, Pw. – Asghar, G. Et Al.: Development of High Strength and Toughness Non-Heated Al-Mg-Si Alloys for High-Pressure Die-Casting – 2021. In: *Acta Metallurgica Sinica-English Letters*, Volume: 34, Issue: 6, Pages: 845-860, ISSN: 1006-7191

[24] Ge, Zh. – Qu, Y. – Zhou, Ya.: Cad Of Gating System for Injection Mold Based on the Secondary Development Technology Of Pro/E – 2011. In: *Manufacturing Processes and Systems*, Pts 1-2, Book Series Advanced Materials Research, Volume 148-149, Page 453-457, ISSN 1022-6680

[25] Majerník, J. – Gerková, J.: Vplyv Konštrukcie Vtokového Systému Na Kvalitu Odliatkov. Posterus. Sk. 2014, Roč. 7, Č. 8, P. 1-5, 6 pp. ISSN 1338-0087

[26] Wang, F. – Ma, Q. – Meng, W. Et Al.: Experimental Study on the Heat Transfer Behavior and Contact Pressure at the Casting-Mold Interface in Squeeze Casting of Aluminum Alloy – 2017. In: *International Journal of Heat And Mass Transfer*, Volume: 112, Pages: 1032-1043, ISSN: 0017-9310

[27] Sharifi, A. – Abadi, Mmh. – Ashiri, R.: Direct Observation Of Effects of Foam Density, Gating Design and Pouring Temperature on Mold Filling Process In Lost Foam Casting of A356 Alloy – 2015. In: Proceedings of the TMS Middle East - Mediterranean Materials Congress on Energy and Infrastructure Systems (Mema 2015), Page 109-118, ISBN 978-1-119-09042-7

[28] Sun, Z. – Hu, H. – Chen, X. – Wang, Q. – Yang, W.: Gating System Design For a Magnesium Alloy Casting – 2008. In: *Journal of Materials Science & Technology*, Volume 24, Issue 1, Page 93-95, ISSN 1005-0302

[29] Zhang, Jz. – Zuo, Lj. – Feng, J. Et Al.: Effect of Thermal Exposure on Microstructure and Mechanical Properties of Al-Si-Cu-Ni-Mg Alloy Produced by Different Casting Technologies – 2020. In: *Transactions of Nonferrous Metals Society of China*, Volume: 30, Issue: 7, Pages: 1717-1730 ISSN: 1003-6326

Juraj Ružbarský
ORCID ID: 0000-0002-7021-5061
Technical University of Kosice
Faculty of Manufacturing Technologies
Sturova 31, 08001 Presov, Slovakia
e-mail: juraj.ruzbarsky@tuke.sk

Tibor Krenický
ORCID ID: 0000-0002-0242-2704
Technical University of Kosice
Faculty of Manufacturing Technologies
Sturova 31, 08001 Presov, Slovakia
e-mail: tibor.krenicky@tuke.sk

Jozef Maščeník
ORCID ID: 0000-0002-9632-1129
Technical University of Kosice
Faculty of Manufacturing Technologies
Sturova 31, 08001 Presov, Slovakia
e-mail: jozef.mascenik@tuke.sk

Tomáš Coranič
ORCID ID: 0000-0002-3403-8141
Technical University of Kosice
Faculty of Manufacturing Technologies
Sturova 31, 08001 Presov, Slovakia
e-mail: tomas.coranic@tuke.sk