# THE EFFECT OF DIE VACUUMING ON THE POROSITY OF PRESSURE CASTINGS

**JURAJ RUZBARSKY[1], JOZEF MASCENIK[1]**

[1]Faculty of Manufacturing Technologies, Technical University of Kosice, Presov, Slovak Republic

**DOI: 10.17973/MMSJ.2026_11_2025112**

**juraj.ruzbarsky@tuke.sk**

Porosity is one of the significant internal defects of pressure castings and can negatively affect their mechanical properties. One of the methods for reducing the amount of air and gases trapped in the die cavity during filling is die vacuuming. This study aims to experimentally evaluate the effect of die vacuuming on the porosity of pressure castings. The experiment was carried out on a CLH 250 horizontal cold chamber die casting machine equipped with a FONDAREX vacuum system. An automotive component made of AlSi10Mg alloy was evaluated. During the experiments, the technological parameters of the process were kept constant, while castings produced without die vacuuming and with die vacuuming were compared. A total of 32 castings were analysed, including 16 produced without vacuuming and 16 produced using die vacuuming. Porosity was determined from metallographic sections using image analysis in ImageJ software. The average porosity of the castings produced without vacuuming was 2.633%, whereas the value determined for the castings produced with vacuuming was 0.912%. The experimental results indicate a significant difference in porosity between castings produced without die vacuuming and those produced with die vacuuming.

**KEYWORDS**

pressure die casting, die vacuuming, porosity, pressure casting, AlSi10Mg

## 1 INTRODUCTION

High-pressure die casting (HPDC) is a manufacturing process that enables the production of complex-shaped metal castings with high productivity [Ruzbarsky 2025b]. The quality of the resulting casting is significantly influenced by the conditions during filling of the die cavity and by the process parameters [Kan 2023]. One of the major defects in high-pressure die castings is the occurrence of internal cavities and pores, which arise mainly from the filling behaviour of the die cavity and the presence of air and gases within the die system [Ruzbarsky 2025a, Gaspar 2022, Hong 2024].

At high injection speeds, the melt undergoes intensive movement and dispersion within the die cavity. During the filling process, air and gases present in the die cavity may become entrapped in the solidifying casting. This results in the formation of porosity, whose extent, size, and distribution can affect the properties of the casting [Zhang 2024, Koru 2024]. Pores act as stress concentrators and may, to a certain extent, reduce the mechanical and fatigue properties of the material [Zhang 2026, Yang 2025].

The amount of air and gases entrapped in the casting is related not only to the filling process itself but also to the venting conditions of the die [Kang 2023]. In conventional high-pressure die casting, back pressure caused by air and gases develops during filling of the die cavity. Due to the short filling time, the gases cannot always be sufficiently evacuated through the venting system. According to [Kan 2023, Zhang 2026], the pressure in the die cavity during the first stage of compression can reach approximately 0.3 MPa, while during subsequent stages of compression, its value may increase to two to three times this level. A schematic comparison of conventional and vacuum-assisted high-pressure die casting is shown in Fig. 1.

In vacuum-assisted high-pressure die casting, air and gases are evacuated from the die cavity using a vacuum system, thereby reducing back pressure. According to [Ruzbarsky 2022], the back pressure when vacuum assistance is applied rarely exceeds 0.02 MPa.

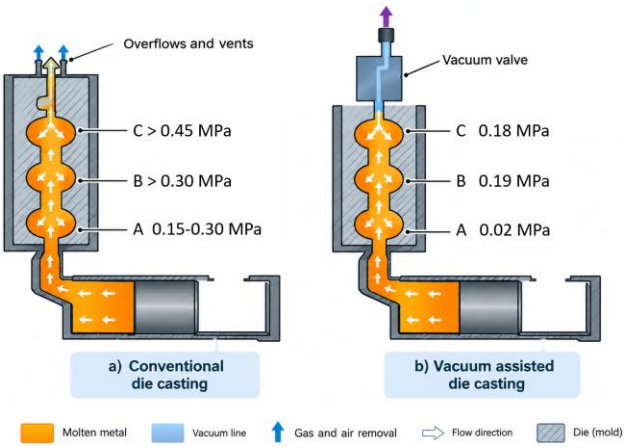



**Figure 1.** Schematic comparison of conventional and vacuum-assisted high-pressure die casting, adapted from [Gaspar 2022]

One method of reducing the amount of air and gases in the die cavity is the use of a vacuum system. The principle of vacuum assistance is to evacuate air and gases from the die cavity before it is filled with the melt, thereby reducing the back pressure acting against the advancing melt. The use of a vacuum system reduces the amount of air and gases present in the die cavity, while the effectiveness of vacuum assistance also depends on the design of the venting system, leakage, and other process conditions [Ruzbarsky 2023]. The principle of evacuating air and gases from the die cavity using a vacuum system is schematically illustrated in Fig. 2.

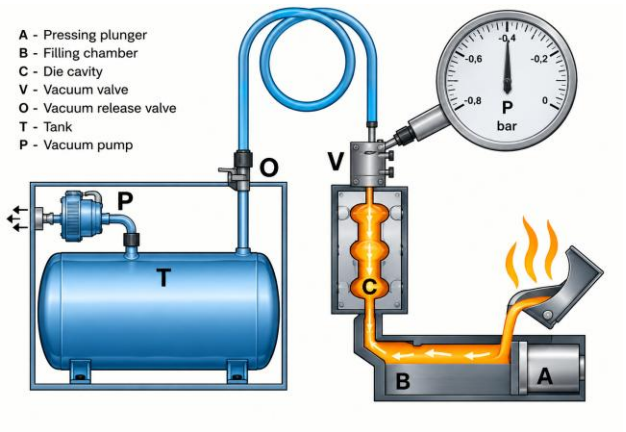



**Figure 2.** Schematic representation of the die vacuuming principle, adapted from [Gaspar 2022]

The effectiveness of die vacuuming should therefore be assessed not only in terms of the removal of air and gases from the die cavity but primarily based on its effect on the resulting casting quality. In this context, porosity represents a suitable parameter for the experimental comparison of high-pressure

die casting conditions with and without die vacuuming [Wang 2024].

The aim of this study is therefore to experimentally evaluate the effect of die vacuuming on the porosity of high-pressure die castings. The experimental comparison was carried out under constant process conditions, with two groups of castings investigated: castings produced without die vacuuming and castings produced with die vacuuming. The difference in porosity was subsequently determined using image analysis of metallographic sections.

## 2 MATERIALS AND EXPERIMENTAL METHODS

### 2.1 Experimental Material and Equipment

The experimental investigation of the effect of die vacuuming on porosity was carried out on a CLH 250 horizontal high-pressure die casting machine designed for the high-pressure die casting of non-ferrous metals. The die cavity was evacuated using a FONDAREX vacuum system.

The experimental material was an ENAC 43 400 (AlSi10Mg) aluminium alloy, whose chemical composition complied with the requirements of EN 1706. The chemical composition of the alloy used is given in Table 1.

| Al | Si | Cu | Fe | Mg | Mn |
|---|---|---|---|---|---|
| 88.06 | 10.70 | 0.09 | 0.50 | 0.33 | 0.15 |
| According to EN 1706 | | | | | |
| balance | 9.0-11.0 | max. 0.1 | max. 1.0 | 0.2-0.5 | max. 0.55 |
| **Zn** | **Ni** | **Ti** | **Pb** | **Sn** | **Other** |
| 0.09 | 0.01 | 0.01 | 0.01 | 0.01 | 0.04 |
| According to EN 1706 | | | | | |
| max. 0.15 | max. 0.15 | max. 0.2 | max. 0.15 | max. 0.05 | max. 0.15 |

**Table 1.** Chemical composition of the experimental AlSi10Mg alloy [%]

The experimental evaluation was carried out on a casting intended for the automotive industry, as shown in Fig. 3. Two process conditions were compared during its production: high-pressure die casting without die vacuuming and high-pressure die casting with die vacuuming.

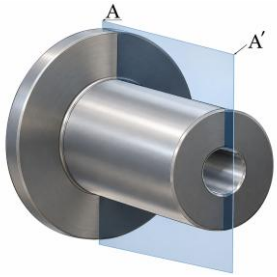



**Figure 3.** Experimental casting showing the location of cross-section A–A′ used for metallographic analysis.

### 2.2 Experimental Conditions

For both production conditions, the same process parameters were maintained on the CLH 250 machine. The plunger speed in the shot sleeve was 1.8 $m \cdot s^{-1}$, the alloy temperature was 720 °C, and the die temperature was 220 °C. The variable experimental condition was the application or non-application of die vacuuming. Die vacuuming was performed using a FONDAREX vacuum system. However, the specific vacuum pressure and the exact timing of vacuum activation were not recorded during the experiments. Therefore, these parameters could not be quantitatively specified in the present study.

This experimental setup enabled the porosity of the castings to be compared while maintaining constant basic process conditions and varying only the method of removing air and gases from the die cavity.

A total of 32 castings were produced. The first group consisted of 16 castings produced without die vacuuming, while the second group consisted of 16 castings produced with die vacuuming. The sample distribution was selected to assess differences in the resulting porosity values between the two process conditions.

### 2.3 Porosity Determination

Porosity was evaluated on metallographic sections of the experimental castings. A cross-section of each sample was prepared at a defined location within the casting, designated as section A–A′ in the original methodology. The metallographic sections were examined using an Olympus GX 51 microscope at 100× magnification. The porosity was evaluated within the selected microscopic field of view corresponding to the defined section.

Image analysis was performed using ImageJ software to determine the area fraction of porous regions within the analysed microscopic field. An example of the image analysis procedure is shown in Fig. 4, where the area fraction of porosity for Sample 3 was determined to be 3.143%. The same evaluation procedure was applied to all analysed images to ensure consistency in the assessment of porosity. The original experimental records did not specify the exact number of microscopic fields analysed per casting or the detailed ImageJ settings used for pore identification; therefore, these parameters could not be reported.

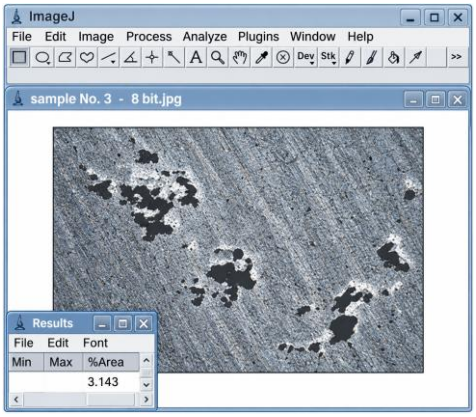



**Figure 4.** Evaluation of sample porosity using ImageJ

Using the same procedure, porosity values were determined for all 16 samples produced without die vacuuming and for all 16 samples produced with die vacuuming. The individual porosity values were then compared, and the average porosity value was determined for each group.

## 3 RESULTS AND DISCUSSION

The experimental evaluation focused on comparing the porosity of high-pressure die castings produced without die vacuuming and with die vacuuming. The same basic process conditions were maintained for both groups. The evaluated parameter was the area fraction of the porous region determined on a metallographic section at a defined location within the casting.

The results of the image analysis of the porosity of the individual samples are presented in Fig. 5. For the group of castings produced without die vacuuming, the porosity values ranged from 2.031% to 3.143%. For the castings produced with die vacuuming, the porosity values ranged from 0.745% to 1.153%.

Comparison of the results shows that all analysed castings produced with die vacuuming exhibited lower porosity values

than the corresponding castings produced without die vacuuming. The average porosity of the group produced without die vacuuming was 2.633%, whereas the average porosity of the castings produced with die vacuuming was 0.912%. The difference between the average values was 1.721 percentage points. Relative to the average porosity of the group produced without die vacuuming, this represents a reduction of approximately 65.4%.

The variability of the measured porosity values was assessed using the sample standard deviation. For castings produced without die vacuuming, the mean porosity was 2.633% with a standard deviation of 0.310 percentage points. For castings produced with die vacuuming, the mean porosity was 0.912% with a standard deviation of 0.103 percentage points. These results indicate lower variability in the measured porosity values in the vacuum-assisted group.

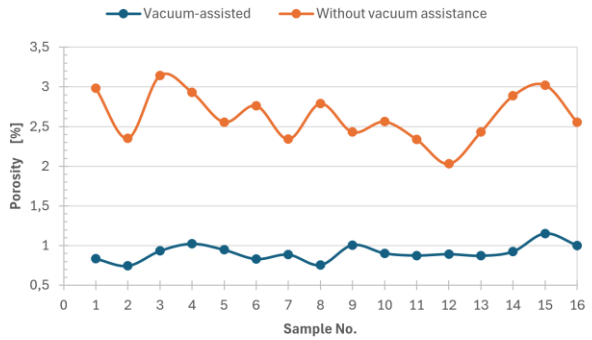



**Figure 5.** Results of image analysis of the porosity of individual samples

A significant difference between the two groups is also evident from the image analysis of the metallographic sections. Fig. 6 presents examples of castings produced without die vacuuming, with porosity values of 2.431% and 3.023%, respectively. Fig. 7 presents examples of castings produced with die vacuuming, with porosity values of 0.745% and 0.831%. In the analysed images, the porous regions are identified as dark to black areas.

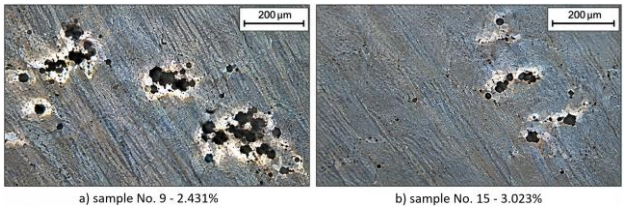



**Figure 6.** Metallographic sections of castings produced without vacuum assistance

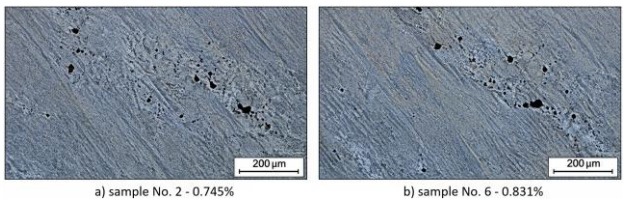



**Figure 7.** Metallographic sections of castings produced with vacuum assistance

### *3.1 Discussion of Results*

The obtained results demonstrate a clear relationship between the method of removing air and gases from the die cavity and the resulting porosity of the casting. In the conventional process, air and gases remain in the die cavity during filling, and their removal is limited by the very short filling time. As the melt advances through the cavity, these gases may become entrapped in the casting, resulting in an increased porous area in the analysed cross-section [Gaspar 2018, Kan 2023, Kang 2023].

Die vacuuming changes the conditions within the die cavity before it is filled. Evacuation using the FONDAREX vacuum system reduces the amount of gas available for entrapment during filling [Ruzbarsky 2022, Kang 2023, Zhang 2026]. This effect was confirmed experimentally, with the average porosity decreasing from 2.633% without die vacuuming to 0.912% with die vacuuming.

In the conventional process, the pressure of air and gases in the die cavity can reach approximately 0.3 MPa, whereas die vacuuming can reduce the back pressure to approximately 0.02 MPa. This reduction provides more favourable conditions for gas evacuation during filling [Zhang 2026]. The observed decrease in porosity is therefore consistent with the reported effect of reduced back pressure [Kang 2023, Ruzbarsky 2023].

Porosity was evaluated at a specific cross-section of the casting, with the measured value representing the area fraction of the porous region within the analysed metallographic field. The results therefore characterise the examined location and cannot be interpreted as the total volumetric porosity of the entire casting without additional measurements [Wang 2024].

Under the investigated process conditions, die vacuuming reduced the area fraction of porosity determined by image analysis and thus contributed to improved internal quality of the high-pressure die castings [Gaspar 2022, Ruzbarsky 2023, Yang 2025].

## 4 CONCLUSION

The study focused on the experimental evaluation of the effect of die vacuuming on the porosity of high-pressure die castings made of AlSi10Mg alloy. The experiment was conducted under constant basic process conditions. Within the available and controlled process conditions, the application of die vacuuming varied between the groups. Castings produced without die vacuuming were compared with castings produced using a vacuum system. Based on the experimental investigation, the results can be summarised as follows:

- For the castings produced without die vacuuming, the average porosity was 2.633%, with individual values ranging from 2.031% to 3.143%.
- With die vacuuming, the average porosity was 0.912%, with individual values ranging from 0.745% to 1.153%.
- The application of die vacuuming reduced the average porosity by 1.721 percentage points, corresponding to a reduction of approximately 65.4% relative to the group of castings produced without die vacuuming.
- A lower area fraction of porosity was recorded for all 16 analysed castings produced with die vacuuming compared with the castings produced without die vacuuming.
- Under the conditions of the experiment, the application of die vacuuming was associated with a substantial reduction in the area fraction of porosity in the evaluated casting cross-section.

For further evaluation, it should be considered that porosity was determined by image analysis at a specific, predefined cross-section of the casting. The obtained values therefore characterise the area fraction of porosity at the examined location and cannot be directly regarded as the total volumetric porosity of the entire casting. Despite this limitation, the experimental results provide a direct comparison of the two investigated process conditions and demonstrate a difference in the porosity level between production without die vacuuming and production with die vacuuming. Based on the results obtained, further research could focus on:

- investigating the effect of die vacuuming at different vacuum pressure levels and with variations in other high-pressure die casting process parameters;
- extending the porosity evaluation to multiple locations within the casting to better characterise the distribution of porosity throughout the casting volume;
- assessing the relationship between porosity and the mechanical properties of the castings.

These recommendations represent possible directions for further experimental investigation and were not within the scope of the present study.


**ACKNOWLEDGMENTS**

This research was funded by the Cultural and educational grant agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic, grant number KEGA 012TUKE-4/2025, and with the project VEGA 1/0834/25.


**REFERENCES**


[Dong 2025] Dong, J., et al. Research on numerical simulation and integrated die casting process of large complex thin-walled aluminum alloy automobile rear floor. Results in Engineering, 2025, Vol. 26, No. 105399. DOI: 10.1016/j.rineng.2025.105399

[Hong 2024] Hong, G.G., Jung, S.S., Choi, Y.S., Lee, Y.C. Effect of Oxygen Injections on the Porosity of High Pressure Die Castings. Metals and Materials International, 2024, Vol. 30, Issue 12, pp. 3444-3457. DOI: 10.1007/s12540-024-01713-w

[Gaspar 2018] Gaspar, S., Coranic, T., Pasko, J. Influence of Die Casting Factors and of Hardening Temperature Upon Mechanical Properties of a Die Cast. MM Science J., 2018, Vol. December, pp. 2639-2642. DOI: 10.17973/MMSJ.2018_12_2018108

[Gaspar 2022] Gaspar, S., et al. Comparison of porosity of casts produced by HPDC and VPDC technologies. MM Science Journal, 2022, pp. 5566-5570. DOI: 10.17973/MMSJ.2022_03_2022005

[Kan 2023] Kan, M., Ipek, O., Koru, M. An Investigation into the Effect of Vacuum Conditions on the Filling Analysis of the Pressure Casting Process. International Journal of Metalcasting, 2023, Vol. 17, Issue 1, pp. 430-446. DOI: 10.1007/s40962-022-00770-4

[Kang 2023] Kang, H.J., et al. Effects of chill vent gap and sleeve-plunger tip clearance on the vacuum degree of mold cavity and mechanical properties in high vacuum diecasting. International Journal of Metalcasting, 2023, Vol. 18, Issue 2, pp. 1160-1172. DOI: 10.1007/s40962-023-01085-8

[Koru 2024] Koru, M., Serce, O. Experimental and theoretical investigation of heat transfer in vacuum assisted high pressure die casting (hpdc) process. Int. Journal of Metalcasting, 2024, Vol. 18, Issue 4, pp. 3013-3027. DOI: 10.1007/s40962-023-01217-0

[Ruzbarsky 2022] Ruzbarsky, J. Influence of die casting speed on properties of casting based on al-si alloys. MM Science Journal, 2022, pp. 6114-6122. DOI: 10.17973/MMSJ.2022_11_2022012

[Ruzbarsky 2023] Ruzbarsky, J., Gaspar, S. Analysis of Selected Production Parameters for the Quality of Pressure Castings as a Tool to Increase Competitiveness. Applied Sciences, 2023, Vol. 13, Issue 14. DOI: 10.3390/app13148098

[Ruzbarsky 2025a] Ruzbarsky, J. Influence of die casting process parameters on the mechanical properties of castings. MM Science Journal, 2025, pp. 8271-8275. DOI: 10.17973/MMSJ.2025_06_2025020

[Ruzbarsky 2025b] Ruzbarsky, J., Zarnovsky, J. Experimental and Simulation Analysis of Die Gating System Design for AlSi9Cu3 Alloy Castings. Applied Sciences, 2025, Vol. 15, Issue 23. DOI: 10.3390/app152312766

[Tang 2026] Tang, Z.W., et al. Research on die-casting defect control by spot cooling water and heat treatment strengthening for ADC12 engine cylinder block. Advances in Science and Technology – Research Journal, 2026, Vol. 20, Issue 7, pp. 521-531. DOI: 10.12913/22998624/220471

[Wang 2024] Wang, X.Q., Ding, Z.G., Li, S.P., Peng, L.M. Computation method for mechanical performances of die-cast aluminum alloys based on non-uniform material properties. Materials Today Communications, 2024, Vol. 40, No. 109683. DOI: 10.1016/j.mtcomm.2024.109683

[Yang 2025] Yang, J., et al. Data-driven analysis of the process, organization and properties of large-size complex thin-walled die-casting aluminium alloys. Engineering Applications of Artificial Intelligence, 2025, Vol. 156. DOI: 10.1016/j.engappai.2025.111244

[Zhang 2024] Zhang, S., et al. Influence of High-Speed Ram Transition Position on Porosity and Mechanical Properties of Large One-Piece Die-Casting Al-Si-Mn-Mg Aluminium Alloy. Materials, 2024, Vol. 17, Issue 24, 6169. DOI: 10.3390/ma17246169

[Zhang 2026] Zhang, Z.W., et al. Manufacturing, Microstructure, and Mechanical Property Evaluation of an Al-Si Alloy Thin-Walled Casting via Vacuum-Assisted High-Pressure Die Casting. International Journal of Metalcasting, 2026. DOI: 10.1007/s40962-026-01938-y


**CONTACTS:**


**Prof. Ing. Juraj Ruzbarsky, PhD.**
Technical University of Kosice, Faculty of Manufacturing Technologies, Dept. of Production Management
Sturova 31, Presov, 080 01, Slovak Republic
+421 55 602 6350, juraj.ruzbarsky@tuke.sk

**Assoc. Prof. Ing. Jozef Mascenik, PhD.**
Technical University of Kosice, Faculty of Manufacturing Technologies, Dept. of Computer-Aided Manufacturing Technologies
Sturova 31, Presov, 080 01, Slovak Republic
+421 55 602 6360, jozef.mascenik@tuke.sk



**LICENSE CREATIVE COMMONS:**

The article is published under the terms and conditions of the Creative Commons Attribution 4.0 International License (CC BY 4.0).