Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal 2024, 18(5), 361–371
https://doi.org/10.12913/22998624/191236
ISSN 2299-8624, License CC-BY 4.0

Received: 2024.04.24
Accepted: 2024.07.17
Published: 2024.08.01

The Influence of Selected High – Pressure Die Casting Parameters on the Porosity of EN AB-46000 Alloy Castings

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ABSTRACT

The EN AB-46000 alloy castings are widely used in automotive industry due to their relative good strength combined with a low density and an excellent conductivity. Porosity of EN AB-46000 alloys is one of the most important defects, responsible for the low strength and poor plastic properties of castings as well as their tightness. Quantitative porosity measurement were performed using quantitative metallography and image analysis methods using ImageJ. The study shows that such parameters of high-pressure die casting are the piston speed in the second casting phase and the final pressure increase in the pressing phase. It has been shown that the appropriate selection of these parameters can significantly reduce the porosity of castings made of alloy EN AB-46000.

Keywords: porosity, aluminium alloys, high-pressure die castings, EN AB-46000 alloy, metallography.

INTRODUCTION

The cast aluminium alloys are widely used in automotive industry due to their relative good strength combined with a low density and an excellent conductivity. These alloys are commonly employed for chassis and engine components which are, for the most part, subjected to strength loads, posing a risk cracking. The strength of cast aluminium alloys is known to be greatly affected by different types of microstructural heterogeneities due to the manufacturing process. According to the developed technology and subsequent treatment, the microstructure features can be significantly modified especially in terms of the morphology and size of its components, i.e.: dendrites of the α(Al) solid solution, silicon particles in the α(Al) + β(Si) eutectic, the form of intermetallics phases, iron-based compounds and casting defects, notably micro-shrinkage pores and gas porosity [1, 2] – Figure 1. However, in spite of the presence of these defects, automotive casting manufacturers must ensure a targeted level of reliability of their components. In the case of pores, manufacturers establish up control procedures using microstructural examination for defect detection and to reject components containing defects presenting an unacceptable risk of failure [3].

In the case of manufacturers of pressure die-cast aluminium alloys, the quality of their products, determined by microstructural tests, is also influenced by casting parameters, i.e. pressure machine settings. It is mainly about choosing the most important ones and selecting them in such a way as to ensure that castings with a minimum (acceptable by the customer) level of porosity are obtained, which is a criterion for assessing their quality and sales possibilities. Despite numerous studies on the understanding of the influence of pressure die-casting parameters on the porosity of Al-Si cast alloy products, the development of casting design methods is still relevant, especially when taking into account the most important factors influencing the achievement of a structure free from casting defects [4].

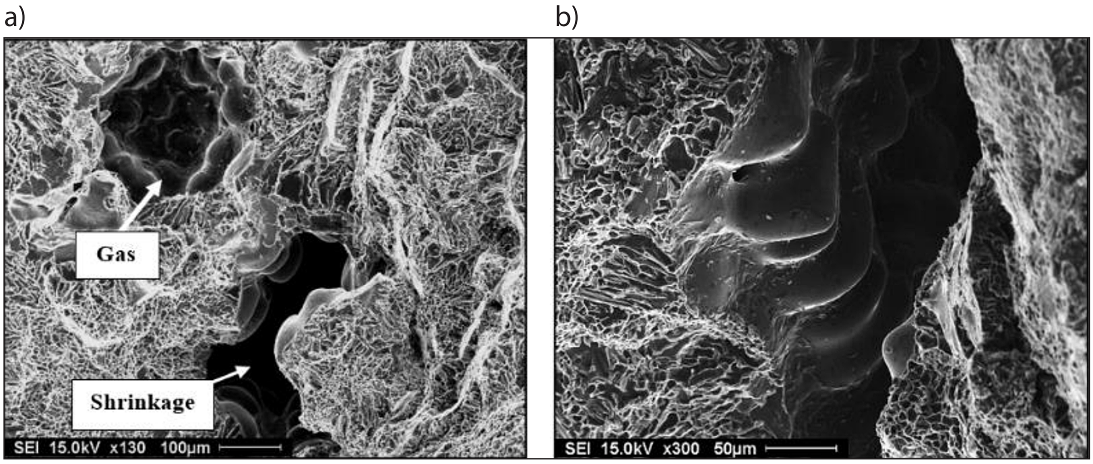

Figure 1. SEM electron images of porosity in 319 alloy (Al6Si-3.5Cu-1.0Fe): a) a mixture of gas and shrinkage, b) a high magnification micrograph of shrinkage reveals dendrites α(Al) [3]

Porosity in aluminium alloys negatively affects the strength and plastic properties as well as the fatigue resistance of castings. According to research [5], an increase in the volume fraction V_V of porosity by approximately 1% reduces the tensile strength R_m by approximately 40%. It also has a negative effect on the castability of alloys [6] and the tightness of castings, which is often a criterion for material selection. Porosity in castings is the result of two co-existing processes, i.e. [7, 8]:

- contraction during crystallization, which causes vacuum pressure of the liquid phase in the dendrite growth zone of the solid solution α(Al) – Darcy's law [9],
- segregation of gases in the liquid alloy, which occurs with varying intensity. Trace gaseous elements are less soluble in the solid phase, causing them to micro segregate into the liquid phase. If the gas concentration reaches the solubility limit, which decreases with pressure and temperature, there follows pore nucleation.

Shrinkage porosity is caused by a reduction in volume due to the density difference between the solid and liquid phases. Cast aluminium alloys, when cooled, exhibit volume shrinkage of 5–6% [10]. For pure aluminium, this shrinkage is approximately 7% [11]. During the crystallization front movement, in the α(Al) dendrite growth zone, the alloy is liquid and tends to equalize the change in the volumes of the liquid and solid phases. The growth of dendrites is accompanied by the reduction of the areas between them, which is an obstacle that the liquid alloy must overcome to fill the voids created. After some time, these areas become completely closed, making it impossible to fill them with the liquid phase. In this way, contraction pores are created, which join into groups and, as a result of dendrite arm splitting, take their shape. The size of such a cluster of shrinkage pores may range from several micrometers to several millimetres [12]. The most common causes of shrinkage porosity include:

- stopping feeding the liquid alloy to the casting solidification areas due to the reduction of the space between α(Al) dendrites [13, 14],
- difficulties in feeding the liquid alloy to the casting solidification areas due to the formation of morphologically unfavourable, often initially crystallizing, β-Fe phases (with high iron content), blocking access to the space between α(Al) dendrites [15, 16].

Gas porosity is the result of the decreasing solubility of gases in the alloy, mainly hydrogen and oxygen, as the temperature decreases [17, 18]. When the solubility limit is exceeded, gases are released intensively, resulting in the formation of gas blow holes inside the casting. Gas blow holes growing and flowing to the surface of the alloy increase the surface tension and develop the phase separation surface [19, 20]. In this way, some of the gas pores are trapped in the solidified alloy. This happens, for example, during high-pressure die casting due to the turbulent flow of liquid alloy through the pouring system and the mould cavity, accompanied by eddying and mixing of the liquid alloy streams [21, 22].

FACTORS INFLUENCING POROSITY IN AL-SI ALLOYS

Al-Si alloys with a hypoeutectic composition have a lower tendency to porosity (approx. 0.3–0.6% – measured by the pore volume fraction) than those with a peri-eutectic composition, approx. 2.5–4.8%, what is related to the different range of crystallization ($T_{lik.}$–$T_{sol.}$) [23, 24] and chemical composition [25, 26]. This composition (type of alloy) is often imposed by the customer, so the contractor cannot change it. However, there are some activities that make it possible to reduce the porosity of castings. The most important ones include:

- maintaining correct values of melting parameters of the charge in the melting furnace,
- correct method of alloy modification and refining [27, 28],
- selection of high-pressure die casting parameters [29, 30] in order to reduce the turbulent alloy flow when filling the mould cavity [31, 32].

In addition to the actions that are often imposed by technology (type of alloy, method of refining and modification, type of heat treatment, etc.), the factors that can be controlled by the contractor (foundry), without the customer's consent, are the casting process parameters. Their analysis shows that the main causes of porosity, especially shrinkage porosity, are as follows:

- during the solidification process, the casting cannot be supplemented from the aluminium distributing liquid and forms holes,
- the pouring temperature is too high and the mould gradient distribution is unreasonable,
- the injection ratio is low and the boost pressure is too low,
- the inner gate is thin, the area is too small, and it solidifies prematurely, which is not conducive to pressure transmission and liquid metal feeding,
- there are hot spots or cross-sections in the casting structure that change drastically,
- the amount of molten metal pouring is too small, the remaining material is too thin, and it cannot be used for feeding.

General trends to reduce the porosity of high-pressure die castings mainly concern activities such as:

- lowering the pouring temperature and reducing the shrinkage,
- optimizing the injection pressure and boosting pressure to improve the compactness,
- modifying the inner gate to make the pressure better, which is conducive to the feeding effect of liquid alloy,
- changing the structure of the castings, eliminating the metal gathering parts, and making the wall thickness as uniform as possible,
- speeding up the cooling of thick parts.

The above-described issues and literature data show that in the case of high-pressure die casting:

- the piston speed in the first phase (V1) should be constant so as not to lead to the turbulence of the liquid alloy and the formation of gas occlusion. This stage aims to bring the liquid alloy into the pouring slot in a manner as stabilized as possible and does not significantly affect the casting porosity. The determined value of V1 is 0.1 $m \times s^{-1}$ [20, 30],
- the piston speed in the second phase (V2) has a significant impact on porosity. On the one hand, it cannot be too small (incomplete filling of the mould cavity - underfills), and on the other hand, it cannot be too large so as not to cause "chips" in the plane of the mould parting line. Moreover, when the speed is too high, it causes excessive wear of the mould [33, 34],
- the piston speed in the third phase (V3) only consists in pressing the casting and does not affect the casting porosity [35, 36],
- an important parameter affecting the porosity of castings is the value of the final pressure increase (PP3) in the pressing phase, which determines the "pushing" of pores into the sprue. When the value is too small, this process does not occur, and when the value is too high, it may also contribute to "chips" and excessive wear of the casting mould,
- the nominal value of the final pressure P3 was set at 30000 kPa.

METHODS FOR ASSESSING CASTING POROSITY

The assessment of porosity of high-pressure die castings made of aluminium alloys is one of the most important criteria determining whether they are approved for use. Porosity control of these elements is required in the acceptance specifications. The most frequently used methods are subjective comparative ones based on the assessment of porosity in castings using the X-ray method (or, less commonly, X-ray tomography) and a standard scale to assign the number of pores revealed to the number of the natural standard. An example of such a porosity assessment method is the ASTM E505 standard for assessing the type and degree of discontinuities, including porosity, occurring in high-pressure die castings made of aluminium alloys. The classification of porosity into permissible or unacceptable according to this standard is characterized by a significant degree of variability in the assessment. The variable nature results from the way the porosity assessment is expressed using conventional formula numbers and not the actual values of the geometric parameters of the microstructure. This methodology of porosity measurement may lead to divergent results in the laboratories of the manufacturer and the recipient of the casting, and thus to misunderstandings between them.

Therefore, in the conducted research, it was decided to use quantitative metallography and image analysis methods [37, 38] to quantitatively assess porosity in castings [39, 40]. Unfortunately, this is a destructive testing method as it requires cutting out samples, making metallographic specimens, recording images with an optical microscope and measuring porosity using quantitative metallography methods together with ImageJ [41]. The obtained results are quantitative and make it possible to draw conclusions about the dependence of the amount and size of porosity on the technological parameters of high-pressure die casting.

REASON FOR UNDERTAKING RESEARCH

Quality control in one of the aluminium alloy pressure foundries revealed an excessive share of defects, mainly related to gas and shrinkage porosity, in a casting that is key to a range of products. This is a casting made of the EN AB-46000 alloy, the correct and incorrect (due to excessive porosity) microstructure of which is shown in Figure 2. This is a typical aluminium alloy with a hypoeutectic composition, from which engine parts are cast under high pressure die-casting.

For pressure-treated products, porosity is the most common criterion for compliance with the customer's specification, and therefore decisive for the sale of the products. The object selected for testing is a typical example of a medium-sized casting (250 by 430 mm, wall thickness from 10 to 12 mm and weight approx. 12 kg), used in the automotive industry as one of the engine parts. The manufacturers, on the one hand, should limit the defects of the produced castings (reduce the share of defective products), and, on the other hand, due to corporate conditions, they cannot directly interfere with the technology and characteristics of the alloy and casting. Such changes require customer's consent and are associated with expensive tests. Therefore, there remain those activities that improve the manufacturer's profitability, are cheap and relatively easy to implement and do not require the recipient's consent. Such activities include, for example, setting the die casting process on a pressure machine. The parameters can be easily changed by observing their impact on the behaviour of the alloy, including porosity. The casting selected for testing was produced on a Bühler Carat 3000 pressure machine with a cold chamber using the parameters shown in Table 1.

AIM AND SCOPE

The aim of the research was to reduce porosity in castings made of EN AB-46000 alloy by selecting those pressure casting parameters that have the greatest influence on it:

a) b) c)

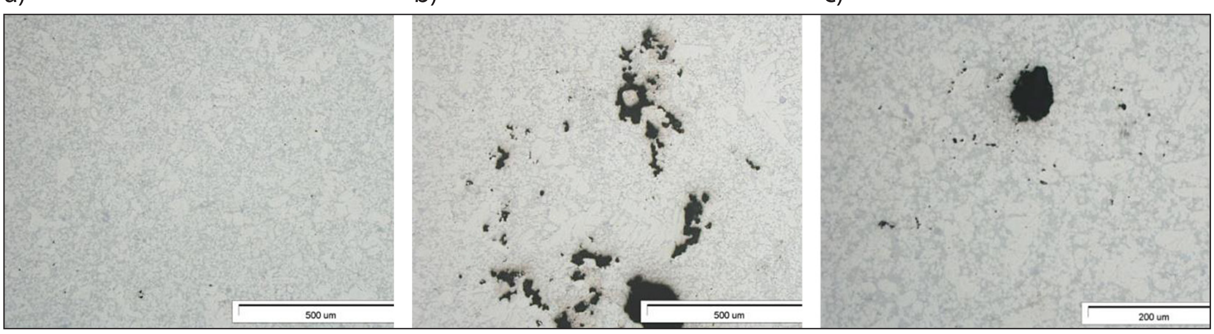

Figure 2. Microstructure of the EN AB-46000 alloy a) low porosity (correct); b) containing shrinkage porosity (incorrect); c) containing gas-type porosity (incorrect)

Table 1. Die-casting parameters of the Bühler Carat 3000 pressure machine and dosing furnace

Number of die-casting parameter	Die-casting process parameter	Unit	Value set
Parameter		Casting machine parameters	
1	Clamping force, Fz	kN	20000–22000
2	Initial piston position	mm	610–620
3	Piston speed in the first phase, V1	$m \times s^{-1}$	0.06–0.30
4	Piston speed in the second phase, V2	$m \times s^{-1}$	3.70
5	Switch-on position of the second phase	mm	380–400
6	Vacuum system activation position	mm	120
7	Vacuum system off position	mm	340–370
8	Vacuum achieved	kPa	5.0–7.0
9	Pressing time, t3	s	4.0–6.0
10	Pressing pressure, P3	kPa	29000–310000
11	Enabling multiplication	mm	480–500
12	Final pressure increase, PP3	$kPa \times s^{-1}$	80000
Parameter		Dosing furnace parameters	
13	Alloy temperature in furnace	°C	700–690
14	Pouring temperature of alloy	°C	680–670

- developing an experiment plan,
- making castings with the parameters presented in the experimental plan,
- testing microstructure in terms of the number and size of pores in castings,
- analysing experimental results.

It was significant that the porosity assessment was performed using actual castings, in places selected by the customer. These are the locations of the castings most susceptible to cracking caused by mechanical loads during use. All the tests were carried out under industrial conditions. It was decided to use quantitative metallography and image analysis methods to assess the porosity of castings. This is a destructive testing method (as opposed to the X-ray method), but the results obtained are quantitative and make it possible to draw conclusions about the dependence of the amount and size of porosity on the technological parameters of high-pressure die casting.

MATERIAL AND METHODOLOGY

The casting selected for testing was made of the EN AB-46000 alloy with the chemical composition shown in Table 2. This alloy was specified by the customer. It has high tensile strength, high wear resistance and very good machinability. It is easy to cast due to its high elastic modulus (75 GPa) and low density (2.76 $kg \times dm^{-3}$). Due to the high strength-to-weight ratio of the EN AB-46000 alloy, castings made of it can have very large dimensions. Prior to the die casting process, the alloy was modified with AlTi5B1 modifier until the titanium content was approximately 0.20% of total weight.

After obtaining the required chemical composition, the EN AB-46000 alloy was refined with argon with the purity of 99.99%. Refining was carried out in three stages:

- in a melting furnace – when melting the charge.

Table 2. Chemical composition of the investigated alloy close to EN AB-46000 alloy

Value						Alloying elements, % of total weight					
	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Pb	Ti	Other
Chemical composition of the investigated alloy											
	9.67	0.94	3.11	0.39	0.41	0.11	0.27	0.89	0.20	0.15	0.11
According to EN 1706											
min.	8.00	0.60	2.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00
max.	11.00	1.10	4.00	0.55	0.55	0.15	0.55	1.20	0.35	0.20	0.25

- in the casting ladle – the so-called ”proper” refining.
- in the dosing furnace in the casting cell – the so-called ”final” refining.

The refining process consisted in blowing the liquid alloy with argon for 8 minutes (flow approx. 15–20 $l\cdot min^{-1}$) at a rotor speed of approx. 300 $rpm\cdot min^{-1}$. The alloy refining process was assessed using the density index. In order to determine the density index, two samples were taken each time: one cooled in air and the other one under reduced pressure. The density index of the alloy taken from the casting ladle was up to 4% and was in line with the customer's requirements.

Finally, the so-called "final refining" process of the alloy in a dosing furnace and a casting cell was carried out. This is to ensure the final cleaning of the alloy just before casting. The liquid alloy is delivered from the dosing furnace through a shot sleeve to a chamber, from where it is pressed into the casting mould. For better air evacuation from the mould cavity, a vacuum system dedicated to the casting machine was used.

To prove the adopted goal, tests were carried out on the influence of selected parameters of the high-pressure die casting process on the porosity of EN AB46000 alloy castings according to the experimental plan presented in Table 3.

The place for collecting samples from the casting was designated by the recipient. Metallographic specimens were made in accordance with the requirements of the Buehler expert system. An Olympus GX-71 optical microscope was used to record images. For each specimen, 20 random fields of view were recorded at 500x magnification. A macro-instruction was developed in ImageJ which included: acquisition of a set of images, normalization, noise removal with a median filter, pore detection using the Otsu binarization method and measurement of the pore volume fraction, the pore volume fraction in the most porous area and the average area of pores.

RESULTS

Porosity of the EN AB46000 alloy castings for variable piston speed in the second phase V2 at constant pressure PP3 (70 000 kPa) are shown in Figure 3.

Porosity of the EN AB46000 alloy castings for variable final pressure increase PP3 at fixed piston speed in the second phase V2 are shown in Figure 4. The results of the quantitative description of the number and size of pores, taking into account the mean value of the pore volume fraction, the pore volume fraction in the most porous area and the average area of pores for the tested castings, as well as the scatter in the results measured by the standard deviation, are presented in Table 4 and Figure 5.

First, the effect of the piston speed in the second casting phase on the porosity was analyzed. The porosity images (Fig. 3) and the porosity measurement results (Table 4 and Fig. 5) indicate that for low speeds V2 = 3.3–3.4 $m\cdot s^{-1}$, regardless of the final pressure increase value PP3, the porosity is very high. This is evidenced by the values of the volume fraction of pores: 1.47–2.94% and the average area of pores: 9.5–29.4 μm^2. The high porosity of the castings for low speeds V2 results from the fact that the liquid alloy fills the gating system too slowly, which causes incomplete filling of the mold cavity. In addition, the shorter solidification time of the

Table 3. Experimental plan for changing the piston speed in the second phase (V2) and the final pressure increase (PP3)

Test number	Speed V2 [1], $m\cdot s^{-1}$	Final pressure increase PP3 [2], $kPa\cdot s^{-1}$
1	3.3	40000 ± 10
2		50000 ± 10
3		60000 ± 10
4		70000 ± 10
5	3.4	40000 ± 10
6		50000 ± 10
7		60000 ± 10
8		70000 ± 10
9	3.5	40000 ± 10
10		50000 ± 10
11		60000 ± 10
12		70000 ± 10
13	3.6	40000 ± 10
14		50000 ± 10
15		60000 ± 10
16		70000 ± 10

Note: [1] V2 values below 3.3 and above 3.6 $m\cdot s^{-1}$ were rejected due to the lack of filling the mould cavity and very high porosity, [2] PP3 values below 4000 and above 7000 $kPa\cdot s^{-1}$ were rejected due to other casting defects (flash, "chips", lack of alloy pressing and very high porosity).

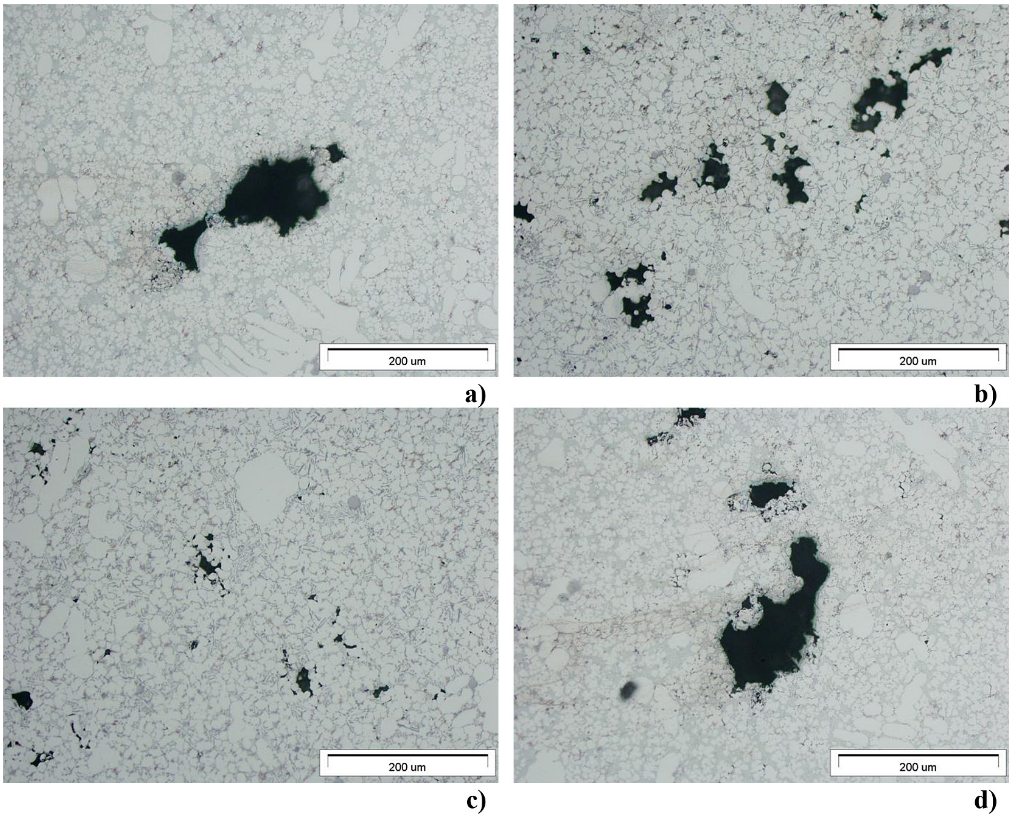

Figure 3. Porosity of the EN AB46000 alloy castings for variable piston speed in the second phase V2 at constant pressure PP3 (70 000 kPa), piston speed V2: a) 3.3 $m \cdot s^{-1}$, b) 3.4 $m \cdot s^{-1}$, c) 3.5 $m \cdot s^{-1}$, d) 3.6 $m \cdot s^{-1}$.

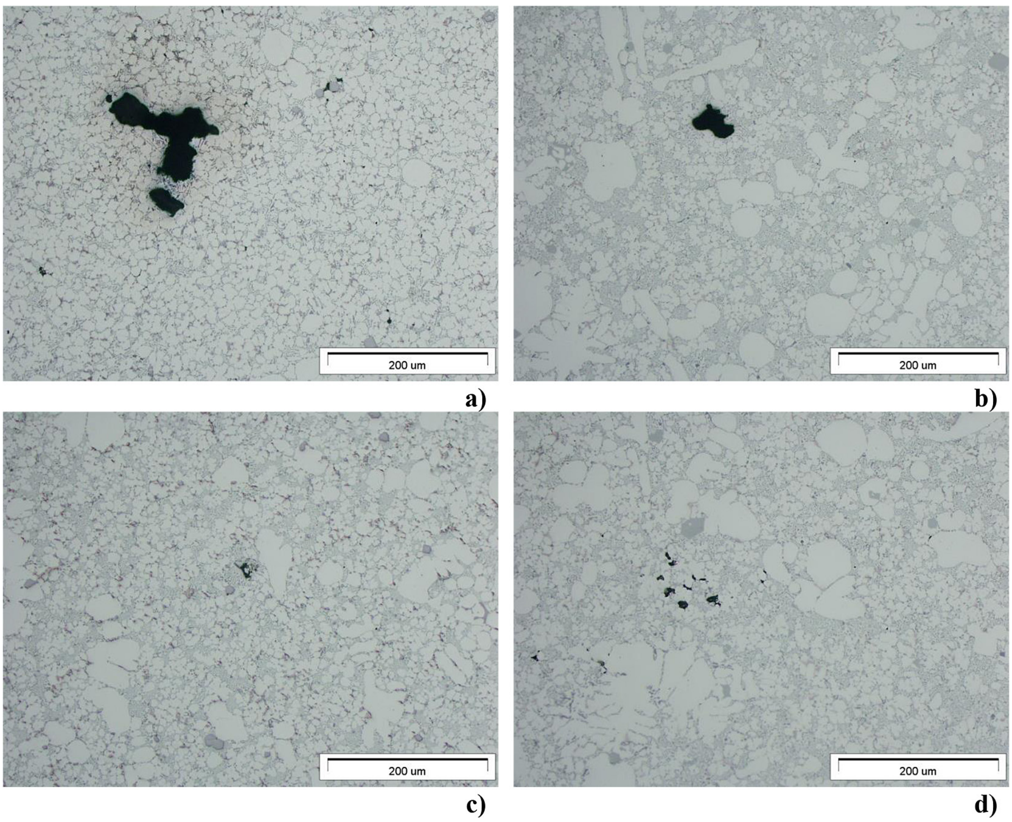

Figure 4. Porosity of the EN AB46000 alloy castings for variable final pressure PP3 at fixed piston speed in the second phase V2 (3.5 $m \cdot s^{-1}$), final pressure PP3: a) 40 000 kPa, b) 50 000 kPa, c) 60 000 kPa, d) 70 000 kPa.

Table 4. Results of quantitative analysis of porosity of EN AB-46000 alloy castings

Test number	Pore volume fraction – mean value, %	Pore volume fraction – the most porous area, %	Standard deviation of volume fraction, %	Average area of pores, μm²	Standard deviation of average area of pores, μm²
1	2.94 ± 0.04	5.78 ± 0.04	0.17	29.4 ± 0.5	2.3
2	2.88 ± 0.03	5.49 ± 0.03	0.15	29.3 ± 0.4	1.9
3	2.62 ± 0.03	5.38 ± 0.03	0.14	28.5 ± 0.5	2.1
4	2.36 ± 0.02	5.11 ± 0.02	0.11	27.7 ± 0.4	2.0
5	2.04 ± 0.02	4.98 ± 0.02	0.08	18.9 ± 0.4	1.9
6	1.96 ± 0.02	4.36 ± 0.02	0.07	16.1 ± 0.3	1.3
7	1.47 ± 0.02	3.03 ± 0.02	0.07	11.3 ± 0.4	1.7
8	1.98 ± 0.02	3.26 ± 0.02	0.07	9.5 ± 0.1	0.5
9	0.53 ± 0.02	1.16 ± 0.02	0.06	8.7 ± 0.2	0.9
10	0.29 ± 0.02	0.63 ± 0.02	0.06	5.2 ± 0.3	1.2
11	0.18 ± 0.01	0.58 ± 0.01	0.05	3.1 ± 0.2	0.8
12	0.26 ± 0.02	0.68 ± 0.02	0.07	5.5 ± 0.1	0.6
13	0.54 ± 0.02	0.88 ± 0.02	0.08	9.7 ± 0.2	1.1
14	1.15 ± 0.02	1.93 ± 0.02	0.08	11.9 ± 0.8	3.5
15	3.04 ± 0.02	3.04 ± 0.02	0.09	16.1 ± 1.0	4.6
16	4.21 ± 0.02	4.21 ± 0.02	0.09	19.2 ± 1.2	5.3

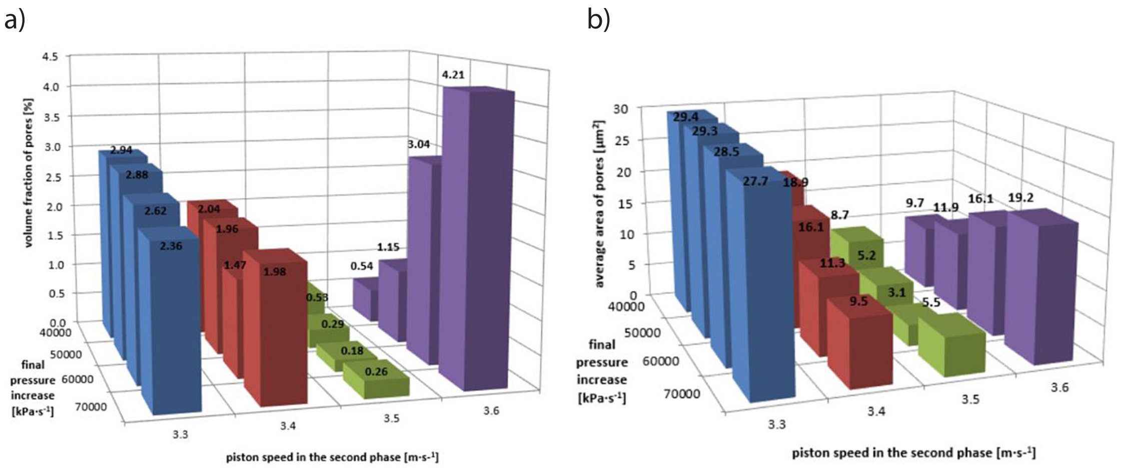

Figure 5. Influence of piston speed in the second phase V2 and final pressure PP3: a) on volume fraction of pores, b) average area of pores

alloy in the mold cavity prevents the alloy from being fed in the third phase.

In turn, for high speed V2 = 3.6 m·s⁻¹, regardless of the final pressure increase value PP3, the castings also have high porosity (Figs. 3 and 5, Table 4). This is evidenced by the values of the volume fraction of pores: 0.54–4.21% and the average area of pores: 9.7–19.2 μm². Too high a speed in the second casting phase causes excessive turbulence of the alloy in the mold cavity, which contributes to the increase in shrinkage porosity. In addition, the excessive work of the squeeze cylinders causes different cooling rates in the casting and increases the heterogeneity of the casting defects (porosity).

In terms of reducing the porosity of castings, the best piston speed value in the second phase of the process is V2 = 3.5 m·s⁻¹. This is evidenced by the values of the volume fraction of pores: 0.18–0.53% and the average area of pores: 3.1–8.7 μm².

Secondly, after setting the piston speed in the second phase V2 = 3.5 m·s⁻¹, the effect of the final pressure increase PP3 on the porosity was analyzed. When the final pressure increase PP3 is too small (40 000–50 000 kPa·s⁻¹), the porosity of the castings is 0.53% and 0.29%, respectively, and the size of the pores is 8.7 and 5.5 μm², respectively (Figs. 4 and 5, Table 4). Too low a final pressure value causes part of the alloy to solidify

Table 5. Comparison of high-pressure die casting parameters before and after introducing changes.

High-pressure die casting process parameter	Value before change	Value after change	Unit
Speed of the second phase, V2	3.70	3.50	$m \times s^{-1}$
Switch-on position of the second phase	380–400	380–400	mm
Pressing time, t3	4.0–6.0	4.0–6.0	s
Pressing pressure, P3	29000–310000	30000	kPa
Final pressure increase, PP3	80000	60000	$kPa \times s^{-1}$
Final pressure, P3	30000	30000	kPa

in the gating system and in the mold cavity and there is no possibility of pushing this part of the alloy into the overflow, which consequently increases the porosity. In addition, the premature transition of the alloy to a semi-solid state in the overflow area makes it impossible to squeeze in the third phase, and consequently increases the porosity of the casting.

Too high a final pressure increase PP3 (over 70,000 $kPa \cdot s^{-1}$) also results in greater porosity of the castings. The volume fraction of pores is 0.26%, and their size is 5.5 μm^2. The reason for this is the high pressure exerted on the gas bubbles present in the alloy, which increases porosity, especially of the gas-type.

In terms of reducing the porosity of castings, the best value for the final pressure increase is PP3 = 60,000 $kPa \cdot s^{-1}$. This is evidenced by the values of the area fraction of pores: 0.18% and the average area of pores: 3.1 μm^2.

The analysis of the conducted research indicates that the high-pressure die casting parameters that have the greatest impact on the change in the microstructure of the EN AB-46000 alloy in terms of porosity are the piston speed in the second phase of the casting process (V2) and the final pressure increase in the pressing phase (PP3). Changing the piston speed in the second phase of the casting process (V2) reduces the porosity of the castings from the range of 0.54–4.21% to the range of 0.18–0.53%, whereas at the optimal value of V2 (3.5 $m \cdot s^{-1}$) changing the increase in the final pressure in the pressing phase (PP3) further reduces porosity from 0.26% to 0.18%. Identification of defects in the tested casting showed that the piston speed in the second phase of the casting process was too high. This resulted in the so-called "chips" of the casting in the plane of the mould parting line, increasing material consumption and causing greater wear of trimming tools. The final pressure increase was also found to be too high, which resulted in excessive wear of the casting mould.

Based on the tests performed in accordance with the experimental plan (Table 3), metallographic tests (Fig. 3–4) and the results of porosity measurements (Table 4), it was found that the best parameters of the high-pressure die casting process of the selected EN AB-46000 alloy casting in terms of reducing porosity are:

- piston speed in the second phase of the casting process: V2 = 3.5 $m \cdot s^{-1}$;
- final pressure increase in the pressing phase PP3 = 60 000 $kPa \cdot s^{-1}$ at final pressure P3=30000 kPa.

As a result of optimizing the high-pressure die casting parameters, the porosity of castings, measured by the pore volume fraction, was reduced from 4.21% to 0.18%. A comparison of the pressure casting parameters before and after the introduced changes to the casting parameters on the pressure machine is presented in Table 5.

CONCLUSIONS

The parameters of the first phase of casting, including the constant speed of the piston movement, do not significantly affect the porosity of castings made of AB-46000 alloy.

It is necessary to strive for optimal reduction of the piston speed in the second phase of casting. This leads to smoother introduction of the liquid alloy into the mold cavity, and thus reduces cavitation and porosity of die castings. The most suitable piston speed in the second phase of the casting process in terms of reducing porosity is V2 = 3.50 $m \times s^{-1}$.

For large casting machines (from about 20000 to 30000 kN), the final pressure increment in the feeding phase PP3 should be about 60000 kPa/s at a final pressure of P3 = 30000 kPa. Such a value of the PP3 parameter causes less wear of the injection mold, cores and injection system, and reduces the so-called "sprues" on the edges of the casting.

Reducing the speed V2 from 3.70 to 3.50 m×s^{-1} and the final pressure increase PP3 from 80000 to 60000 kPa×s^{-1}, with other parameters remaining unchanged, results in obtaining the lowest porosity of the casting – the volume fraction of pores is reduced from 4.21% to 0.18%.

Reducing the speed of the injection piston in the second phase of casting resulted in lower porosity due to: smoother introduction of the liquid alloy into the mould cavity – reduced turbulence and limited cavitation, i.e. closing the air through the separation of material streams caused by less turbulent flow of the alloy in the mould.

An additional benefit of reducing the V2 speed is:
- lower wear of the injection mould,
- lower core wear due to the lack of the so-called “overheating”,
- lower wear of the injection system (chamber, piston, rings),
- lack of the so-called “chips” on the casting edges,
- reduced number of defective castings.

The benefits of reducing the PP3 final pressure increase are:
- reduced number of deformations of castings, especially large-size castings with thin walls,
- easier pushing the casting out of the injection mould (using less force when pushing it out),
- more stable operation of the pressure machine,
- more repeatable action of squeezing cylinders (lower back pressure);when the final pressure increase PP3 was too small, below 60 000 kPa×s^{-1}, the material transformed into the solid phase, which made pressing in the third phase impossible.

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