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Influence of the Selected Factors on the Ceramic Moulds Permeability Determined by the New Method

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Abstract

Ceramic moulds in the investment casting technology are made by depositing on the wax pattern subsequent layers of a liquid ceramic mass together with a granular matrix. A quality of castings depends on building of individual layers. The results of the ceramic moulds permeability obtained by means of the newly developed measuring method are presented in the hereby paper. Due to the applied solution it is possible to perform measurements also for the first layers which have the decisive influence on a permeability of the whole multilayer ceramic mould. Investigations of the influence of the matrix grain size and annealing temperature on the permeability of ceramic moulds were carried out.

Keywords: Innovative foundry technologies and materials, Investment casting technology, Permeability, Ceramic moulds, New measurement methodology

1. Introduction

Manufacturing ceramic moulds for investment castings by means of the investment casting method is based on a cyclic process of immersing a wax pattern in a liquid ceramic mass, sprinkling it with coarse-grained ceramic material and removing of wax by melting in an autoclave, followed by drying a multilayer mould. The next stage constitutes a mould annealing process in a temperature range from 400 to 1100^{o}C, carried out until the sufficient mechanical strength of a mould is achieved. The final stage is the process of pouring the ready mould with liquid metal and cleaning the obtained casting [1, 6, 8].

Individual layers, characterised by relevant properties, of a ceramic mould deposited on the wax pattern decide on the quality of castings. One of the main parameters of this technology is the permeability, which decides on the ability to carry away gases from the mould cavity during its pouring with liquid metal. This property decides on the quality of the obtained casting surface, shape reproduction and the gaseous origin defects occurrence.

Each layer is built of different highly-refractory materials, starting from the finest and ending with the most coarse-grained. Generally, it can be stated that a structure of a ceramic mould is - to a high degree - random and heterogeneous. Properties of a liquid moulding sand have a significant influence on the morphology of the formed ceramic moulds (CMC) [4].

Such method of making moulds causes obtaining a porous structure, where spaces in between grains are pores. Matrix grains glued by a moulding sand form a porous body with a lattice of capillaries of irregular cross-sections and shapes. A ceramic mould is required to have the proper strength but on the other hand to have the permeability. Therefore, the first layer, called the near pattern layer, should be characterised by better technological properties and lower permeability than the remaining layers. Such system protects against burning-on as well as against the penetration of gases, formed in the mould, into liquid metal. The permeability in the properly prepared mould should be increasing as a distance between the mould and liquid metal increases. Such system occurs in the mould which is sprinkled with the refractory grained material [11].

Several papers [2, 3, 5, 7, 10, 12-15] presenting investigations of the permeability of multilayer ceramic moulds can be found in the domestic and foreign technical literature. However, in contrast to classic moulding sands, in permeability tests of ceramic moulds none generally applied measurement method was developed. In the investment casting method a permeability is not often determined. This is caused by manufacturing not standard shaped elements (shell moulds).

The results [9] of the permeability investigations obtained by means of the new measuring method are presented in paper [9]. Investigations concerned the influence of the solid phase in the liquid ceramic moulding sand (Ludox AM and SK) on the permeability of the multilayer ceramic mould. The newly developed method allows to determine the ability of the first layers to carry away gases, which decides on the multilayer mould permeability.

2. Description of the measuring equipment

The measuring method developed in the Laboratory of Foundry Moulds Technology of the Faculty of Foundry Engineering was applied in investigations. The main aim of the study was working out a fast and, at the same time, easy measuring method of the ceramic moulds permeability, which will allow to perform measurements on simple samples and universal laboratory equipment.

For the permeability assessment the apparatus type LPiR1 was used. This apparatus together with the new tester is presented in Figure 1.

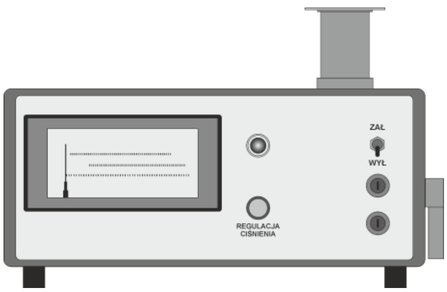


Fig. 1. Apparatus for the permeability assessment, type LPiR1, with the mounted tester

The tester with the tested flat sample is mounted in the place of the measuring tube in the apparatus. The tester consists of a plastic connector of a diameter: d = 50 mm and of a tested sample in a plate shape glued to it. The sample is glued to a plastic connector by means of silicone, which aim is to seal the connection. A plastic measuring tube, used as a connection in an applied hydraulics can be of a single or multiple use.

3. Preparation of samples

The matrix for preparing samples was designed and made. When this matrix was poured with wax the shape of plate of dimensions: 90x70x5 mm was obtained (Fig. 2).

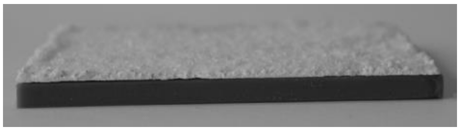


Fig. 2. Wax plate with a coating deposited on two sides

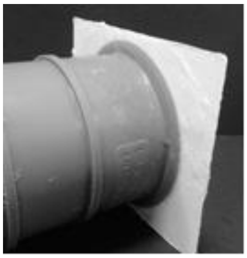
Samples for measurements were prepared in the following way: on degreased wax patterns three layers of ceramic moulding sand were deposited. On each layer a highly refractory material characterised by the same grain size d_a (Mullit I or Mullit II or Mullit III) was deposited. Individual matrix grain sizes are presented in Table 1. After depositing of all layers and drying moulds a wax was removed from them. Next, moulds were again dried and subjected to heat treatments.

Table 1.
Grain sizes of the matrix applied at making ceramic moulds

Kind of the applied matrix	d_a [µm]
Mullit I	108,51
Mullit II	326,46
Mullit III	624,99
d_a – arithmetical average	

Tests were carried out for ceramic moulds annealed in 8-hour cycles at temperatures: 400, 700, 900 and 1100°C.

The next stage constituted joining, by means of a silicone, the ceramic mould with the plastic pipe connector of a diameter = 50 mm (Fig. 3). Probes with the ceramic mould, prepared in such way, were assembled in the apparatus for the permeability assessing and the measurement was carried out.



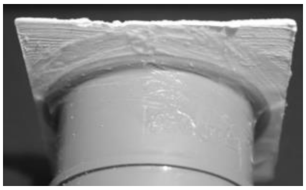


Fig. 3. Probes with a ceramic mould prepared for the permeability measurement

The aim of the hereby study was the determination of the annealing temperature and matrix grains sizes influence on the ceramic moulds permeability.

4. Results of permeability tests

In relation to recommendations of reducing or eliminating alcoholic binders and substituting them by binders of new generation based on colloidal silica, applications of aqueous binding agents started since they are environment and workers friendly and limit the emission of volatile organic substances. The aqueous binder, based on colloidal silica, of the trade name Ludox AM was applied in this study. More and more fractions of inorganic silica binders based on aqueous solution of silicic acid sol (colloidal silica) are currently observed. However, the application of these binders causes several difficulties related to making moulds. These problems concern: longer drying times, lower permeability, strength and worse wettability of the wax pattern surface by a liquid ceramic moulding sand.

During making moulds quite often their damage occurs in the moment of melting a wax pattern and even after its annealing when the sample is assembled in the device for measuring permeability. This is closely related to a brittleness a negative feature of ceramic materials.

Therefore the developed method of gluing flat ceramic moulds to a probe, limits a tendency of breaking even of thin (of three layers: $g \cong 1.5$ mm) moulds. This limitation is one of the most important good points of this method.

For the determination of the permeability value of 1 mm of the ceramic mould thickness the following equation was used:

$$P = P_{reading} \cdot \left(\frac{d}{50} \right) \qquad (1)$$

Overall moulds permeability depends on the size, described in equation No. 2:

$$P_{reading} = \frac{V \cdot l}{F \cdot t \cdot p} \qquad (2)$$

where:

P $_{reading}$ – value read from the apparatus,

V – air volume passing through the sample (200 cm^3), m^3 (cm^3),

l – sample height (5 cm), m (cm),

F - surface of the sample cross-section (19,6 cm^2), m^2 (cm^2),

t – time, in which 200 cm^3 of air will pass through the sample s (min),

p – air pressure in the space under the sample N/m^2, Pa, (G/cm^2),

d – ceramic mould thickness (mm).

In practice, the reading - from the apparatus measuring the permeability - is multiplied by proportions of the ceramic sample thickness to the height of the standardized sample (50 mm). This significantly facilitates performing the measurement and permeability calculations.

4.1. Assessment of the annealing temperature and matrix grain size influence on the moulds permeability

The influence of the annealing temperature of ceramic moulds on their permeability is presented in the hereby paper. Heat treatments of moulds were performed for eight hours at temperatures: 400, 700, 900 and 1100°C. The influence of the matrix grains size on the permeability of ceramic moulds was also determined.

The influence of the grain size on the permeability of ceramic moulds made on the basis of aqueous binder such as Ludox AM, is shown in Figure 4. In order to determine the influence of the matrix grains size of d_a = 108.51 μm (Mullit I) used for sprinkling individual layers of ceramic mould Mullit I was supposed to be deposited on each layer. The same operation was repeated for each matrix. Ready moulds were subjected to 8-hours long heat treatment at a temperature range from 400 do 1100°C (400°C- for 2h, 700°C- for 2h, 900°C- for 2h, 1100°C- for 2h).

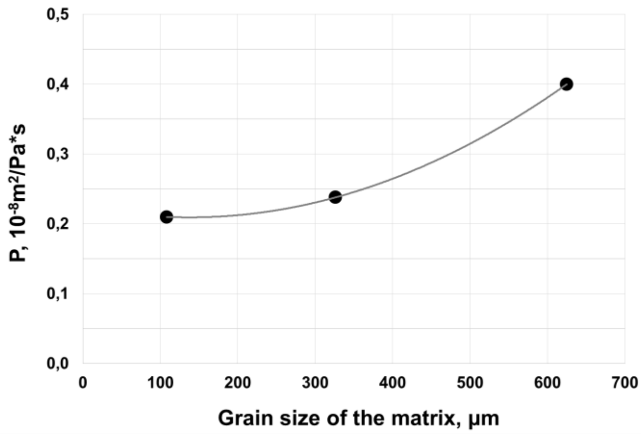


Fig. 4. Influence of grain sizes on the permeability of ceramic moulds annealed at temperatures: 400-1100°C

From the performed investigations it results that together with a matrix grain size increase the ceramic moulds permeability also increases (moulds are based on grains of one size: Mullit I or Mullit II or Mullit III) (Fig. 4). The highest permeability values were obtained solely for moulds made of the same matrix, characterised by the largest grains.

The permeability pathway of the ceramic moulds annealed for 8 hours at a temperature of 1100°C, built of different matrix grains (Mullit I - the first layer, Mullit II - the second layer, Mullit III - the third layer) (Fig. 5) is very similar to the one obtained for moulds built of the matrix of the largest grains (Fig. 8). This indicates that the decisive influence on permeability has the first layer made of the matrix of the finest grains. Subsequently deposited layers are characterised by large enough ability to gas flow that their deposition does not change the total permeability of the ready ceramic mould.

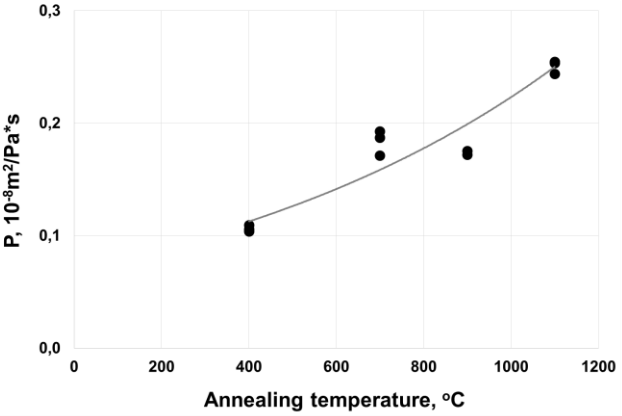


Fig. 5. Influence of the annealing temperature on the permeability of the ceramic mould built of three layers, where on each layer different matrix was deposited: on the first - Mullit I, on the second - Mullit II and on the third - Mullit III

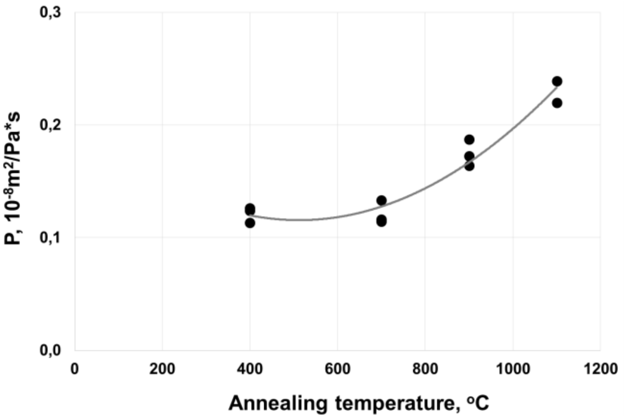


Fig. 6. Influence of the annealing temperature on the permeability of the ceramic moulds made on the matrix: Mullit I (d_a=108.51 μm)

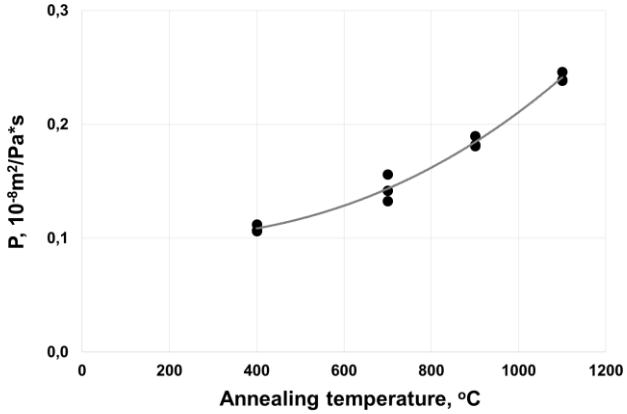


Fig. 7. Influence of the annealing temperature on the permeability of the ceramic moulds made on the matrix: Mullit II (d_a=326.46 μm)

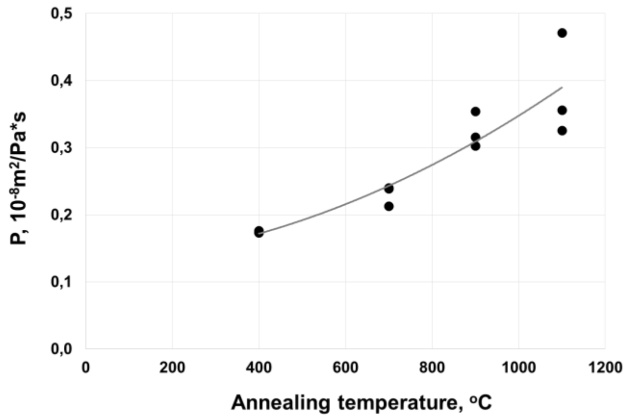


Fig. 8. Influence of the annealing temperature on the permeability of the ceramic moulds made on the matrix: Mullit III (d_a=624.99 μm)

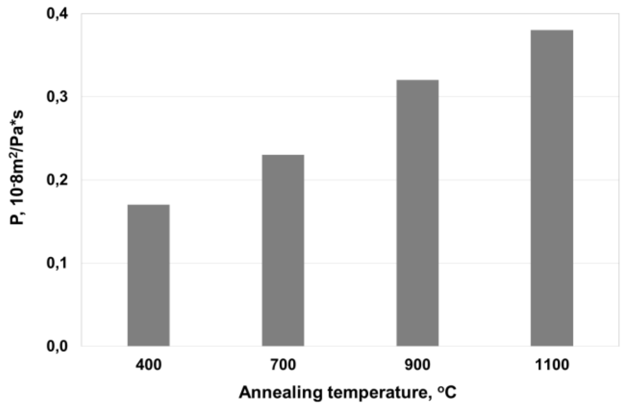


Fig. 9. Influence of the annealing temperature on the permeability of the ceramic moulds made on the basis of Ludox AM binder with Mullit III matrix

It results from the performed investigations that the annealing temperature has an influence on the permeability of multilayer ceramic moulds (Figures 5-8). The highest ability to carry away of gases characterises moulds annealed at a temperature of 1100^{o}C in 8-hours cycle, and the maximum value of their permeability equals to app. 0.38 [$10^{-8}m^2/Pa*s$], while the lowest ability moulds annealed at a temperature of 400^{o}C their permeability equals to app. 0.15 [$10^{-8}m^2/Pa*s$] (Fig. 9).

The annealing process leads to increasing the moulds dimensions (volume) and to increasing their porosity. The side effect of this process is the observed permeability increase.

The microscopic photographs of the flat surface of the ceramic mould applied for the permeability testing are presented in Figure 10 (mould after drying) and in Figure 11 (mould after annealing). Figure 10 presents the ceramic mould after melting (dried) where the wax remains are seen, while Figure 11 presents the burned mould from which wax was completely removed.

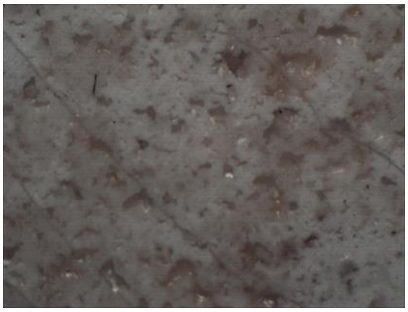


Fig. 10. Ceramic mould after melting of wax and drying (magnification 30x)

Fig. 11. Ceramic mould after 8-hour annealing at a temperature of 1100^{o}C (magnification 30x)

At high temperatures a sintering effect occurs as well as a removal of the wax remains and bound water, thus clearing capillaries, which - the most probably - is the reason of obtaining higher permeability values.

5. Conclusions

The new measuring method was applied for investigating the permeability of ceramic moulds. The grain size of the matrix applied for individual layers influences the ability to carry away of gases only in case when the whole mould is made of the same matrix. In such case the larger matrix grain size the higher permeability is obtained.

The performed investigations indicate that the heat treatment process influences the permeability of multilayer ceramic moulds. The application of a high annealing temperature (app. 1100^{o}C) of moulds leads to achieving higher permeability values.

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