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New Investigation Method of the Permeability of Ceramic Moulds Applied in the Investment Casting Technology

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Abstract

The new investigation method of a permeability of ceramic moulds applied in the investment casting technology, is presented in the paper. Some concepts of performing permeability measurements are shown. Investigations in which the influence of the solid phase fraction in the liquid ceramic moulding sand (LCMS) on a permeability of a multi-layer ceramic mould were performed and discussed. The permeability was estimated during two the most important stages of the technological process: in the first – after wax melting and in the second – after mould annealing. Also an influence of the matrix grain sizes (material for sprinkling) on a ceramic mould permeability was estimated.

Key words: Innovative Foundry Technologies and Materials, Investment casting technology, Permeability, Ceramic moulds

1. Introduction

Ceramic moulds made in the investment casting technology have generally heterogeneous built. Production of ceramic moulds for investment casting by means of a lost foam method consists in a cyclic process of immersing a wax model in a liquid ceramic moulding sand and powdering it with coarse-grained ceramic materials (matrix), up to obtaining the proper shell thickness [4, 6, 8]. One of the main problems, essentially deciding on the casting quality obtained in the investment technology, is covering a model with several layers of a ceramic moulding sand of exactly determined properties. A permeability of ceramic moulds is one of more important parameters, deciding on a reproduction of mould shapes and surface quality of produced castings.

Simultaneously, it is an ability to carry away gases from a mould cavity when it is poured with liquid metal. A permeability determination of moulding sands for making moulds and cores is done on the standardized shaped rolls, according to the rules assumed for classic moulding sands. A permeability of moulding sands used in investment casting technology is not often determined, due to a preparation of not standardized shaped elements (shell moulds) [9]. Multi-layer shell moulds are used in the investment casting technology. They have a granular (porous) structure, where spaces between grains are pores. Sand grains agglutinated by ceramic sands form a porous body with a network of capillaries of irregular cross-sections and shapes.

Materials, of which individual layers are formed, decide on a permeability of moulds and quality of produced castings.

A refractory coating is required - from one side - to be of a proper strength and - from the other - to be permeable.

Therefore the first layer, called near-model layer, should be characterised by better technological properties and by a worse permeability than the remaining layers. Such system protects against a burn-on and against a penetration of gases, formed in a mould, into liquid metal. A permeability in the properly made mould should be increasing as a distance from the contact with liquid metal increases. Such system occurs in the mould which is powdered by refractory granular materials [9].

In contrast to classic moulding sands, in testing the ceramic mould layers permeability, none generally applied measuring method was developed. There are several works presenting a permeability of multi-layer ceramic coatings where models of foamed polystyrene are used, either in a sphere form (of a diameter 50 mm) or a cube with rounded edges (Fig. 1 and 2) [11, 12].

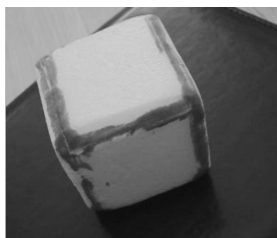


Fig. 1. Polystyrene model in a cube form, with rounded edges [13]



Fig. 2. Ceramic mould used for the permeability testing [13]

In turn, there are much less papers presenting the permeability results of ceramic moulds made by the investment casting method [1, 2, 3, 5, 7, 13]. Disks, spheres and cylinders are the most often used as wax models (Fig. 3). They are also used in the permeability assessment.

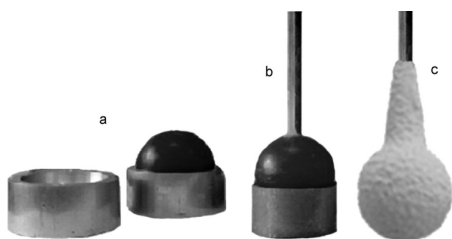


Fig. 3. Schematic presentation of making the mould for the permeability determination: a) Aluminium mould together with the sphere wax model, b) Wax sphere model with the quartz tube (Vycor), c) Test samples after depositing the ceramic coating and sprinkling with powdered material [2]

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 4.

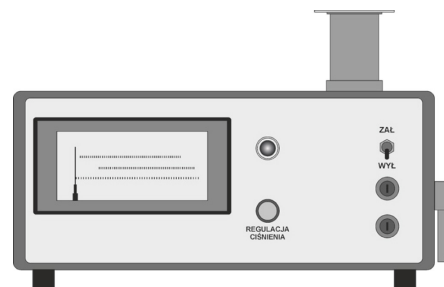


Fig. 4. Apparatus for the permeability assessment, type LPiR1, with the mounted tester

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, which after being poured with wax, gave the plate shape of dimensions 90x70x5 mm (Fig. 5) was designed and made.

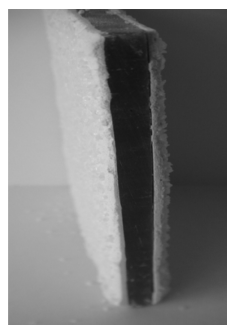


Fig. 5. Wax plate with the deposited ceramic coating

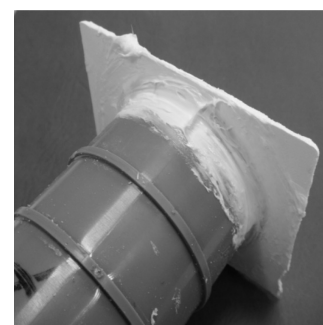


Fig. 6. Tester with the ceramic mould prepared for permeability measurements

Investigations were performed for green sand moulds (after wax melting) and for moulds after the heat treatment (after annealing). Measurements were carried out in some stages. Three layers of ceramic moulding sand with a matrix were

deposited on degreased wax models. The sample for the permeability testing of ceramic moulds is shown in Figure 5. The sample was designed in such a way as two identical plates (samples) would be formed in a moment of wax melting. Due to such solution, two independent measurements can be performed for the same mould, prepared in one cycle.

The permeability investigations were carried out for ceramic moulds (of three layers) made of:

- Ceramic moulding sand (on the basis of binding agents Ludox AM and SK) of three various solid phase contents (67, 68 and 69%) for moulds:
 - of green sand and annealed, where individual layers were built of ceramic sands and matrix of the smallest grain size (Mullit I),
- Ceramic moulding sand (on the basis of binding agents Ludox AM and SK) of three various solid phase contents (67, 68 and 69%) for moulds:
 - of green sand and annealed, built of layers with matrices of various grain sizes: 1st layer - Mullit I, 2nd layer - Mullit II, 3rd layer - Mullit III.

Grain sizes of the applied matrix are shown in Table 1.

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	

The next step constituted joining of the ceramic mould, by means of silicone, with the plastic connector of a diameter: $d = 50$ mm (Fig. 6). Testers prepared in such a way together with the ceramic mould were mounted in the apparatus for the permeability assessment and the measurement was taken.

4. The obtained permeability results

Hydrous binding agents on the basis of colloidal silica of the trade name Ludox AM and SK were applied in tests. Higher and higher fractions of inorganic silica binders (colloidal silica) are currently applied in the world. These binders create technological difficulties due to a bad wettability of a model system surface by liquid ceramic moulding sands.

Ceramic moulds have a layered structure and are mainly made of ceramic materials. These materials belong to brittle materials, which is caused by several inner and outer factors, such as: microstructure, surface state, grain size, sample size and shape, etc. This property is highly unfavourable and brings a lot of problems. Brittleness of materials causes that during making moulds they are often damaged when the wax model is melted and even after their annealing when samples are mounted for the measurements. The developed methodology of gluing flat moulds to the tester, limits a tendency of braking - even thin (of three layers) - moulds and this constitutes one of the most important advantages of the method.

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

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

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

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

where:

- $P_{reading}$ – value read from the apparatus,
- V – air volume passing through the sample (200cm^3 , $\text{m}^3(\text{cm}^3)$),
- l – sample height (5cm), m (cm),
- F – surface of the sample cross-section ($19,6\text{cm}^2$, $\text{m}^2(\text{cm}^2)$),
- 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 ($1\text{ mm water column } \text{H}_2\text{O} = 9,80665$), 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.

Ceramic moulds should be characterised by several specific properties, such as: proper refractoriness, no reactivity with a metal material, small thermal expansion, stability of properties, easiness of cleaning, permeability and strength during being poured with liquid metal.

4.1. Assessment of the influence of the solid phase content on the ceramic moulds permeability

The results of the moulds permeability after the first stage of making the ceramic shell (after wax melting) and after the second stage (after the heat treatment) are presented in the paper. The main purpose of investigations was to determine what influence has the solid phase percentage fraction in LCMS and what influence has the grain size of the matrix applied as matrix.

An influence of the solid phase content being: 67, 68, 69% of aluminium oxide, on the permeability of ceramic moulds made of aqueous binding agent (Ludox AM) is presented in Figure 7. Moulds were made in several cycles: deposition of the ceramic sand layer and powdering the mould surface with the finest matrix I. Figure 8 also presents the influence of the solid phase content, for the same binding agent, but for matrices of various grain sizes applied for successive layers. Matrix I was applied for the first layer, matrix II for the second layer and matrix III for the third layer. Samples were subjected to the permeability assessment

directly after the wax melting as well as after the 8-hour annealing cycle in the temperature range from 400 to 1100°C (400°C- 2h, 700°C- 2h, 900°C-2h, 1100°C- 2h).

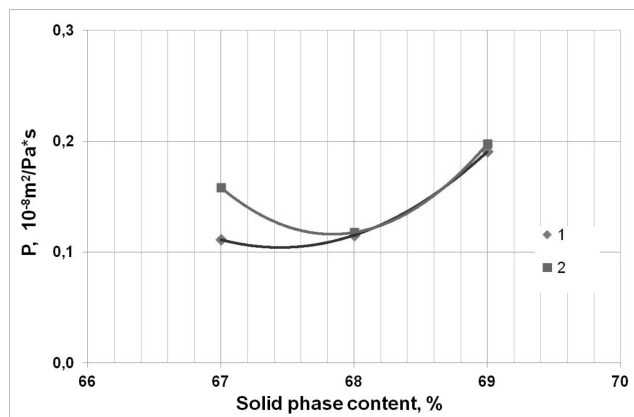


Fig. 7. Influence of the solid phase content in LCMS on the permeability of moulds with Ludox AM and matrix I for moulds: 1- after wax melting; 2- annealed in temperatures: 400-1100°C

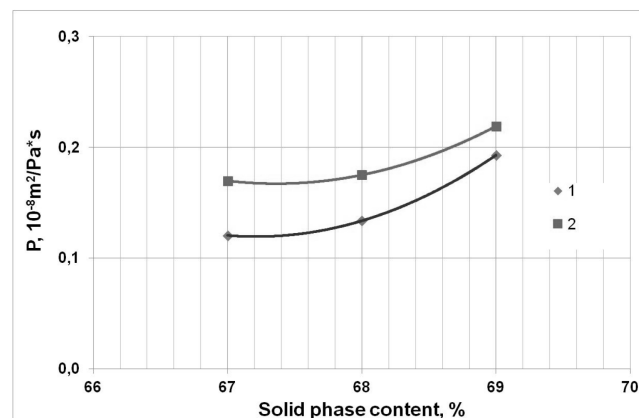


Fig. 8. Influence of the solid phase content in LCMS on the permeability of moulds with Ludox AM and I, II and III matrices for moulds: 1- after wax melting, 2- annealed in temperatures: 400-1100°C

The analysis of the obtained results indicated that an increase of the solid phase content in LCMS causes the higher permeability both for green sand and annealed moulds. Ceramic moulds subjected to the 8-hour thermal treatment are characterised by the higher permeability that green sand moulds.

The same investigations were performed for the ceramic moulding sand prepared with the binding agent Ludox SK. The results of these tests are presented in Figure 9 and 10.

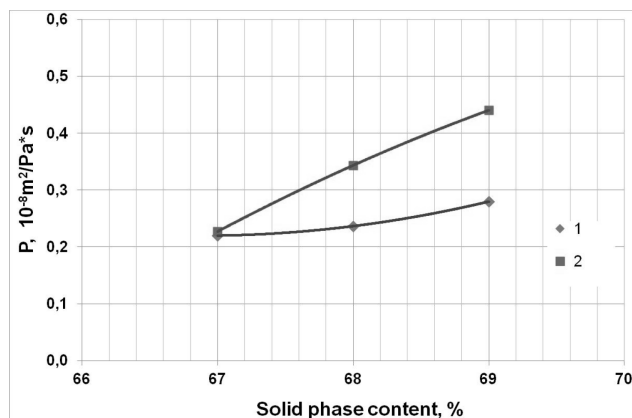


Fig. 9. Influence of the solid phase content in LCMS on the permeability of moulds with Ludox SK and matrix I for moulds: 1- after wax melting; 2- annealed in temperatures: 400-1100°C

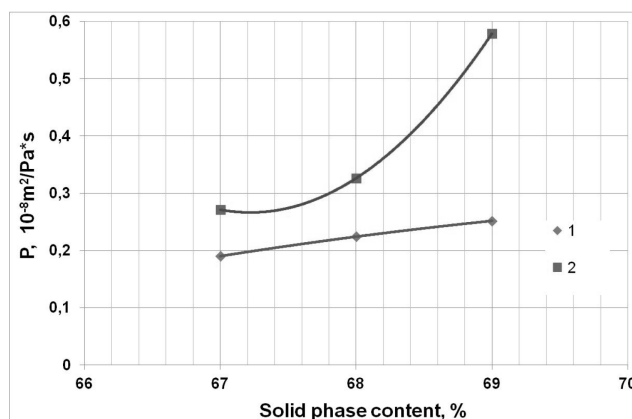


Fig. 10. Influence of the solid phase content in LCMS on the permeability of moulds with Ludox SK and I, II and III matrices for moulds: 1- after wax melting, 2- annealed in temperatures: 400-1100°C

In an analogous way as in the previous case, regardless of various matrix grain sizes, very similar dependencies are obtained. The first layer, in both cases, were prepared on the same matrix (Mullit I). This indicates that the first layer decides on the permeability of the multi-layer ceramic mould. Successively deposited coatings are characterized by as much high ability for a gas passage that they do not influence the total permeability of the ready ceramic shell.

Ceramic moulds made with Ludox SK after the heat treatment in temperatures from 400 to 1100°C, are characterised by a higher ability to carry away gases. The most probably this is due to the composition of the binding agent, which is modified by a polymer. Polymers are stable up to a temperature of 200°C. Above this temperature, their partial decomposition occurs. Organic compounds undergo burning, forming empty intergranular spaces. This effect causes that multi-layer ceramic moulds are characterized by a higher porosity and permeability.

Conclusions

Both domestic and foreign references provide various methods of investigations of the ceramic moulds permeability. Since none of the methods is standardised, the main purpose of this study was the development of the new measuring method, simple and user friendly.

The results obtained by means of the new method are similar to the results obtained by the authors, who were applying much more complicated methods.

The ability of moulds to carry away gases was determined just after wax melting as well as after annealing in a temperature range: 400-1100°C. Increased content of the solid phase (67, 68, 69%) causes the permeability increase. Ceramic moulds made with Ludox SK after the heat treatment in temperatures from 400 to 1100°C, are characterised by a higher ability to carry away gases, due to the modification by means of the introduced polymer. In case of moulding sands prepared on the basis of binding agents Ludox AM and SK at applying various matrix grain sizes very similar dependencies occur. In both cases the first layer of the mould decides on the ceramic shell permeability.

The developed method of the ceramic moulds permeability investigations, as one of a few, allows to determine the first layers permeability, which decide on the multi-layer mould permeability. In other methods the measurement becomes possible when the number of coatings is not less than five. Thick layers are necessary for providing to samples the structural strength necessary for taking the measurement.

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Nowa metoda oceny przepuszczalności form ceramicznych stosowanych w technologii wytapianych modeli

Streszczenie

W pracy przedstawiono nową metodę badań przepuszczalności form ceramicznych stosowanych w technologii wytapianych modeli. Zaprezentowano koncepcje prowadzenia pomiarów przepuszczalności form ceramicznych. Wykonano badania, w których określono wpływ udziału fazy stałej w ciekłej masie ceramicznej (CMC) na przepuszczalność wielowarstwowej formy ceramicznej. Oceniono przepuszczalność w dwóch najważniejszych etapach procesu technologicznego: w pierwszym - po wytopienia wosku oraz w drugim - po wyżarzeniu formy. Oceniono również wpływ wielkości ziarna osnowy, zwanej potocznie „obsypką” (materiałem do obsypywania), na przepuszczalność formy ceramicznej.

Słowa kluczowe: Innowacyjne materiały i technologie odlewnicze, Technologia wytapianych modeli, Przepuszczalność, Formy ceramiczne.