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ARCHIVES
of
FOUNDRY ENGINEERING

10.24425/afe.2020.131276

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 2020
Issue 1/2020

17 – 22

3/1

The Assessment of the Permeability of Selected Protective Coatings Used for Sand Moulds and Cores

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Received 15.07.2019; accepted in revised form 07.10.2019

Abstract

The article presents the results of permeability measurements of a zirconium alcohol coating applied on moulds and cores. The introduction extensively discusses the reasons for the application of protective coatings, as well as their advantages and disadvantages. Also, the problems related to the application of protective coatings are presented i.e. limited permeability and thus the possibility of the presence of gas-originated defects in the casts. Next, the paper discusses the methods of measuring the permeability of protective coating proposed by Falęcki and Pacyniak. The study also presents an indirect permeability measurement method. For the investigations, zirconium alcohol coatings with the three conventional viscosities 10, 20 and 30s were used. The viscosity was determined by means of the Ford cup with the clearance of 4mm. The coatings were applied onto profiles of Φ 50 x 50 mm, made of moulding sand consisting of a sand matrix with the mean grain size of d_L = 0,11, 17, 24, 31 and 34 mm and phenol-formaldehyde resin. The effect of the matrix grain size on the permeability of the sand with and without a coating was determined.

Keywords: Permeability, Protective coatings, Coating viscosity, Core, Mold

1. Introduction

The preparation of casts is a complex, multi-stage process. However, its main aim is to obtain a product with the desired specific properties. The basic characteristic determining the quality of production is the lack of casting defects formed inside, as well as such that are visible on the surface. The quality requirements for cast products are increasing. The physical, chemical and mechanical properties of casts are determined by a range of factors affecting the course of their structure formation. During the process of filling the mould with liquid metal, we observe the operation of physical and chemical factors in the area of the metal-mould interface. This operation is connected with [1,2,11]:

- the wettability of mould material by molten metal
- the degree of reactivity of the alloy in the liquid state with the moulding sand and the core sand
- the materials used to prepare the mould and the cores

In order to prevent a reaction between the liquid alloy and the mould or core, protective coatings are applied on the mould or the cores. The use of protective coatings makes it possible to limit or even eliminate some of the casting defects which can be formed on the surface of the cast. These defects include: burns, metal penetrations, veinings, sand buckles, surface roughness and thermal deformation. The advantages provided by protective coatings are obtained as a result of [3,4,13]:

- increasing the strength of the mold and core surface
- preventing the formation of cracks and folds on the surface of the mold and core
- minimizing the adhesion of the core sand and the moulding sand with the surface of the cast
- covering the pores in the moulding sand, which stops the penetration of the liquid casting alloy into the inter-granular spaces of the sand.

The full efficiency of the coating is affected by [5,12,14]:

- thickness of the applied coating,
- the way it is applied,
- the liquid coating's ability to penetrate into the inter-granular spaces, optimally to the depth of two or three sand grains
- covering the mold or core with several layers of the coating
- coating with a warm Surface
- the coating being applied at the optimal moment, i.e. after the binding process of the self-hardening sands has been completed
- full evaporation of the diluent from the coating

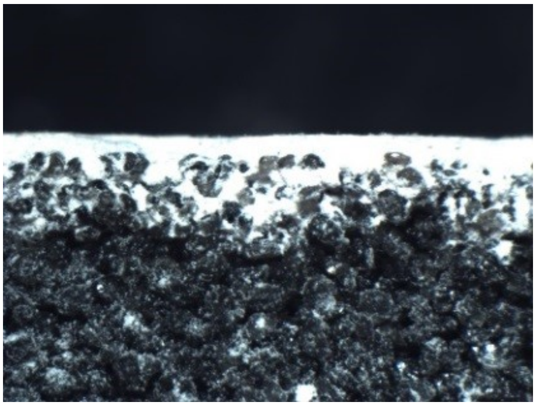

Fig. 1. Penetration of the coating into the intergranular spaces depending on the matrix grain size – coating with arbitrary viscosity 20s. coating was deposited by immersing, magnification 10x

The main component of protective coatings is a grain matrix. It is recommended for the mean diameter of the protective coating matrix grain to be within the scope of 0,05 – 0,08 mm. In the case of the sand used for moulds and cores, the mean matrix grain size, depending on the sand type (fine, medium, large), can equal from dL = 0,2 mm up to 0,4 mm, i.e. it is twice as large. This is why the coating fills the inter-granular spaces of the sand close to the surface, or even penetrates into the inter-granular spaces at the depth of 2-4 grains [1,2]. Figure 1 shows a coating applied onto the core. We can notice a thin layer formed on the core and penetration of the coating into the inter-granular spaces. The thickness of the formed layer as well as the depth of the coating's penetration into the inter-granular spaces depends on the viscosity of the coating itself, the grain size of the moulding sand matrix as well as other factors. This issue is more extensively discussed in our previous [6].

Applying a protective coating favours improvement of the cast surface quality, as it eliminates a range of defects. However, a protective coating can be a direct or indirect cause of the formation of other flaws in the casting. Depositing a protective coating onto the mould results in reduced permeability of the moulding sand. Low permeability of the mould and thus insufficient gas release from the mould, can cause the presence of a range of casting defects, such as misruns, external gas cavities, pitted skin, punctures and others [7,8].

The gases causing the formation of casting defects are [7,9]:

- the gases - air filling the mold cavity against liquid metal pouring
- the gases obtained during the casting process – a faulty construction of the gating system
- the gases contained in the foundry alloy
- the gases formed as a result of a thermal destruction of the binder components in the sand and the components in the protective coating
- the gases resulting from poorly dried coating - incomplete evaporation of the diluent

In order to limit the disadvantageous effect of low permeability of the mould on the presence of gas-originated casting defects, we should understand the degree to which the application of a protective coating lowers the permeability.

In 2002, a scientific team led by Falęcki developed a method of measuring the permeability and strength of protective coatings. The principle of the measurement consisted in depositing a layer of coating onto a grid and then letting it dry. The coating was applied through submersion. The sample prepared in this way was placed in a measuring device. Next, the whole was mounted on a permeability measuring apparatus and the measurement was performed. In this method, several layers of the coating could be deposited onto the grid, thus changing the coating's thickness. The surface area of one mesh of the measuring grid was about 0,004 cm^2. Additionally, after a proper spigot had been fixed onto the measuring device, it was possible to measure the strength of the coating. Figure 2 shows the schematics of the device used for the measurement of the permeability and strength of the protective coating [9].

In turn, in 2003, Pacyniak proposed another method of preparing test samples. The coating was deposited onto round polyethylene profiles in a special sleeve. In this method of sample preparation, it is possible to control the coating thickness by means of a spacer roll. After drying, the sample of hardened coating was removed from the profile. Next, the sample was placed in a attachment with a rubber membrane, and the set prepared in this way was mounted on the permeability measuring apparatus. An advantage of such a solution is the possibility to control the thickness of the coating, its disadvantage being the lack of the possibility to measure the strength of the coating and the difficulty in mounting the sample in the attachment because of the risk of its cracking. Figure 3 shows the schematics of the apparatus used to prepare thin coating layers [10].

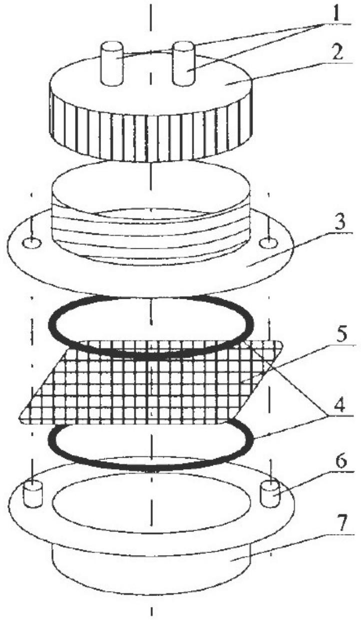

Fig. 2. Schematics of the permeability and strength measuring device [9]: 1 – compressed air inlet and outlet spigots, 2 - strength measuring nut, 3 – upper body, 4 – packing washers, 5 - measuring grid, 6 – pins, 7 – lower body used for mounting the device in the permeability measuring apparatus

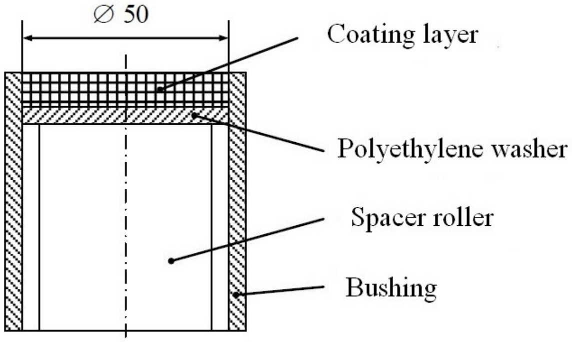

Fig. 3. Scheme of instrumentation for making thin coating layers

Both measuring methods are very suitable for the measurements of the permeability of protective coatings used in the case of the full cast moulding technology, where the total thickness of the coating is equal to the thickness of the coating formed as a result of its deposition onto an EPS model. In turn, in the case of applying a coating on sand moulds and cores, the total thickness of the coating is the sum of the thickness of the layer formed on the surface of the moulding sand and the degree of the coating's penetration into the inter-granular spaces. And so, in the performed investigations, another solution of protective coating permeability measurement was applied.

2. Own investigations

2.1. Aim and the investigation methodology

The indirect measurement method was used to perform the tests.

The permeability measurements were made on a zirconium alcohol coating with three conventional viscosities 10, 20 and 30s. The coating's viscosity was determined by means of the Ford cup with the opening diameter of 4 mm. The coating was deposited onto cylindrical samples by way of submerging the profiles in the coating. The cylindrical profiles were made from sand of the following matrix grain size:

- BK7 - $d_L = 0{,}11$ mm, main fraction Fg = 78,1 % (0,10/0,16/0,071)
- BK6 - $d_L = 0{,}17$ mm, main fraction Fg = 83,8 % (0,16/0,10/0,20)
- BK5 - $d_L = 0{,}24$ mm, main fraction Fg = 80,9 % (0,2/0,16/0,32)
- BK4 - $d_L = 0{,}31$ mm, main fraction Fg = 88,6 % (0,40/0,20/0,32)
- BK3 - $d_L = 0{,}44$ mm, main fraction Fg = 85,6 % (0,40/0,63/0,32)

In the first place, cylindrical profiles with the dimensions Φ 50 x 50 mm were prepared (Fig. 4). The sand used to prepare the samples consisted of a „Szczakowa” sand matrix and a phenol-formaldehyde binder in the following proportions:

- Sand grains – 100 parts by weight
- binder – 1,5% in relation to the amount of sand
- Hardener - 50% - in relation to the amount of binder

Fig. 4. Cylindrical profiles with the dimensions fi 50x50 mm before and after applying a protective coating

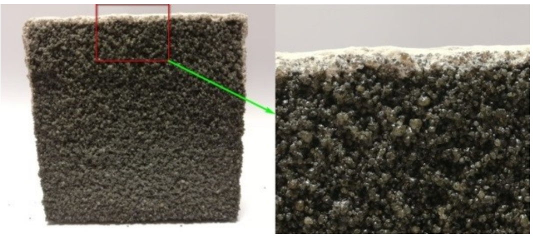

Fig. 5. View of the thickness of the coating layer formed on the core as well as the size of the penetration into the inter-granular spaces

After mixing, the sand was condensed on a vibration table, so that a uniform apparent density of the sand would be reached. The samples condensed in this way were left to harden for 24 hours. After hardening, each cylindrical profile was weighed and its dimensions were measured. The measurements were performed in order to calculate the apparent density of the sand. Next, the cylindrical profile was placed in a special attachment for the permeability measurement (Fig. 6). The attachment was mounted on the permeability measuring apparatus LPiR by Multiserw (Fig. 7) and the measurement was performed. The permeability test of the profiles themselves – without a coating - was made in order to provide a reference point. After the measurement, the profile was removed from the attachment and a coating was deposited onto it (Fig.4). After the coating had been dried, the height of the sample was measured again, which was necessary, as the sample's height had changed after the coating was applied, i.e. it increased. Figure 5 shows the thickness of the coating layer formed on the core as well as the degree of penetration into the inter-granular spaces. The following step was mounting the cylindrical profile with the deposited coating onto the attachment and performing a measurement. The sample was fixed in such a way so that the surface of the profile covered with the coating would be in the upper part of the attachment.

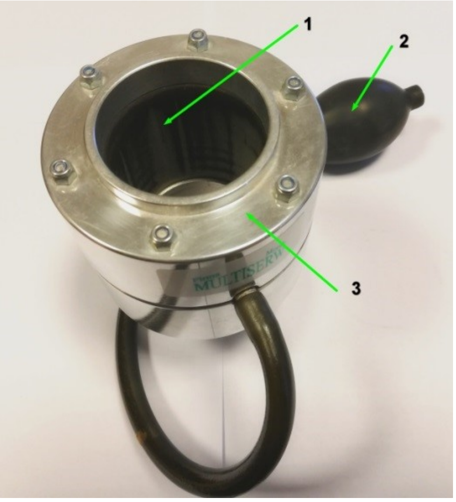

Fig. 6. Attachment for the permeability measurement; 1 - rubber sealing membrane, 2 - "pear" pumping air, 3 – housing

The permeability tester, with the permeability value according to equation (1), is scaled for the sample height h=50 mm. And so, if the height of the sample is different than 50 mm, in order to obtain the actual permeability value, it should be calculated from equation (2).

$$P = \frac{V \cdot h}{F \cdot \tau \cdot p} \left[\frac{m^2}{Pa \cdot s} \cdot 10^{-8} \right] \tag{1}$$

P – permeability
V – the volume of air flowing through the sample [m^3]
h – height of the sample [m]
τ– time of V volume flow through the sample, [s]
p – air pressure [Pa]

$$P_w = P_z \cdot \frac{h_z}{h} = P_z \cdot \frac{h_z}{0{,}05} \tag{2}$$

P_w – permeability calculated
P_z – permeability measured on the apparatus
h_z – measured height of the sample [m]
h – height of the standard cylindrical sample = 0,05 [m]

Fig. 7. LPiR device for measuring the permeability of Multiserw company

The coating of a given viscosity was each time deposited on four profiles made of sand with a specific grain size of the matrix. The permeability result is the average obtained from the four measurements.

2.2. Results of investigations

Figure 8 shows the effect of the matrix grain size on the permeability of the sand. The apparent density of the moulding sand equaled 1,55 g/cm^3. In the case of the sand with the mean matrix grain size d_L = 0,11 mm, the sand permeability equals about 100x10^{-8} m^2/Pa·s. With the increase of the grain size, the permeability increases as well, and for the matrix grain size d_L = 0,44 mm, the sand permeability equals about 1850 x10^{-8} m^2/Pa·s. The character of the changes is linear.

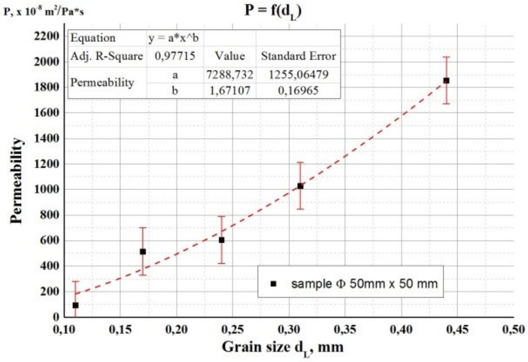

Fig. 8. Influence of the grain size of the molding sand matrix on its permeability

In turn, figures 9 – 11 present the permeability measurement of moulding sand with a protective coating. In the case of the cylindrical profile being covered with a coating of the conventional viscosity 10s (Fig.9), the measured permeability values are practically one order of magnitude lower than those of the sand without a coating. When the matrix grain size is d_L = 0,11 mm, the permeability of the coated sand equals about 40 x10^{-8} m^2/Pa·s and is 2,5 times lower than that of the sand without a coating. Also in this case, with the increase of the matrix grain size, an increase of permeability is observed. For d_L = 0,44 mm, the permeability of the sand covered with the coating equals 160 x10^{-8} m^2/Pa·s and is over 11 times lower than that for the non-coated sand.

The bigger permeability difference between the coated and non-coated sand, and for the matrix with a bigger and smaller grain, results from the penetration properties of the coating. When the sand is on a matrix with a larger grain, the depth of the coating penetration into the inter-granular spaces is bigger than in the case of a matrix with a smaller grain. The permeability of sand covered with a coating depends on the matrix grain size and the total thickness of the coating. As it was mentioned before, the total thickness of the coating is the sum of the thickness of the layer formed on the surface of the mould and the thickness of the coating penetrating into the inter-granular spaces.

Figure 10 shows the change in the permeability of the moulding sand covered with a coating of the conventional viscosity 20s. Here, we can also observe an increase in permeability together with the increase of the grain size of the moulding sand matrix. However, these changes are much smaller, as with the matrix grain size increase from d_L = 0,11 mm to d_L = 0,44mm, the permeability changes from 21 to 38 x10^{-8} m^2/Pa·s. What is more, we can notice that the permeability value for the sand with a coating of the viscosity 20s is at least twice as low as that for the sand covered with a coating of the conventional viscosity 10s.

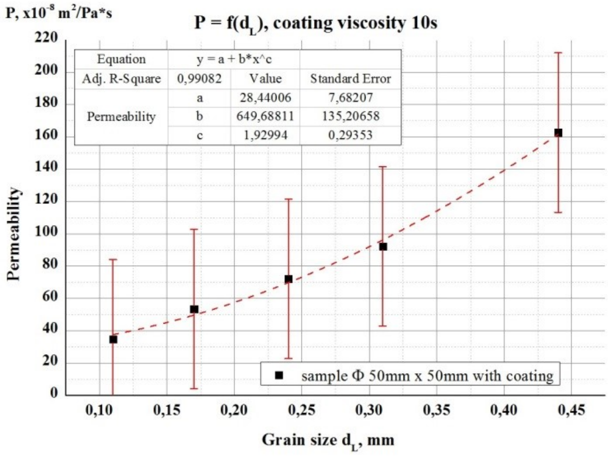

Fig. 9. Influence of the grain size of the molding sand matrix on the permeability of the mass covered with a protective coating with a conventional viscosity 10s

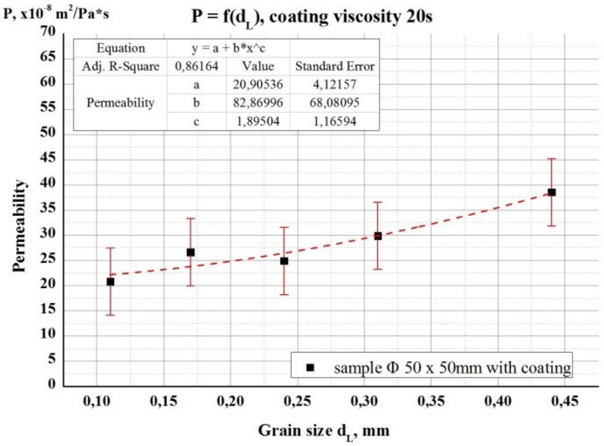

Fig. 10. Influence of the grain size of the molding sand matrix on the permeability of the mass covered with a protective coating with a conventional viscosity 20s

In the case of a coating with the conventional viscosity of 30s deposited on the sand (Fig. 11), we can observe a further drop of permeability. For the sand with the matrix of d_L = 0,11 mm, the permeability is only 12 x10^{-8} m^2/Pa·s, whereas for the sand with the highest matrix grain size d_L = 0,44 mm, the permeability equals 24 x10^{-8} m^2/Pa·s.

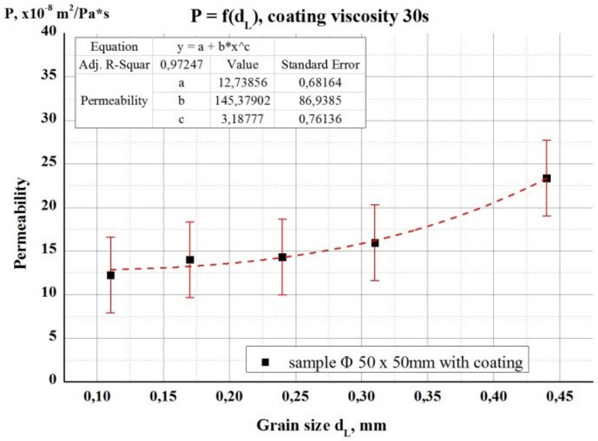

Fig. 11. Influence of the grain size of the molding sand matrix on the permeability of the mass covered with a protective coating with a conventional viscosity 30s

The last of the presented diagrams (Fig. 12) shows a compilation of the changes in the permeability of the sand covered with coatings of three conventional viscosities. In the case when the coating is very thin – conventional viscosity 10s – we can observe a big effect of the grain size of the moulding sand matrix on the permeability, while with denser coatings – conventional viscosity 20 – 30s – that effect is much smaller.

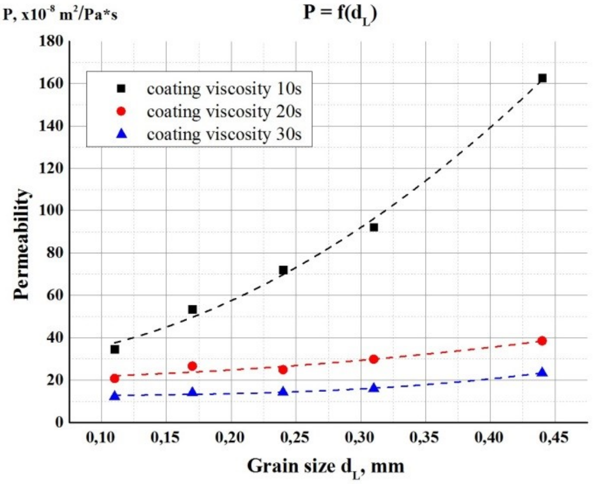

Fig. 12. Comparison of mass permeability measurement results covered with a coating of different viscosity

3. Summary and conclusions

Based on the performed studies, it is possible to draw the following conclusions:

- Depositing a protective coating onto the mould causes a large drop in the permeability of the moulding sand. Depending on the grain size of the matrix, the permeability of the sand with a coating is from 2,5 up to 11 times lower than in the case of the sand without a coating.
- The permeability of the moulding sand covered with a coating depends on two factors, i.e. the grain size of the moulding sand matrix and the thickness of the coating.
- With the increase of the grain size of the moulding sand matrix, we observe an increase of the permeability of the sand covered with a coating. In the case of a coating with the conventional viscosity of 10s, together with the increase of the matrix grain size from d_L= 0,11 mm to d_L = 0,44 mm, the permeability value increases over four times, i.e. from 38 to 162~~-~~x10^{-8} m^2/Pa·s. In turn, for coatings with the conventional viscosity of 20 and 30s, the permeability increase is less intensive, i.e. only two times.
- The higher the conventional viscosity of the coating, the lower the permeability. For example, for the moulding sand with the matrix of d_L = 0,24 mm, covered with a coating of the viscosity of 10s, the permeability equals 71 x10^{-8} m^2/Pa·s, whereas for the sand with a coating of the viscosity of 30s, the permeability is only 16~~-~~x10^{-8} m^2/Pa·s.

Acknowledgments

The research received founding from NCBIR no. 5.72.170.626

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