THE DRYING KINETICS OF PROTECTIVE COATINGS USED ON SAND MOLDS

Investigation results of the drying rate of the selected protective coatings (water and alcohol) are presented in the article. Coating drying rate was determined for the first and second layers. The coating was applied to moulding sand cores. The rate of drying coatings were tested for three coating apparent viscosities estimated by means of the Ford 4 mm cup. Drying rates of the protective coating were examined by using the gravimetric technique and ultrasonic technique. Measurements were carried out in a continuous way under controlled conditions: constant ambient temperature and air humidity. Research shows that the drying time of the second coating layer is longer by 20 – 30 % than the first layer.

Key words: foundry, molds, protective coatings, kinetics of drying, gravimetric technique, ultrasonic technique

INTRODUCTION

The casting production is a complex and multistage process. One of the stages is the deposition of protective coatings on moulds and cores. Protective coatings are applied in order to obtain a smooth mould surface, and due to that an improvement of the casting surface, strengthening the upper moulds layer or minimizing a reaction between mould and liquid metal. The applied coatings are protecting the casting against certain defects such as: burn-on, veins, sand buckles and other. Some coatings can favourably influence the casting structure [1 – 6].

Coatings based on alcoholic diluents were up to now applied in the foundry practice. However, due to new environment protection standards, especially concerning emissions of volatile organic compounds (VOCs) into the atmosphere, limits in an application of easily evaporating substances were introduced. This forced changing alcohol–based coatings into water-based ones [7].

A drying process of the coating layer deposited on the mould is rather slow, under atmospheric conditions. The evaporation rate of diluent depends on its volatility and heat of vaporization. In case of alcohol its volatility is 10 times higher than that of water and heat of vaporization four timer smaller, which causes that water-based coatings are drying much longer. Drying process rate depends on several factors: kind of coating, ambient temperature, air humidity, air flow (exchange), thickness of a coating layer or matrix grain sizes. The drying time of protective coatings is relatively less known element of making moulds and preparing them for pouring. In case of coatings deposited by layers on the core it is necessary to know the drying time of each layer since the next one can be only deposited when the previous layer is completely dry. Pouring with liquid metal the mould with not sufficiently dry coating can cause casting defects such as: burn–on, veins, skin blowholes or non-metallic inclusions. Two methods of the drying times estimation: gravimetric (weight) and ultrasound, are presented in the paper [7 – 13].

AIM AND METHODOLOGY OF INVESTIGATIONS

The drying process of the protective coating depends on several factors. The performed investigations were aimed at determining the influence of the apparent viscosity of the coating on its drying process pathways and on the process kinetics. The coating viscosity decides on its layers thickness. In addition, the influence of the solid phase on the kinematic viscosity was determined.
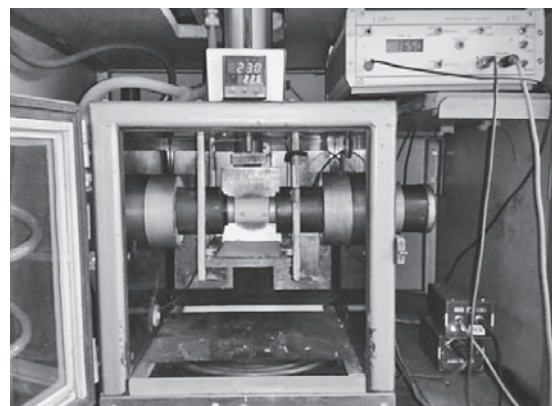

Figure 1 Stand for ultrasound investigations of the kinetics of the protective coatings drying process [14, 15]

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The gravimetric and ultrasound techniques were utilized in determining the coating drying process. Measurements were made in a continuous way and systematically recorded in the computer. The experimental stand for gravimetric measurements was already presented in paper [7], while the stand for ultrasound tests is shown in Figure 1. The core with deposited coating is placed in between heads. The reader records the time of the ultrasound wave passing through the sample.

Investigations were carried out at retaining constant external conditions: temperature, air humidity, air flow, i.e. a possibility of exchanging vapours from the coating to surroundings. All the cores, on which the coating was deposited, were of the same size [7].

RANGE AND THE INVESTIGATIONS COURSE

The alcohol-based protective coating Zirkofluid 1219 of the Huttenes-Albertus Company and water-based protective coating WC-R of the Prec-Odlew Company were subjected to investigations. Coatings were deposited on the cores made of the moulding sand with furan binder. Moulding sands were prepared on the high-silica sand „Szczakowa" matrix of the average grain size: $d_L = 0,24$ mm. depositing was done by immersing the core in the liquid coating of the apparent viscosity determined by means of the Ford's cup 4 mm. The outflow time from the Ford's cup is the apparent viscosity measure. Three coatings of a apparent viscosity: 11 s; 20 s; 30 s were selected for tests. They corresponded, respectively to the kinematic viscosity: $v = 16 \cdot 10^{-6}$; $61 \cdot 10^{-6}$ and $112 \cdot 10^{-6}$ m²/s. Three times of the core immersing in the coating were applied 1 s; 10 s and 30 s.

The influence of the coating viscosity on the kinetics of drying was determined. The drying times of the first and the second coating layer in dependence of the viscosity and immersion time were determined.

PATHWAYS OF THE PROTECTIVE COATING DRYING PROCESS

Examples of the results of the pathways of the protective coating drying process are presented in Figures 2 and 3. The drying degree of the coating was determined by means of equation [7]:

$$S_{wp} = \frac{m_{p(0)} - m_{p(x)}}{m_{p(0)} - m_{p(k)}} * 100\%$$

where:
S_{wp} – coating drying degree
$m_{p(x)}$ – coating mass in the given moment
$m_{p(0)}$ – coating mass in the initial moment (t = 0) – coating contains a diluent
$m_{p(k)}$ – coating mass after drying – coating does not contain a diluent

The drying process of the alcohol-based coating presented in Figure 2 has a similar character of changes for
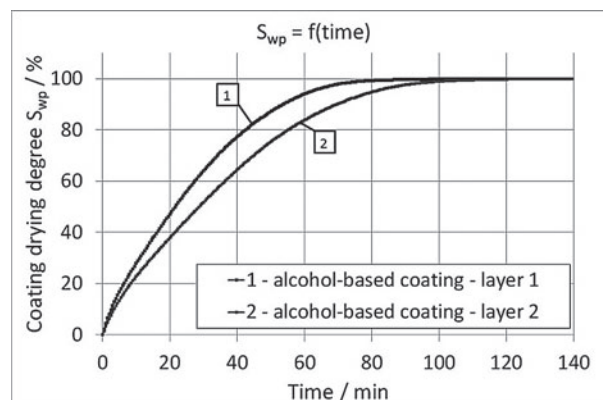

Figure 2 Drying process of the alcohol–based protective coating. Kinematic viscosity of the coating $v = 61 \cdot 10^{-6}$ m²/s, ambient temperature T = 22 °C , air humidity W = 24 %, immersion time t = 30 s

the first and second layer. However, there is a significant difference in the drying rate of the first and the second layer. The drying time of the first layer equals app. 80 minutes, while of the second app. 110 minutes.

Analogous pathways for the water-based coating are presented in Figure 3. Similarly as in case of the alcohol-based coating, there is a significant difference between drying times of the first and the second layer. However, the essential difference constitutes the drying time of the water-based coating, which is more than 4 times longer than of the alcohol-based coating and equals app. 300 minutes for the first layer and app. 480 minutes for the second one. The difference in drying times of the layers is probably a result of the penetration (soaking) of the first layer by a diluent during the deposition of the second layer. In effect, the process of the diluent removal from the second layer is hindered by a longer distance.
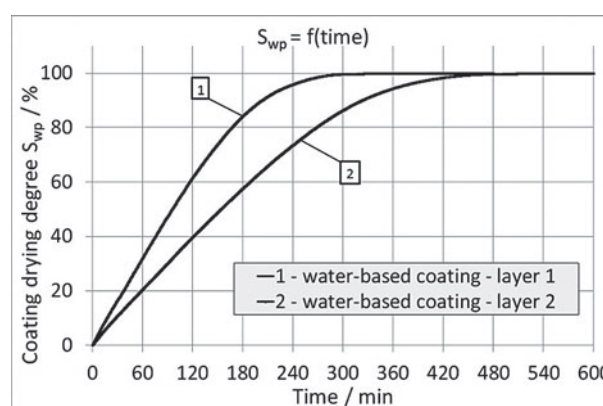

Figure 3 Drying process of the water–based protective coating. $v = 61 \cdot 10^{-6}$ m²/s, T = 22 °C, W = 24 %, t = 30 s

Successive Figures present the dependence between the kinematic viscosity of the coating and its drying time. It can be noticed, when analyzing diagrams, that with an increase of the kinematic viscosity (a decrease of a diluent content in the coating) drying times of both layers are longer. Described phenomenon results from

the fact that, with an increase in the viscosity of the coating increases the thickness of the applied layer. For a kinematic viscosity of the coating $61 \cdot 10^{-6}$ m²/s thickness of the first layer before drying is about 350 μm, while the kinematic viscosity of $112 \cdot 10^{-6}$ m²/s thickness of about 550 μm. The relationship between the thickness of the layer and kinematic viscosity is linear. Differences between two kinds of coatings occur in relation to the intensity of this prolongation. This intensity, in case of the alcohol–based coating, is the same for each layer and equals app. 15 minutes (Figure 4). Whereas, in case of the water–based coating (Figure 5), there is a higher intensity of the drying time prolongation. With the kinematic viscosity increase from $16 \cdot 10^{-6}$ m²/s (apparent 11 s) to $112 \cdot 10^{-6}$ m²/s (apparent 30 s) the drying time was prolonged by approximately 150 minutes, while for the first layer this prolongation was shorter, equal app. 70 minutes.
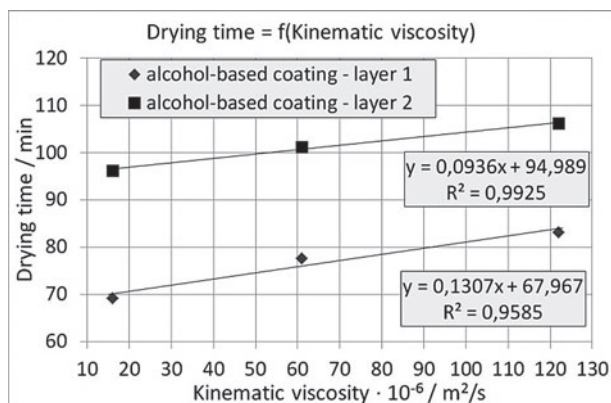

Figure 4 Influence of the alcohol–based coating kinematic viscosity on its drying time. Sand grain size d_L = 0,24 mm, T = 22 °C, W = 23 %
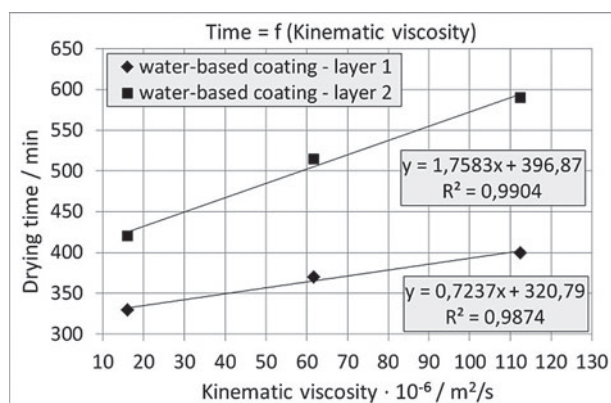

Figure 5 Influence of the water–based coating viscosity on its drying time, d_L = 0,24 mm, T = 22 °C, W = 23 %

The influence of the solid phase in the alcohol-based coating on its kinematic viscosity is presented in Figure 6. The character of changes is exponential. Decreasing the solid phase content in the coating to approximately 64 % causes the kinematic viscosity decrease to app. $16 \cdot 10^{-6}$ m²/s (apparent viscosity 10 s). Below this value the diluent viscosity decides on the coating viscosity (mixture of a solid phase and diluent). Whereas, in-
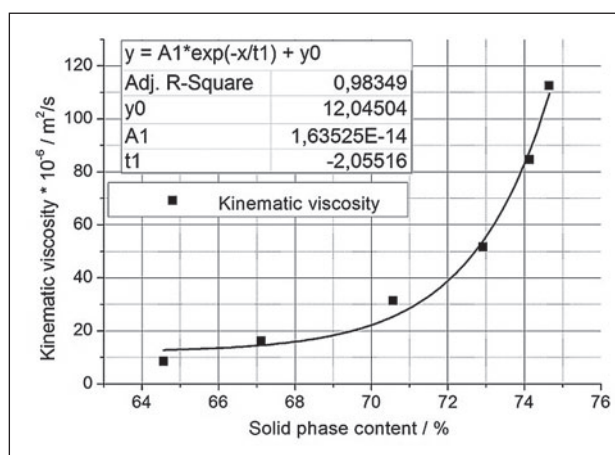

Figure 6 Influence of the solid phase content in the alcohol–based coating on its kinematic viscosity

creasing the solid phase content above 75 % causes that the coating becomes very thick (kinematic viscosity $128 \cdot 10^{-6}$ m²/s – apparent 35 s.) and even changes from the liquid state into a paste.

Figure 7 presents pathways of the drying process of the alcohol–based protective coating recorded by means of the ultrasound technique. In this technique the ultrasound wave velocity passing through the investigated sample is recorded. The higher velocity the higher sample strength (moulding sand hardening degree) and in case of the protective coating its drying degree is higher. The wave velocity for the sample (core of the furan moulding sand) without the coating equals 1800 m/s. After depositing the first layer the wave velocity for the core with the coating equals app. 1550 m/s. In time, at the first stage, weakening of the core strength (the wave velocity decreased to 1200 m/s) the so called „softening" of the core is observed. This is caused by the coating diluent penetration into intergranular spaces and weakening of bonds between matrix grains. In the next stage the wave velocity increases, it means the protective coating drying process proceeds (diluent evaporation). The character of this process is comparable with the one observed by means of the gravimetric technique. In case of the second layer the effect of 'softening', i.e. a diluent penetration, is also observed. The drying pro-
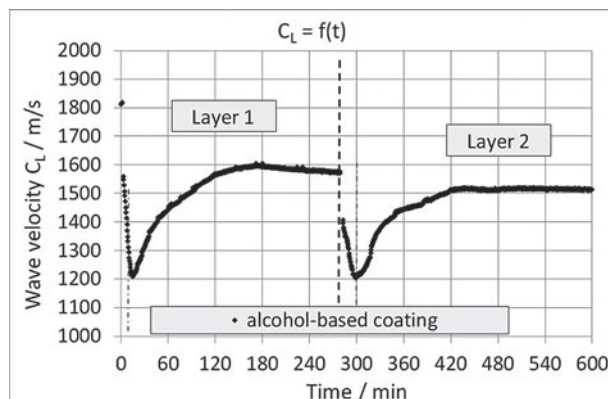

Figure 7 Pathways of the drying process of the alcohol–based protective coating, ultrasound investigations

cess of the protective coating occurs only in the second stage.

CONCLUSIONS

The performed investigations of the viscosity influence on the pathway of the drying process of the water-based and alcohol–based protective coatings, deposited on cores and moulds, allow to present several conclusions.

- The drying time of the first layer of the coating is shorter than that of the second layer.
- The viscosity influences the coating drying time at constant climatic conditions (ambient temperature, humidity, lack of air flow).
- With the kinematic viscosity increase from $16 \cdot 10^{-6}$ to $112 \cdot 10^{-6}$ m^2/s (a diluent content decrease in the coating, increasing the thickness of the layer) the coating drying time becomes longer. Intensity of its prolongation for the alcohol–based coating is similar for both layers, while for the water based coating this intensity is larger for the second layer.
- The ultrasound technique allows to observe, more precisely, the effects accompanying the drying process of the protective coating. Due to this technique it is possible to observe – in the first phase of the process – the core 'softening' effect, it means decreasing of its strength.

Acknowledgements

REFERENCES

[1] K. Seeger, Przegląd Odlewnictwa, 7–8 (2012), 322–326.
[2] M. Holtzer, A. Bobrowski, D. Drożyński, J. Mocek, Archives of Foundry Engineering 13 (2013) 1, 39–44.
[3] J. Jakubski, S.M. Dobosz, P. Jelinek, Archives of Foundry Engineering 5 (2005) 15, 164-169.
[4] J. Kubicki, A. Kochmańska, Archives of Foundry Engineering 1 (2001) 2 127-133.
[5] A. Kochmańska, J. Kubicki, Archives of Foundry Engineering 9 (2009) 2, 129-132.
[6] M. Holtzer, R. Dańko, S. Żymankowska-Kumon, Metalurgija 51 (2012) 3, 337–340.
[7] Ł. Jamrozowicz, J. Zych, T. Snopkiewicz, Archives of Foundry Engineering 13 (2013) 1, 45-50.
[8] J. Kolczyk, J. Zych, Metalurgija 52 (2013) 1, 55-58.
[9] Ł. Jamrozowicz, Archives of Metallurgy and Materials 58 (2013) 3, 891-894.
[10] J. Jakubski, St. Dobosz, Archives of Foundry Engineering 18 (2006) 6, 453-458.
[11] C. Senderowski, Z. Bojar, Archives of Foundry Engineering 7 (2007) 1, 147-152.
[12] T.Pacyniak, R.Kaczorowski, Archives of Foundry 3 (2003) 8, 147-156.
[13] Z. Falęcki, W. Jankowski, A. Wojtaszek, J. Żurakowski, Solidification of Metals and Alloys 43 (2000) 2, 147-154.
[14] J. Zych, AGH Institutional Scientific and Educational Publishing, Dissertations and Monographs 163 (2007), Kraków.