DRYING PROPERTIES OF A CERAMIC MASS RESISTIBLE TO AGGRESSIVE ENVIRONMENT

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ABSTRACT

The drying statics of plastic ceramic mass intended for production of acid resistible products is investigated. The equilibrium state of the mass and the desorption isotherms are designed for the temperatures of 25°C and 66°C is investigated. The drying sensitivity of the mass has been determined by two methods. The following is determined:

- The equilibrium moisture of the ceramic mass which defines the final product moisture of drying prior to further technological treatment;
- The critical moisture and shrinkage of the plastic ceramic mass while drying;
- Quantitative characteristics of the drying sensitivity;

Based on the final results and the conducted survey some conclusions, directly connected with the kinetics of the drying process are formulated.

Keywords: chemical resistant ceramics, drying, equilibrium moisture, drying sensitivity.

INTRODUCTION

The processes of drying and firing are among the most essential technological levels connecting with the production of the ceramic products [1, 2]. They define the quality and cost of the production and thus they demand serious surveying and scientific arguments.

Conducting a survey regarding the equilibrium state of the moist material with the gaseous environment is essential for determining the moving power of the drying process as well as for investigating the internal structure of the material. The equilibrium state is characterized by the isotherms of sorption and desorption. They represent the dependence between the equilibrium moisture content of the material and the relative humidity of the air in the processes of sorption and desorption at a constant equilibrium temperature [1-8].

The tendency of the materials, and in particular the moist ceramic masses, to deform and to crack when they are exposed to special drying conditions is called “drying sensitivity”. It is proven that the drying sensitivity of the ceramic masses can not be determined by using only one property [4, 7]. The tendency of the mass to defect during drying depends on factors, such as: mineralogical and granulometric composition of the mass components, linear drying shrinkage, plastic and capillary properties.

EXPERIMENTAL

Object of survey

The object of the survey of the present work has been a ceramic mass intended for production of the acid resistible products prepared in industrial condi-
tions. The basic mass components are: clay (70%), fire - clay (20%) and sand (10%).

Experimental pilot installation for studying of the equilibrium state

The principal scheme of the pilot installation is shown on Figure 1. By using a dynamic method of the particular experiment for a period of 5 to 6 hours, the pilot installation determines the equilibrium moisture content of different materials within the temperature range 20°C to 90°C and relative air humidity varied from 10 to 100%.

![Figure 1. Pilot installation for studying the equilibrium state: 1 - Moisture chamber; 2 - Heating coil; 3 - Controller; 4 - Contact thermometer; 5, 10, 14 - Heat exchanger; 6, 9 - Thermostat; 7, 15 - Drop remover; 8, 13 - Control thermometer; 11 - Working chamber; 12 - Testing material; 16 - Air velocity indicator; 17 - Vacuum pump.](image)

The air blown through the investigated material goes into chamber 1 where it will get humidity. The temperature necessary for that process is programmed automatically in advance. When passing through the heat exchanger 5, the moist air is cooled with 3-5 K and thus it reaches the saturation state. With saturation temperature \( t_s \) and relative humidity \( \varphi = 100\% \) the air passes through the cyclone 7 intended for separating the water drops. Maintenance of the necessary temperature within the heat exchanger and the cyclone can be done by the thermostat 6. Further, the saturated air goes through the heat exchanger 10 where the air is heated to the temperature \( t_1 \) belonging to the sorption isotherm which is determined by the experiment. Thus, the relative humidity of the air can obtain the value desired for the particular experiment according to the equation:

\[
\varphi = \left( \frac{p_v(t_1)}{p_v(t_s)} \right) \cdot 100 = \left( \frac{p_v(t_s)}{p_v(t_1)} \right) \cdot 100 \, \%,
\]

where:  \( p_v(t_1) \) is the partial pressure of the superheated vapour in the air with temperature \( t_1 \), Pa;

\( p_v(t_s) \) - the partial pressure of the saturated vapour with temperature \( t_s \), Pa;

\( p_v(t_s) \) - the partial pressure of the saturated vapour with temperature \( t_s \), Pa;

When reaching the parameters necessary for the experiment (temperature \( t_1 \) and relative humidity \( \varphi \) ) , the air goes into the working chamber 11. It blows the particles of the testing material 12 placed in a cartridge with a perforated bottom. The working chamber has double wall in which the heating fluid coming from thermostat 9 circulates and maintains the temperature \( t_1 \) that corresponds to the determined sorption isotherm.

After the testing sample is blown, the air is cooled in the heat exchanger 14 and consequently passes through the drop remover 15 and thus, the air facilitated by the vacuum pump 17 is released into the atmosphere. In order to ensure the appropriate blowing velocity of the testing material (3 to 4 m.s\(^{-1}\)) the air flow is controlled by a speed indicator 16.

**TESTING METHODS**

**A. Isotherms of desorption**

After reaching the equilibrium state, the sample of the testing material is measured and dried till reaching an absolute dry state. After repeating the test measurement, the equilibrium moisture is calculated. Consequently, from the experiment results the isotherm \( W_i = W_i(\varphi) \) is designed. In the present study the isotherms of desorption for two temperatures have been obtained experimentally:

- \( t_i = 25^\circ \text{C} \) - the temperature of the environment which the material has after drying and before treatment. With that temperature the limits of the final moisture necessary for conducting the drying process can be estimated;

- \( t_i = 66^\circ \text{C} \) - the temperature that determines the drying sensitivity of the ceramic mass by Alviset's method [4, 6];

**B. Drying sensitivity**

Despite the availability of a great number of methods proposed until now [4], there is no method that can solve precisely the problem. That is why the
drying sensitivity has to be determined by using at least two different methods. Our study was conducted by using the following methods:

**Chijsky-Bigot’s Method**

The application of that method is recommended because of its satisfying final results and simplicity. It is widely applied in the industrial laboratories. By drawing the dependence between the relative linear shrinkage and the current absolute humidity of the ceramic mass the coefficient of drying sensitivity can be determined:

\[ k = \frac{W_m - W_{cr}}{W_{cr}} \]  

(2)

where:

- \(W_m\) - the moulding moisture of the mass, %;
- \(W_{cr}\) - the critical moisture at which the linear drying shrinkage finishes, %;

From the value of the coefficient of the drying sensitivity, the plastic ceramic masses are estimated as follows: slightly sensitive (\(k < 1.2\)), moderately sensitive (\(k = 1.2-1.8\)), highly sensitive (\(k > 1.8\)). Thus, obviously only a quantitative estimation can be obtained [4-7]. An important advantage of this method is the establishment of the critical moisture at which the shrinking of the investigated mass stops.

**Alviset’s Method:**

From the desorption isotherm \(t_i = 66^\circ\) C the energy showing the connection between the moisture and the material is calculated by the following equation:

\[ E = \frac{R_e \cdot T_i \cdot \ln \frac{100}{\varphi}}{\ln \frac{100}{\varphi}} \cdot \frac{1}{W_e} \cdot kJ/kg, \]  

(3)

where:

- \(R_e = 0.4615\) kJ/(kg.K) is the specific gaseous constant of water;
- \(T_i = 339.15\) K - the absolute temperature of the isotherm;
- \(\varphi\) - relative humidity of the air, %.

The calculated results are presented graphically by the equation

\[ E = E \left( \frac{1}{W_e} \right). \]

Depending on the position of the line a quality estimation of the drying sensitivity (slightly sensitive, moderately sensitive, highly sensitive) of the ceramic mass can be made. An important advantage of this method is the possibility of conducting additionally a quantitative estimation by using the Alviset’s number:

\[ A = \frac{\Delta E}{\Delta \left( \frac{1}{W_e} \right)} \text{ kJ} \cdot \text{kg}^{-1} \cdot \% \]  

(4)

The calculated values of \(A\) distinguish exactly the ceramic masses which fall into the same area of the drying sensiveness [6].

**RESULTS AND DISCUSSION**

In the Fig. 2 the isotherms of desorption of the investigated ceramic mass are drawn. The typical S-like curves confirm that the mass belongs to the group of the colloid-capillary-porous materials [5 - 7].

The isotherm at \(t_i = 25^\circ\) C shows that the value of the equilibrium moisture content of the ceramic mass is \(W_e \equiv 3.3\) % with relative humidity \(\varphi = 60 - 70\)%. Therefore, the final moisture necessary for drying the production has to be lower in order to further appropriate the storage of the products in industrial conditions and prior to further technological treatment.

The maximum equilibrium moisture of the mass with an isotherm \(t_i = 25^\circ\) C reaches \(W_e^{max} \equiv 5.8\) % and respectively \(t_i = 66^\circ\) C - \(W_e^{max} \equiv 4.0\) %.

Fig. 3 represents the results for the drying sensiveness of the ceramic mass by the Chijsky-Bigot’s method. As the average value of the relative linear shrinking of the mass is defined \(C_i = 5.6\)%. The process of shrinking finishes when reaching the critical moisture

![Fig. 2 Isotherms of desorption](image-url)
$W_{cr} \equiv 10,3\%$. The value of the coefficient of the drying sensitivity $k = 1.0$ defines the mass as slightly sensitive.

Fig. 4 presents graphically the results for the drying sensitivity determined by the Alviset’s method. The position of the line in the area of the moderately sensitive masses as well as its inclination show that the plastic mass is moderately sensitive to drying. This is confirmed by the value of Alviset’s number $A = 690.8$, $kJ \cdot kg^{-1} \cdot \%$ where the $A$ value significantly exceeds the values of $A = 97-270$, $kJ \cdot kg^{-1} \%$ which have been determined for the plastic porcelain masses [6] defining them as slightly sensitive.

CONCLUSIONS

The study of the statics of the drying process of a plastic ceramic mass intended for manufacture of products resistant to aggressive environment provide the following conclusions:

- The final level of moisture in the drying process, which is admissible in order to achieve industrial and energy effectiveness is determined.
- Although the two applied methods provide different results, it is more acceptable the stone mass to be classified as moderately sensitive to drying process. When selecting the optimal drying regime both the influence of the geometrical form of the different products and the drying sensitivity of the mass should be taken into consideration.

- The established critic moisture $W_{cr} \equiv 10,3\%$ shows that the beginning of the drying process should be conducted less intensively so that to reduce the risk of the appearance of highly moist gradients as well as mechanical tensions within the drying production. When reaching the critical moisture it is possible to apply more intensive drying process.

REFERENCES