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PROGNIZATION OF QUALITY CHARACTERISTICS OF PRODUCTION OF CERAMICS PRODUCTION

Abstract: *In this paper we study the production conditions for predicting the quality of products, taking into account the phase and chemical transformations in the fired products, with the lack of reliable data on the thermophysical properties of the product material and their variation in the firing process, with the complexity of the geometry of the problem under consideration.*

Key words: *burning, water absorption, tunnel furnace, strength, forecast, regression method.*

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Introduction

In the production environment, the average water absorption (VP) and the lowest strength ($Pr_{11,13}$) in the cage are usually chosen to predict product quality. This choice is due to the fact that, as shown by the results of experimental studies, it is these values that are indicative of the presence of brick bricks.

Materials and Methods

Among the methods used for forecasting, the most effective are the following: regression analysis [1], moving average [2], exponentially weighted average [3], Holt and Holt-Muir [4], dual and adaptive smoothing of Brown [3,4]. We will analyze these methods from the point of view of expediency of their use at development of mathematical models of properties of finished goods.

With regression analysis, structural and parametric identification is performed. There are a number of algorithms for choosing the structure of regression models, the most common of which are [5]: the method of all possible regressions, the method of exceptions, the step regression method (inclusions method), the Efraimson sequential algorithm, the method of sequential elimination of functions, the method of group accounting of the argument.

For statistical analysis, 20 factors that should be included in the models were identified, then the total number of equations by the method of all possible regressions was 1048576. It can be seen that the creation and study of models using this method will take a long time and is very laborious. The method of exclusion can be effectively applied only in the case of a normal distribution of all factors and their uncorrelatedness between themselves. It requires a

search of a large number of equations. The inclusion method avoids manipulating a large amount of factors. However, it does not allow us to estimate the influence of the inclusion of the last factor on the previously introduced ones. This drawback is taken into account in the Efraimson method [6,7]. But its use for automatic selection is hampered by the fact that in the method of successive exclusion of functions, errors are added to the approximation and elimination of factors, which, with a considerable number of factors, can substantially distort the approximating functions.

The application of the tactics of self-organization of mathematical models by the method of group analysis of the argument (MGAA) of this method of feature is suitable for modeling complex systems. The MGAA algorithm is based on the use of the method of all possible regressions. Its success, to a large extent, is determined by a successful choice of supporting functions. The method is characterized by cumbersome calculations, and the model chosen for the next adaptation period may have a different structure, which will necessitate new searches.

It follows that the diversity of methods for obtaining the structure of the regression equation can't unequivocally be said about the best of them. The choice and application of each of them must be carried out for each specific task.

To obtain mathematical models of the firing process, the inclusion method and the method of least squares for the calculation were chosen.

To model all experimental data were divided into two independent samples, one of which was used to find the parameters of the model of a given structure, and the other was used to verify the quality of the predictive properties of the obtained dependences.

The following equations most accurately described the experimental data [8,9].

I. To determine the $Pr_{11,13}$.

$$Pr_{11,13} = b_0 + \sum_{i=1}^{12} b_i x_i, \quad (1)$$

$i = \overline{1,3}\ x_i = \{T25, T26, T28\}$,
$i = 4,5\ x_i = \{K_{perd}, W_{pf}\}$,
for
$i = \overline{6,8}\ x_i = \{T25^2, T26^2, T28^2\}$,
$i = \overline{9,12}\ x_i = \{T25 \cdot C_{Al_2O_3}, T26 \cdot C_{Al_2O_3} \cdot T26 \cdot C_{(CaO+MgO)}, T28 \cdot C_{Al_2O_3}\}$.

$$Pr_{11,13} = b_0 + \sum_{i=1}^{13} b_i x_i, \quad (2)$$

$i = \overline{1,3}\ x_i = \{T25, T26, T28\}$,
$i = 4,5\ x_i = \{K_{perd}, W_{pf}\}$,
for
$i = \overline{6,7}\ x_i = \{T25^2, T26^2\}$,
$i = \overline{8,11}\ x_i = \{T25 \cdot C_{Al_2O_3}, T26 \cdot C_{Al_2O_3} \cdot T26 \cdot C_{(CaO+MgO)}, T28 \cdot C_{Al_2O_3}\}$,
$i = 12,13\ x_i = \{(T25 \cdot C_{Al_2O_3})^2, (T26 \cdot C_{Al_2O_3})^2\}$.

II. For the water absorption.

$$VP = c_0 + \sum_{i=1}^{6} c_i x_i, \quad (3)$$

$i = \overline{1,3}\ x_i = \{T25, T26, T28\}$,
$i = 4\ x_i = \{K_{perd}\}$,
for
$i = 5\ x_i = \{T26 \cdot C_{(CaO+MgO)}\}$,
$i = 6\ x_i = \{(T26 \cdot C_{(CaO+MgO)})^2\}$.

$$VP = c_0 + \sum_{i=1}^{8} c_i x_i, \quad (4)$$

$i = \overline{1,3}\ x_i = \{T25, T26, T28\}$,
$i = 4\ x_i = \{K_{perd}\}$,
for
$i = 5,6\ x_i = \{T25 \cdot C_{(CaO+MgO)}, T26 \cdot C_{(CaO+MgO)}\}$,
$i = 7,8\ x_i = \{(T25 \cdot C_{(CaO+MgO)})^2, (T26 \cdot C_{(CaO+MgO)})^2\}$.

$Pr_{11,13}$ - average strength values in the 13th row of the 11th group of packages, VP-absorption, K_{perd} degree of processing of raw materials, W_{pf} - relative residual moisture.

As a result of statistical analysis of the results of experimental studies, 20 factors were selected for inclusion in the model. Selecting the factors having a higher coefficient of pair correlation, equations were

obtained which, reaching structural saturation, did not include important factors, from the point of view of theory and practice, having smaller coefficients of pair correlation. Therefore, structural identification was conducted starting from different locations in the sample of factors. This explains the existence of two equations for each product property.

The obtained models were tested for adequacy. For this, Fisher's F-criterion was used [10]:

$$F = \frac{S_{ad}^2}{S_{втв}^2}\left\{\frac{N-(M+1)}{\sum_{u=1}^{U} P-u}\right\},$$

S_{ad}^2 - variability of adequacy

$$S_{ad}^2 = \frac{\sum(y_i - \hat{y}_i)^2}{N-M+1}$$

$(y_i - \hat{y}_i)$ is the experimental and modeled value of the brick indicators, respectively; N - number of points on which the model is built; M is the number of factors included in the model; $S_{\text{втв}}^2$- dispersion of reproducibility with the degree of freedom $k = \sum_{u=1}^{U}(P-u)$.

In the production environment it is practically impossible to create the same conditions for all kilns in order to calculate $S^2_{\text{втв}}$. The results of parallel experiments were considered values of qualitative indicators selected from the same places of different packages of the stove car.

$$S_{всп}^2 = \frac{\sum_{u=1}^{U}\sum_{p=1}^{P}(y_{pu}-M_u)^2}{\sum_{u=1}^{U}(P-1)},$$

U - the number of rows from which samples were taken; P is the number of selected bricks from each row.

Mathematical models (1) - (4) turned out to be adequate for experimental data at a significance level of a = 0.05.

The dispersion of adequacy was chosen as the criterion of model accuracy (5). Also, taking into account the interval of strength and water absorption estimates, the condition for the hit of the experimental and predicted values in one interval was checked. The results of the study of models (1) - (4) are given in Tables 1 and 2.

As can be seen from them, the values of the product indices calculated by the models (1), (4), have a smaller $S^2_{\text{ад}}$ and are more often in the same interval with the experimental values. The statistical analysis performed [3,6] showed that with the significance level α = 0.05, the accuracy of models (1) - (2) and (3) - (4) is comparable.

Comparison of the accuracy of the regression models (1) - (4) and other empirical dependences is given in Table 3.4 (calculations were carried out for the forecasting depth τ = 1, 2, 3).

Table 1. Comparison of experimental and predicted values for strength

№ points	1	2	3	4	5	6	7	8	9	10	…	21	22
$Pr_{11,13}$	11,0	9,8	11,4	17,9	7,3	8,4	20,4	19,1	11,7	15,2	…	11,0	8,7
$Pr_{11,13}$ (1)	11,5	11,3	14,4	19,0	8,1	8,6	19,1	19,6	11,7	14,0	...	11,1	8,7
S_{ad}^2	1,93												
Interval	+	-	-	+	+	+	-	+	+	-	…	+	+
$Pr_{11,13}$ (2)	11,4	10,6	11,5	17,7	8,1	7,0	20,0	18,6	11,5	15,6	…	11,6	8,7
S_{ad}^2	1,34												
Interval	+	-	+	+	+	-	+	+	+	+	…	+	+

Table 2. Comparison of experimental and predicted values for water absorption

№ points	1	2	3	4	5	6	7	8	9	10	…	21	22
$VP_{эксп}$	16,9	20,2	17,0	15,9	21,3	20,2	16,8	16,2	17,8	18,6	…	21,2	20,8
VP(3)	16,6	17,9	16,7	17,3	20,9	20,6	18,2	17,2	17,4	18,9	…	21,3	20,5
S_{ad}^2	0,61												
Interval	+	-	+	+	+	-	-	+	-	+	…	+	+
VP (4)	17,1	17,8	16,9	17,2	20,7	20,5	17,4	16,5	17,5	19,0	…	21,5	20,5
S_{ad}^2	0,57												
Interval	+	-	+	+	+	-	+	+	+	+	…	+	+

Table 3. Comparative analysis of the accuracy of empirical dependencies for strength prediction

Method	S_{ad}^2		
	τ = 1	τ = 2	τ = 3
1	2	3	4
Model (1)	1,34	1,97	2,54
Model (2)	1,93	2,79	3,12
Holt	21,68	24,71	16,04
Holt v Muir	22,20	26,61	16,10
Brown's Double Exponential Smoothing	18,82	25,37	15,02
Adaptive smoothing of Brown	15,12	16,28	16,91
Exponentially weighted mean	14,44	15,52	14,11
Moving Average	6,75	1,18	12,22

Table 4. Comparative analysis of the accuracy of empirical dependencies for predicting water absorption

Method	S_{ad}^2		
	τ = 1	τ = 2	τ = 3
1	2	3	4
Model (3)	0,61	1,12	1,03

Model (3)	0,61	1,12	1,03
Model (4)	0,57	1,09	0,98
Holt	3,17	4,25	3,78
Holtv Muir	3,21	4,39	3,90
Brown's Double Exponential Smoothing	10,59	12,95	12,80
Adaptive smoothing of Brown	3,02	2,65	2,62
Exponentially weighted mean	3,01	3,17	2,84
Moving Average	0,95	1,56	1,74

Conclusion

The accuracy of the models (1) - (4) at the significance level a = 0.05 is recognized higher than the accuracy of other empirical dependencies, therefore it was decided to use the created regression equations to predict the brick properties.

Analyzing the results obtained, it was decided to keep two models for each property, (2) and (4) to accept both the main ones, and (1), (3) - as competing with them.

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