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Utilization of the Statistical Method of Planned Experiment (PLANEX) for research of building materials properties

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Summary

The mathematical (statistical) Method of planned experiment (PLANEX) enable creation of mathematical models of choice for example building materials properties functionality (e.g. water absorption, strength) on selected independents of variables (for example value of firing temperature, quantity of cement) in selected intervals by force of statistically rated multinominals. All calculations are performed in MS Excel software. The paper describe particular example of PLANEX utilization in development of new ceramic bodies – ceramic tiles.

KEYWORDS: method of planned experiment (PLANEX), properties of building materials.

1. INTRODUCTION

The aim of the experimental laboratory work was to examine the fine fly ash from black coal as a basic raw material for the production of ceramic tiles and thus determine the properties of fired fly ash body at firing temperature interval from 1100 till 1200 °C prepared according to the standard requirements and processing of dry pressed ceramic tiles (wall and floor) – group B according EN 14411.

Table 1 – Choice requisite properties of ceramic tiles (group B).

Properties		BIa	BIb	BIIa	BIIb	BIII
Water absorption [%]	average individually	≤ 0,5 Max. 0,6	0,5 - 3 Max. 3,3	3 - 6 Max. 6,5	6 - 10 Max. 11	> 10 Min. 9
Bending strength [MPa]	average individully	≥ 35 Min. 32	≥ 30 Min. 27	≥ 22 Min. 20	≥ 18 Min. 16	≥ 15[1)]

[1)] for body thickness over 7,5 mm

2. EXPERIMENTS

The Method of planned experiment (PLANEX) was used, which enables the creation of mathematical models of choice fly ash body properties functionality

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(e.g. water absorption, bending strength) on selected independents of variables in selected intervals by force of statistically rated multinominals (table 2).

Table 2 – Selected intervals of independent variables in terms of PLANEX

Variables		middle (0)	interval of change	High mark (+)	Low mark (-)
X_1	Pressing pressure [MPa]	35	10	45	25
X_2	Firing temperature [°C]	1150	50	1200	1100
X_3	Soaking time [min]	20	10	30	10

PLANEX imposed composition of test mixtures 1 – 17 (table 3). In the table 3 there are showed determine properties of prepared test mixtures 1 -17 – firing shrinkage, bending strength, water absorption and bulk density. Software PLANEX computed mathematical models as polynomial functionality.

Table 3 – Test specimens and their properties by PLANEX

Type and number of mixture					**Firing shrinkage (FS)**	**Bending strength (R)**	**Water absorption (E)**	**Bulk density (B)**
No.	**Mixture type**	**X_1**	**X_2**	**X_3**	**[%]**	**[MPa]**	**[%]**	**[kg.m^{-3}]**
1	+++	45	1200	30	11,8	35,0	0,5	2135
2	++-	45	1200	10	11,1	32,2	2,0	2150
3	+-+	45	1100	30	4,7	13,6	19,5	1690
4	+--	45	1100	10	4,0	12,3	19,7	1685
5	-++	25	1200	30	13,3	33,1	0,5	2150
6	-+-	25	1200	10	10,6	31,5	1,0	2185
7	--+	25	1100	30	4,3	13,1	20,9	1660
8	---	25	1100	10	3,5	12,3	21,1	1650
9	+00	45	1150	20	7,0	23,1	15,4	1820
10	0+0	35	1200	20	12,4	38,4	0,7	2165
11	00+	35	1150	30	6,6	17,9	14,1	1810
12	-00	25	1150	20	7,0	17,1	17,0	1760
13	0-0	35	1100	20	3,5	14,3	18,9	1675
14	00-	35	1150	10	4,8	22,5	16,9	1765
15	000	35	1150	20	5,7	20,1	16,5	1790
16	000	35	1150	20	5,6	20,0	15,7	1815
17	000	35	1150	20	5,5	20,2	16,5	1795

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2.1. Firing shrinkage

$$FS = 837{,}27946 + 0{,}014992x_1 - 1{,}522375x_2 - 0{,}211326x_3 + \\ + 0{,}007964x_1^2 + 0{,}000699x_2^2 - 0{,}005036x_3^2 - 0{,}00045x_1x_2 + 0{,}0005x_2x_3 [\%] \quad (2)$$

Firing shrinkage of fly ash bodies is increased with increasing the firing temperature first of all (it is exposure to the sintering process). Firing shrinkage is not influenced very much by the pressing pressure. Also less expressive is the influence of final temperature soaking time duration (figure 1). Drying shrinkage reaches minimal values, and that explains why general shrinkage of firing fly ash ceramic body consists only of firing shrinkage.

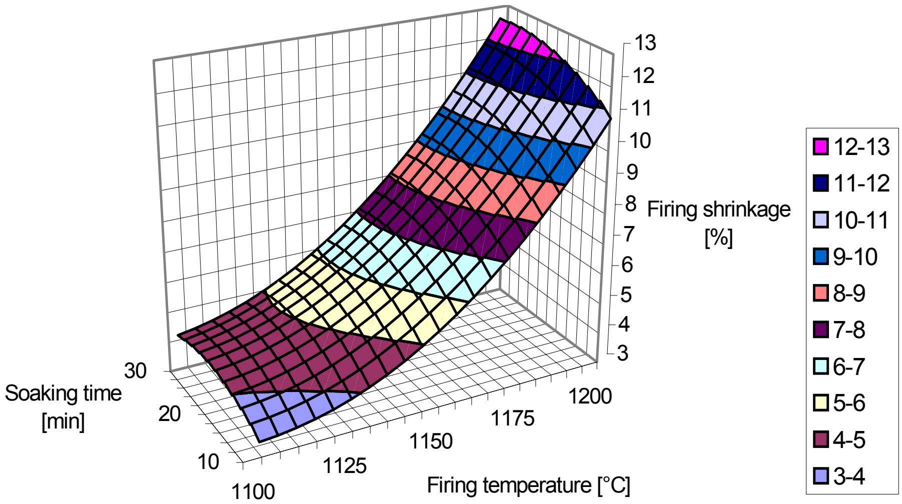

Figure 1. Firing shrinkage – constant pressing pressure 35 MPa

2.2. Water absorption

$$E = -2838{,}588989 - 1{,}629193\ x_1 + 5{,}207783\ x_2 - 0{,}0511\ x_3 \\ + 0{,}007467\ x_1^2 - 0{,}002361\ x_2^2 + 0{,}000928\ x_1x_2 [\%] \quad (3)$$

Water absorption (according to EN ISO 10545-3 by boiling method) also depends on sintering level of body, and thus corresponds to the shrinkage of fired fly ash body. Here again features height firing temperature, smaller influence on water absorption has the duration of final temperature holding time, however the influence of the pressing pressure is unconvincing.

Fly ash bodies, without any admixtures (only water), fired at a temperature of 1200 °C with a soaking time of 30 minutes run to water absorption in wheel diameter 0,5

% (abstractedly from pressing pressure), which is the limited value for so-called highly sintered tiles of type Gres Porcellanato (group BIa). Division qualities of fly ash body is stated in the table according to EN 14411 dependent on temperature slops and duration of soaking time in figure 2. It is evident that intensive sintering happens only after an overrun of firing temperature 1150 °C.

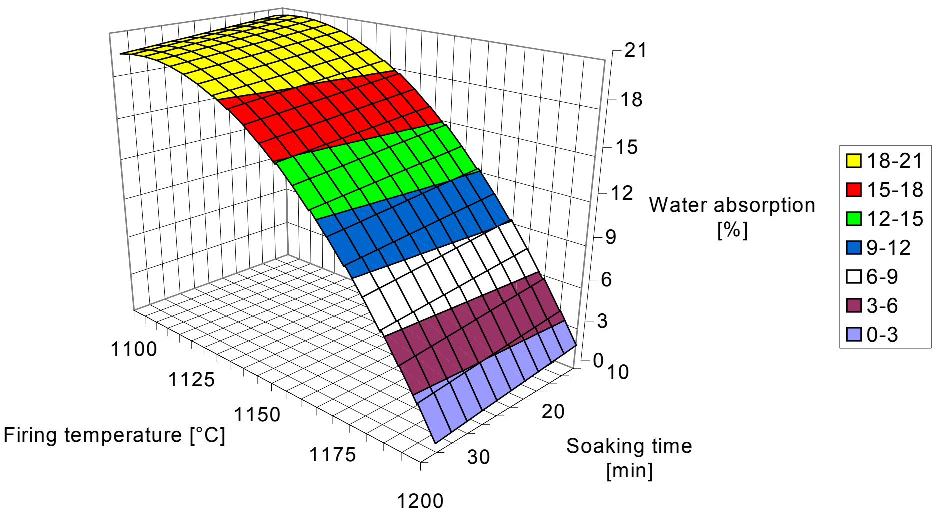

Figure 2. Water absorption - constant pressing pressure 35 MPa

2.3. Bending strength

$$R = 2343{,}18044 + 0{,}441102\, x_1 - 4{,}261184\, x_2 - 0{,}187281\, x_3 + 0{,}014234\, x_1^2 + 0{,}001931\, x_2^2 - 0{,}013234\, x_3^2 + 0{,}000525\, x_1 x_2 + 0{,}002125\, x_1 x_3 + 0{,}000575\, x_2 x_3 \left[MPa\right] \quad (4)$$

Bending strength (according CSN EN ISO 10545-4) generally corresponds to the water absorption of firing body. It is important the fact that the bending strength corresponds to the standard requirements for qualitative groups of ceramic tiles body according to Table 1.

Mild bending strength decreases in firing bodies, which have been pressed at a pressure of 45 MPa and firing at a maximal firing temperature (1200 °C) with the longest soaking time (30 min.) is necessary adjudicate for the rising of secondary closed porosity in body.

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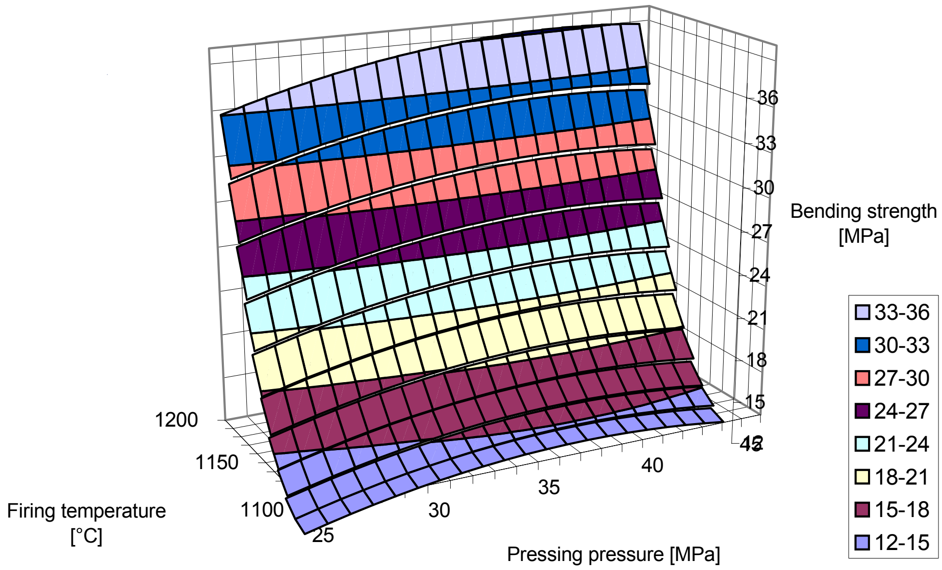

Figure 3. Bending strength – constant soaking time 30 min.

2.4. Bulk Density

$$B = 59595{,}1845 + 33{,}8125\,x_1 - 106{,}75347\,x_2 + 18{,}6875\,x_3 + 0{,}049106\,x_2^2 - 0{,}02875\,x_1x_2 - 0{,}01625\,x_2x_3\left[kg.m^{-3}\right] \quad (1)$$

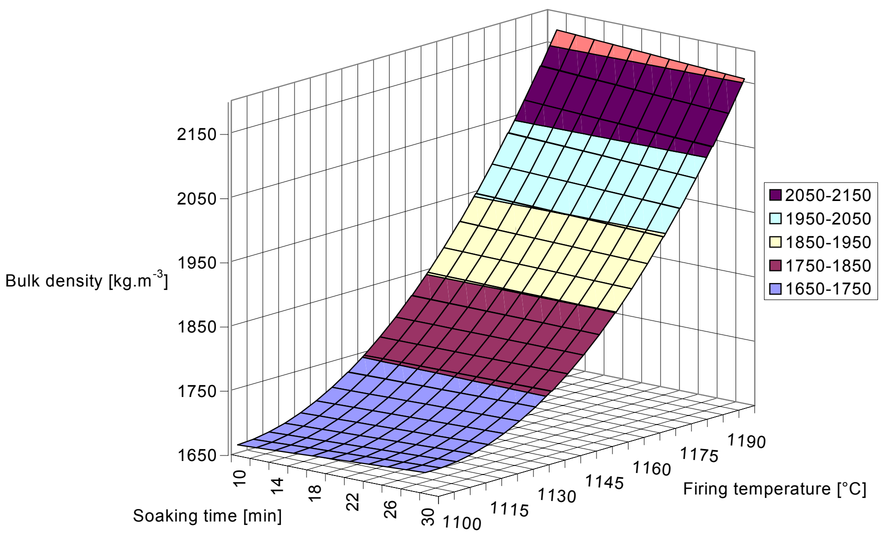

Figure 4. Bulk density – constant pressing pressure 35 MPa

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3. CONCLUSIONS

The paper showed a case study of Method of planned experiment (PLANEX), which enables to determine the regularity of the different variables influence (in this case for instance the value of pressing pressure, firing temperature etc.) on selected properties of the ceramic body (water absorption, strength etc.) with utilization of the planned experiment method and in view of the optimization of demanded properties of the ceramic body by evaluation of results with methods of mathematical statistics.

Under the term mathematical description of process properties (in this case the properties of the ceramic body) we understand the system of polynomial equations connecting the dependent variable with acting (affecting) variables. The dependent variables we call in the theory of experiment planning the variables characterizing the properties or the process. The acting variables in the examined process can express in arranged units the quality (type of opening material, fluxing agent etc.) or the quantity (mass of the individual admixture).

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