PRESENTATION OF TWO-DIMENSIONAL PROPERTY FUNCTION FOR CERAMIC FLOOR TILES

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This paper reports about the results of an investigation that deals with the influence of two physical quantities: sintering temperature and specific surface area onto the flexural strength as well as water absorption of floor tiles. It would in general propose mathematical models of numerous variables, but here the form of two-dimensional functions was found satisfactory.

Data basis used for the simple numerical procedure was obtained by the experiments performed with floor tiles prepared from three fractions of defined ratio and thermally treated in the temperature range from 850° C to 1150° C.

Property functions were accepted as the objective functions, whose extremes were found and used for defining the optimal working parameters.

INTRODUCTION

Mathematical model of ceramic system, which defines dependency of some important system property upon relevant independent variables, enables not only predicting of ceramics behavior for arbitrary chosen variables but optimizing the values of independent variables in a way to guarantee extremes (minimum or maximum) of concerning properties [1, 2, 3]. Whereas the great number of paremeters can be changed independently, some kind of problem simplification has to be applied. One of the possible ways is to exclude all less important varibles, i.e. to accept only those whose influence is dominant. In view of this, a two-dimensional function approach has been suggested.

One of the most important characteristic of sintered ceramic tiles, as far as mechanical properties are concerned, is the flexural strength, the higher the better. Also, the information about theirs ability to absorb water, as low as possible, is of interest. Both properties are functions of the interactions of many different phenomena such as: consolidation of raw material in powder state, changing the textural parameters of initial raw material under defining firing conditions and so on. All these phenomena are functions of powder characteristics, which are result of grinding procedure, as well as other technological parameters.

On the other hand, the particle size distribution of atomized powders and the sintering temperature are the two quantities which can be changed independently. But, defining their parallel influence onto the final feature of sintered product can be useful for the optimization procedure.

Although the problem of predicting the tiles behaviour and optimizing conditions of their producing is extremely interesting there are not many reports about investigations on that matter. In the paper [2] the Simplex-lattice mixture design was applied to three fractions of raw material, with different granular composition. They were combined and used for making floor tiles. A few important properties of dried as well as fired elements were measured and, at the same time, calculated by the correlations expressed as the functions of mentioned fractions. Finally, an optimization procedure was performed and the global optimum for flexural strength was found. So, important physical characteristics of ceramics were treated only as ones, from granulation dependent properties, without taking other variables into account.

In the paper [4], three-component system: $SrTiO_3$ – $BaTiO_3$ – $CaTiO_3$ had been analyzed with the aim to predict the influence of particular components upon the sintering temperature as a function, that was optimized in the work reported two years later [5] . Sintering temperature, adopted as the objective function, might serve as the basis for minimization energy requirements that is the problem of great practical importance.

This paper defines flexural strength as well as water absorption ability of floor tiles as the functions dependent on two already mentioned independent variables i.e. both sintering temperature and specific surface area, which is the characteristic of the particular ratio of the atomized powder, prepared from the same batch of the raw material.

EXPERIMENTAL INVESTIGATIONS

In order to settle an experimental basis for defining the mathematical models of tiles property i.e. for deriving the polynomials for prediction of both flexural strength and water absorption experiment was carried out on the three mixtures, whose contain the defined ratio of atomized powder fractions (Table I). Fractions A, B and C were separated by sieving from the industrial batch. The raw material,

Table I

Characteristics of mixtures concerning particle size distribution

Fraction	Medium size [μm]	Diameter for 30% [μm]	Diameter for 70% [μm]	Specific surf. area [m^2/kg]
A	345.26	287.48	404.82	28.7
B	356.16	301.49	414.66	102.0
C	43.54	25.95	78.06	240.6

Table II

Results of experiments

a) Flexural strength [MN/m^2]

Sintering temp. t [°C]	Fraction A $S_A = 28.7$ [m^2/kg]	Fraction B $S_B = 102.0$ [m^2/kg]	Fraction C $S_C = 240.6$ [m^2/kg]
850	5.56	4.87	4.35
950	20.03	22.26	19.74
1050	20.93	23.58	29.31
1150	31.74	30.16	31.86

b) Water absorption [%]

Sintering temp. t [°C]	Fraction A $S_A = 28.7$ [m^2/kg]	Fraction B $S_B = 102.0$ [m^2/kg]	Fraction C $S_C = 240.6$ [m^2/kg]
850	16.87	17.06	17.89
950	14.80	14.85	15.43
1050	11.82	11.98	12.55
1150	1.16	0.90	0.30

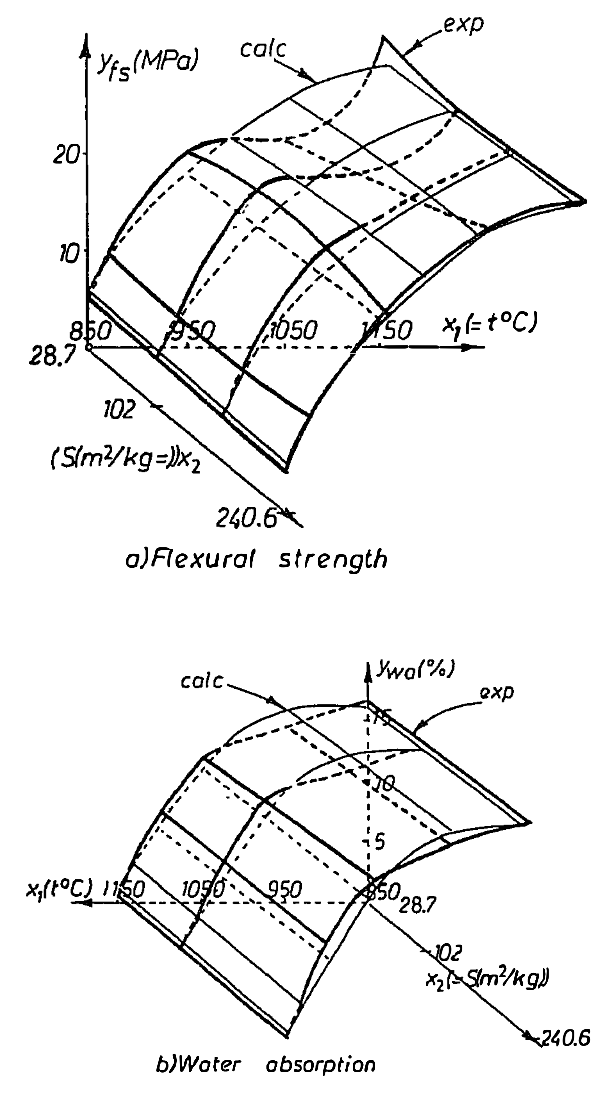

Fig. 1. Two-dimensional property functions.

obtained by drying procedure, presents a mixture of illite-kaolinite clays with a content of 27 mass percent carbonates (dolomite and calcite minerals). The fractions (from Table I) were the basis for preparation of model systems in laboratory scale (sample dimensions 120 × 80 × 10 mm, and pressure 4 – 7 MPa), which were thermally treated at 850°C, 950°C, 1050°C and 1150°C. The final products were tested by standard methods in order to determine their flexural strength as well as water absorption ability (Table II).

So performed experiment enables defining the influence of both parameters: sintering temperature and specific surface area onto product characteristics, which will be done by regression analysis. Specific surface area is chosen from all measured quantities as a parameter which substitutes other characteristics of particles (such as medium size, particle size distribution etc.). Other considered parameters were the medium sizes of particles of A, B and C – fractions. However, analysis of their values indicates the cluster nature of B fraction (unlike to the A – fraction), that eliminates particle diameter as an useful elementary parameter.

Table III

Comparative analysis of adequateness for some usually applied polynomials

No	Polynomial	Sum of squares of deviations between Exp. and Calc. values Flexural str.	Water absorp.
1	$y_1 = b_1x_1 + b_2x_2$	714.8	976.0
2	$y_2 = b_1 + b_2x_1 + b_3x_2$	130.6	72.1
3	$y_3 = y_2 + b_4x_1x_2$	125.6	71.2
4	$y_4 = y_3 + b_5x_1^2 + b_6x_2^2$	63.5	9.4
5	$y_5 = y_4 + b_7x_1^3 + b_8x_2^3$	69.0	29.9
6	$y_6 = y_4 + b_7x_1x_2(x_1 - x_2)$	53.4	9.3
7	$y_7 = y_6 + b_8x_1x_2(x_1 - x_2)^2$	53.0	9.2

RESULTS OF REGRESSION ANALYSIS

A few different two-dimensional polynomials were chosen as mathematical expressions of floor tiles behaviour. They can be reviewed in Table III along with the sum of squares of deviations between experimental and calculated values, which was adopted as a measure of polynomial adequateness.

It is obvious that the greater the number of parameters in the polynomial, the smaller the difference between measured and predicted values, although there are exceptions (eg. the third order polynomial – No 5 in Table III fitted worse than the second order polynomial – No 4 in Table III). Having in mind all relevant facts as well as giving the priority to the simpler forms, second order polynomial was chosen for simulation both flexural strength and water absorption ability (equation 4 in Table III).

Complete form of accepted correlations is as follows:

- for flexural strength:

$$y_{FS} = -281 + 0.532x_1 - 5.774 \times 10^{-2}x_2 + 6.594 \times 10^{-5}x_1x_2 - 2.284x_1^2 \quad (1)$$

- for water absorption:

$$y_{WA} = -164.878 + 0.407x_1 + 2.605 \times 10^{-2}x_2 - 2.682 \times 10^{-5}x_1x_2 - 2.280 \times 10^{-4}x_1^2 + 9.539 \times 10^{-6}x_2^2 \quad (2)$$

Graphical presentation of both two-dimensional property functions (1 and 2) is obvious from Fig. 1., together with experimentally determined values of flexural strength and water absorption.

It can be noticed that measured flexural strength values form a surface which has not only inflexion line, but there the region of points was found at which first order derivative (slope) of property function takes zero. Appearance of constant flexural strength for temperatures between 950 – 1050°C can be explained by changes in microstructure of examined systems. After 950°C some crystalline and glass phases appear causing the effect of stagnation both flexural strength and water absorption. The phenomenon is typical of all fractions (A, B and C) although some differences in the position and the length of the stagnation interval exist. It can be explained by the fact that changing in microstructure are extremely complexed functions of the system of textural characteristics, where the features of the particle form play the prime role.

This is why that the ordinary cubic polynomial (No 5 in Table III) fits experimental values worse than a quadratic one (No 4 in Table III). Its more complex modifications (polynomials No 6 and No 7 in Table III) do this better, but for the sake of simplicity were not suggested as mathematical models.

As far as water absorption is concerned the similar conclusion can be made, although stagnation of absorption values is not so evident as in the case of flexural strength. Therefore, adequateness of quadratic polynomial is quite satisfied.

OPTIMAL VALUES OF SINTERING TEMPERATURE AND SPECIFIC SURFACE AREA

Analysis of property functions (defined by equations (1) and (2)) shows that there is no need for difficult optimization, i.e. maximum of flexural strength and minimum of water absorption can be found without applying any of optimization techniques. Both quadratic functions show the monotonous course of y-values or, precisely, they are the typical examples of response surfaces whose do not have extremes for the region of interest. In such a case, the maxima or minima are always located at one of the boundaries and are easy to find.

Flexural strength increases approximately six times while rising of sintering temperature from 850°C to 1150°C, whereas water absorption decreases more than twenty times for the same change of temperature. On the other hand, influence of the second independent variable (specific surface area) upon the mentioned properties is almost negligible. However, one can notice a small increase of flexural strength as well as a small decrease of water absorption for the system C at the highest temperature.

Having in mind all simplifications, it can be concluded that the maximum of flexural strength and the minimum of water absorption will be reached under the conditions when one uses the mixture composed of small particles (great specific surface area) and heats it up to 1150°C.

CONCLUSION

It is well known, the quality of floor tiles is affected by far too many different factors so that it is impossible to take them into consideration all together particularly in a sole equation which describes the tiles behaviour. Assuming that the granular composition of raw powder as well as the sintering temperature are the most important variables. These two main quantities were chosen to be changed with the aim to investigate theirs influence on the two physical-mechanical tile properties: flexural strength and water absorption. Interesting results were obtained.

As far as sintering temperature is concerned, its influence on the tiles quality was undoubtedly and quite expectantly proved. Namely, flexural strength monotonously increases but water absorption monotonously decreases while rising the sintering temperature. Only a short stagnation interval was noticed, as a consequence of forming some crystalline and glass phases.

On the other hand, conclusions about specific surface area influence on the tiles quality are rather strange but this can be explained. It might be supposed that powder (C) which contains small particles will be better able to be sintered than the powder (A) consisting of large particles. But, this statement does not take into account the reactivity of raw material which can be so dominant as to eliminate the influence of granular characteristics [6]. This is obviously the reason why the powders behaviour might be independent of theirs granulation.

However, tiles properties were simply expressed as functions of both variables in order to find their values which guarantee maximum of flexural strength and, at the same time, minimum of water absorption. Once again was concluded that the sintering temperature influences the tiles quality much more than the granulation of raw powder, for the analyzed system.

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NÁVRH DVOJROZMĚRNÉ FUNKCE VLASTNOSTÍ KERAMICKÝCH DLAŽDIC

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Matematický model keramického systému definující závislost ohybové pevnosti a nasákavosti na příslušných nezávislých proměnných umožňuje jednak předpověď vlastností keramiky, optimalizaci nezávislých proměnných způsobem zaručujícím extrémy (maximum nebo minimum) dotyčných dvou vlastností. Obecně je takový model velmi složitý. Zde však byly, jako nejdůležitější proměnné, vybrány teplota výpalu a distribuční křivka velikostí částic (vyjádřená specifickým povrchem).

K vytvoření experimentální základny byly provedeny pokusy s třemi směsemi obsahujícími definovaný poměr jemné složky. Frakce A, B a C byly získány prosátím z půmyslové vsádky. Sušená surovina představuje směs illito-kaolinitových jílů s obsahem 27 hmotových % uhličitanů (dolomitové a vápencové minerály). Frakce vytvářejí základ k přípravě modelových systémů tepelně zpracovaných při teplotách 850, 950, 1050 a 1150°C.