Concerning the account of the edge effects in the ceramic item deformation

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Abstract: *We have examined the method of the account of the edge effects influence on the thin-walled ceramic items under their own weight during firing. This method is meant for the correction of the modeling results according to the FEM and includes the material samples tests.*
Key words: *ceramic items, prediction method, modeling, finite-element method, deformation, creep, viscosity.*

INTRODUCTION

To reduce the energy-output ratio of the ceramic items firing one uses active fluxes, and in this case the item tendency to deformation increases and the size precision decreases. Technological methods of the resistance to deformation rate by the optimum material composition and firing schedules are restricted by the material properties and the conditions of the specific production. Prediction of deformation with the use of CAE program at the projection stage makes it possible to reduce it by form correction and stiffening of the items structure. Usually the prediction methods are based on sample tests under compression and also on the calibration of the materials models properties, and should go through validation of the numerical solution.

For the account of the items deformation of different forms and wall thickness in the given firing conditions, the calibration method of the design parameter that is the base of the integrated approach [1] that allows prediction of the item deformation under its own weight during firing, was produced. Not only the results of the sample tests during pure shear ensure the prediction precision, but also the experimental data that define the edge effects influence. The calibration method appliance in terms of modeling deformation of the item, its form and loading conditions that are representative for most thin-walled ceramic items is the main object of this work.

During the deformation of the solid items like large-size electric insulators, the impact of the surface phenomena on the material rheology is small. To predict the deformation of the thin-walled items like light shells, it is needed to consider the edge effects, because their influence, as the wall thickness is reduced, becomes decisive. Multifactorial environment of the surface phenomena determines the practical impossibility of their detailed account. Instead of this, in the tasks that require the integrated approach, it is appropriate to apply the variables calibration with the coefficients that generalize the unaccounted events actions. The calibration ensures the needed precision rate of prediction and allows analyzing of the reasons of its deviations. The calibration method must be checked by the modeling material which is characterized by the broadest coverage of the known properties. Among fine-grained ceramic items we can consider the porcelain materials to be the most difficult for prediction because of their non-permanent composition and high tendency to deformation [3].

METHODOLOGY

The solution of the prediction task according to the FEM of the deformation of the porcelain thin-walled rings loaded with the shear load has been considered in this work [1]. To define, in the CAE program, the material that was presented by the Newton’s law for the viscous flow, we used the temperature dependence of the shear viscosity of the thin-walled cylindrical porcelain samples which were fired at a temperature of 900 °C [2]. The tests were made at the heat with the rate 2 °C/min to 1350 °C, with the following cooling along with the furnace. The sample deformation during testing was followed by the ovalization of its initial round form with its development gap in the part of the frontal plane of the symmetry from the similar deformation in the area of the end surface.

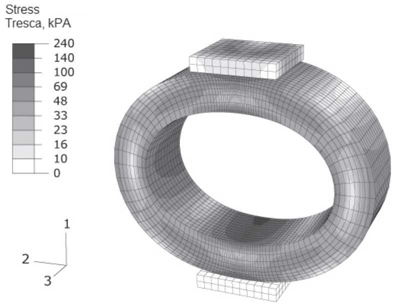

Fig.1. FE-model of the ring at the stage of calculating at a temperature of 1350 °C: distribution of the maximum shear stress (“Tresca stress”) on the end surface

The modeling was made in the statement for one part of the ring being cut by the frontal plane of the symmetry. Compressive stress on the ring was taken by the surfaces of the top and lower plates modeled as rigid bodies. The firing shrinkage was determined by the rate of the volumetric deformation with the corresponding anisotropy coefficients. Computer visualization of the modeling results (fig. 1) showed their full and high-quality correspondence to the experimental ones.

For quantitative comparison of the results we used the function *D* (*w*, *h*) defining the share (%) of the lateral deformation of the ring:

$$D = \frac{w-h}{w+h} \cdot 100\ \%$$

Where *w* and *h* — respectively the lengths of the horizontal and vertical axis of the oval that lays in the end surface of the inner circle of the initial ring. This function expresses the share of the ring deformation without reference to shrinkage and overall scale; its figures are located in the range from null, if there is no deformation, to 100 %, in case of contact of the top and lower surfaces of the ring inner circle.

The share of the lateral deformation of the ring *D* after firing under stress, in accordance with the experiment data, was (20±5) % with the confidence probability 0.80; and according to the FE-modeling data *D* = 17.4 %. The modeled deformation was less than the real one (by 13 %) because the influence of the edge factors enhancing deformation was not modeled at this stage.

In the firing of ceramic items the unaccounted surface phenomena appear to a variable degree according to the form complexity and technological conditions. The suggested calibration method distinguishes their influence on deformation and the material behavior during the pure shear processed with the main tools of the prediction method.

The calibration method includes

(i) experimental research of the deformation of the calibration sample

(ii) modeling of the deformation of the calibration sample according to the FE-method

(iii) comparison and analyzing of the modeling process and experiments results

(iv) application of the obtained data

Cantilevers-samples in the shape of rectangular beams were cut from relatively thin walls of the cylindrical workpieces molded as well as the thin-walled rings, by the cold slip casting, and went through the pre-firing at 900 °C. The tests were made by the item bend under its own weight; one end of each sample was fixed in the refractory equipment, at the same time that it is free — was working as a cantilever with the dimensions $4\cdot10^{-2}$; $1\cdot10^{-2}$; $0.25\cdot10^{-2}$ m. The thermal regime had the same heating rate as in the rings testing, but the maximum temperature was limited to 1300 °C. According to the testing results, the average deflection was $(0.60\pm0.16)\cdot10^{-2}$ m (confidence probability 0.95).

FE-model of the cantilever (fig. 2) was built with the dimensions equal to the corresponding experimental samples, and with the boundary conditions modeling the anchorage admitting volumetric deformation.

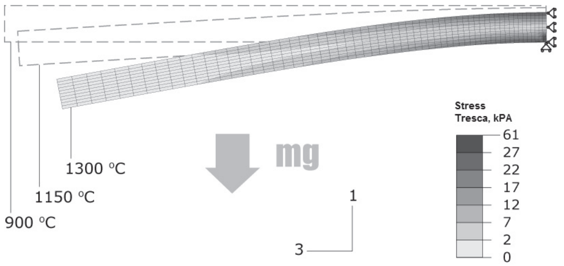

Fig. 2. The FE-model deformation at different stages of modeling being equal to the temperature, and the distribution of the maximum shear stress

The amount of the cantilever deflection resulting from modeling was also less than the real one, like in case of the ring model deformation. The relative deviation of the modeling results from the experimental ones was 21 %. This number was accepted as the amount of the calibration coefficient E_{cant} which reflects the degree of the influence of the edge effects on the cantilever deformation under its own weight.

To sum up, the E_f coefficient locally depends on the loading condition of the construction element of the workpiece and must increase as the form factor f equal to the proportion of the surface area to the construction element volume, grows. It was accepted that E_f depends with the direct proportion on the form factor f:

$$E_f = f \cdot K_{edge}$$

Where the proportion coefficient K_{edge} reflects the ratio of the influence of the edge effects under the given loading conditions and the firing environment on the rheological behavior of the material in the abstraction from the defined sample form with the use of form factor f allowing take into account the form change of the construction element, for example the wall thickness of the workpiece.

The coefficient definition K_{edge} ($2.1\cdot10^{-4}$ m) calculated with the account of the form factor of the cantilever allowed, in the deformation modeling, switching from the loading conditions of the pure shear to the conditions, in which the bend deformation dominate.

To make the modeling results of the ring deformation include the calibration data that account the edge effects influence, we found its form factor f and the coefficient

$$E_f = f \cdot K_{edge} = 807 \cdot 0.00021 = 0.17 .$$

CONCLUSIONS

In summary, the ring deformation calculated by the modeling with the account of the calibration coefficient, exceeded the deformation obtained in the results of the experiment, with the relative deviation of 4.7 % that confirmed the correctness of the method.

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This paper has been reviewed