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A novel design of compression unit for determination of optimal pressure under bilateral compression of ceramic products

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ABSTRACT

It has been given the design and general view of a unit for determination of settlement of press-powders under bilateral compression of ceramic products. The device of the fixed and movable holder-clamp for measuring settlement of the powder allows the use of compression unit in hydraulic presses of various designs. It has been shown the scheme of preparation of the press-powder from loam for testing the unit in the lab conditions. It was described in details the sequence of experimental determination of settlement of the press-powder under bilateral compression. The compression curves of the lower, upper, and total settlements of the press-powder are presented. The functional dependencies between the settlement and the pressing pressure were determined by the method of approximating polynomial. There are given the equations of the sixth order, which shows complete coincidence of the calculated and experimental compression curves. The compression unit and the method for determining optimal pressing parameters ensure the manufacture of defectless raw material without fractures of delamination and overpressing with considering particularity of material composition and technological properties of clay raw materials.

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1. Introduction

Ceramics used by man for their needs for a long time. The application area of it is quite various: from kitchenware to ceramic coatings of space rockets [1]. The ceramic products with natural stone and wood are also used in construction since antiquity. Building ceramics history has more than 5–7 thousand years [2].

1.1. Problem statement

Two methods of molding are most commonly used for making ceramic. The method of plastic molding is based on hand molding of raw material in molds or clay extrusion in an auger extruder [3,4]. A Plastic dough is prepared from high-quality clay with a moisture content of 23–27% by mass for this process [5]. The semi-dry pressing method of a brick is based on pressing of concentrated clay powders with moisture content typically 6–10% with a specific pressure of 12–30 MPa [6].

Recently, production of building ceramics is increasingly faced with the problem of reducing the reserves of high-quality natural clays [7,8]. Therefore, it is important to expand the ceramic raw material base by means of using a technogenic and low-quality natural raw materials [9–13]. For such raw materials, the most suitable method is the compression pressing of products using new mass preparation methods for the material [14].

The pressing process of defectless raw-brick is an important technological operation and depends on many factors [15]. It is necessary to apply the optimum pressing pressure depending on the type and condition of the raw material for the production of products without fractures of delamination and overpressing. Usually, the optimal parameters of pressing pressure and moisture of the press powder are selected empirically when developing the technology, and developed method of compression curves can be used [16].

1.2. Objective and research tasks

The investigation of influence of the method of application the compressing load on the pressing quality has been showed that

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it occurs more uniform distribution of the average density and water absorption along the height of ceramic products under bilateral pressing [17].

Modern presses and mold designs provide two-way compression of raw materials at existing semi-dry pressing brick factories. The aim of the current study was developing of novel design of a laboratory unit for determining settlement of press-powders under bilateral compression. In accordance with the aim, the following tasks have been solved:

- development and manufacture of the mold, providing bilateral compression of the press-powder;
- design and manufacture of the unit for bilateral fixation of settlement of press-powder depending on the applied pressure value;
- determination of settlement of press-powder from clay raw materials at its bilateral compression up to 50–60 MPa;
- graphic representation of compression curves for settlement of the lower and upper punches of the mold depending on the applied pressure value;
- pressing cylindrical samples under bilateral compression of press-powders.

2. Experiments

2.1. The design of the unit for determining the settlement of press-powders with bilateral compression

The developed device for determining the settlement of press-powders in assembled form consists of two parts: a mold for bilateral compression of powder (Fig. 1), and a platform with pointer gages to measure of the settlement (Fig. 2).

The steel structure of the press-mold consists of a hollow cylindrical matrix (Fig. 1a) and two movable corpulent punches (Fig. 1b and c). Under pressure of press table punches are move towards each other by vertical and compress pressing material with two sides in matrix (Fig. 3a). As a result, the mold provides bilateral pressing of samples of diameter 40 mm and height 35–45 mm. Height of samples depends on applied pressure value and press-powder parameters.

Design of the unit for determination of settlement of press-powders consist of base plate (Fig. 2a), there are fixed guiding pivot-rod (Fig. 2e) with fixed holder-clamp (Fig. 2c). Movable holder-clamp (Fig. 2d) is fixed on mold matrix (Fig. 1a) by means of fixing bolts. There are two pointer gages of settlement fixed on holder-clamps (Fig. 2b). The determination of settlement of upper punch was carried out with the pointer measurer, that fixed by immovable holder-clamp on guiding pivot-rod by means of fixing bolts. The determination of settlement of lower punch was carried out with the second pointer gage, that fixed by movable holder-clamp on matrix by means of tightening screw (Fig. 3a). As a measurer were used standard factory-made thickness indicator of construction type IH-10MN, IH-3.5MN.

The developed design of the fixed and movable holder-clamp allows applying the compression unit with using various hydraulic presses.

The general structural pattern of created unit for determination of settlement of press-powders under bilateral compression (Fig. 3a) and its picture (Fig. 3b) make a visual representation about its working on hydraulic press with bottom pressure.

2.2. Preparation technique of the press-powders from clay raw materials

Approbation of the created unit was carried out on the example of standard clay raw materials used in the semi-dry brick pressing technology [18]. In the current work it was used the loam from Novokuznetsk deposit. The material is low dispersed (the number of particles with a size of less than 0.001 mm is 20–30%). It has a low content of coarse-grained inclusions larger than 0.5 mm. Loam is a semi-acid, moderate plastic, low-melting raw material. According to the mineral composition, the clay raw material belongs to the montmorillonite-hydromica group. The non-plastic part of loam is represented by quartz, carbonates, feldspars, chlorite, and amphiboles [19].

Preparation of press-powders from loam was carried out by following scheme:

- clay raw materials were dried on air to residual moisture 6–8%;
- it was prepared the coarse grinding of loam at a laboratory jaw crusher to a particle size of no more than 30–40 mm;
- it was carried out the drying of loam to constant-mass in drying cabinet under temperature 100–105 °C;
- it was carried out the fine grinding of loam at a laboratory grinding mill to a particle size of no more than 1 mm;
- moistening of loam was performed in count to 8–10% by weight;
- it was made the moisture levelling and homogenization of press-powder. Moistened loam was grinded through a sieve with mesh size 1.2 mm and kept in desiccator during 5–6 h.

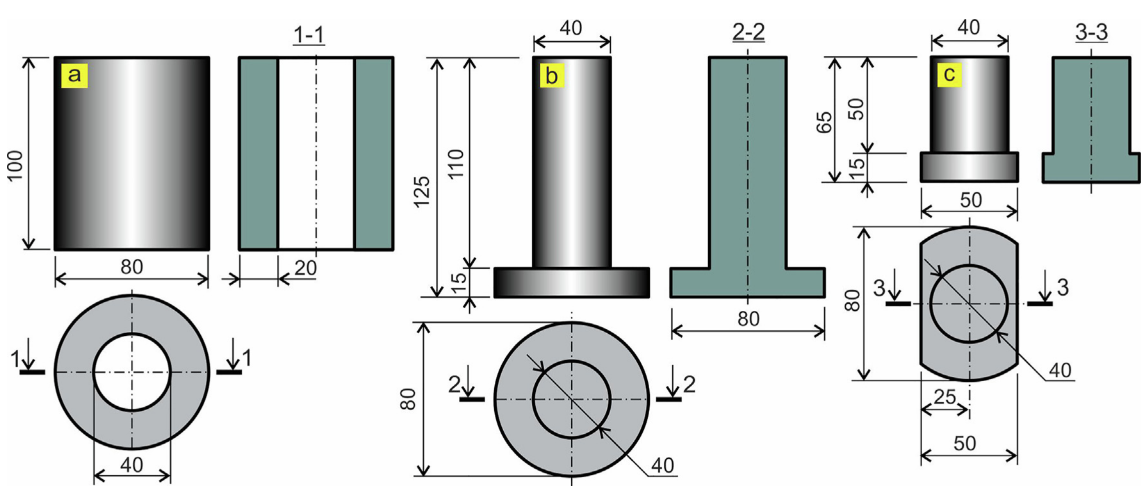

Fig. 1. Design of mold for bilateral pressing of ceramic samples: (a) cylindrical matrix; (b) upper punch; (c) lower punch.

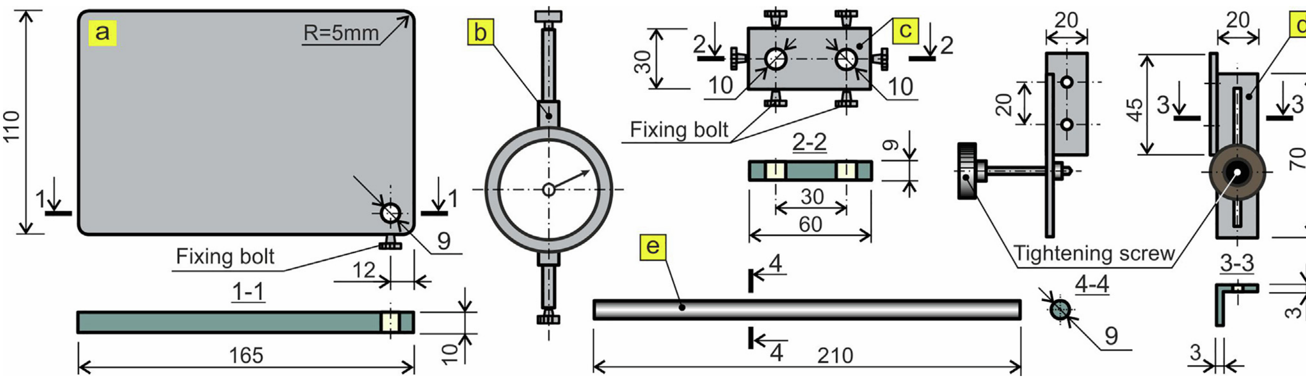

Fig. 2. Design of the labor unit for determination of settlement of press-powders under bilateral compression of ceramic products: (a) base plate; (b) pointer gage (2 pcs.); (c) fixed holder-clamp; (d) movable holder-clamp; (e) guiding pivot-rod.

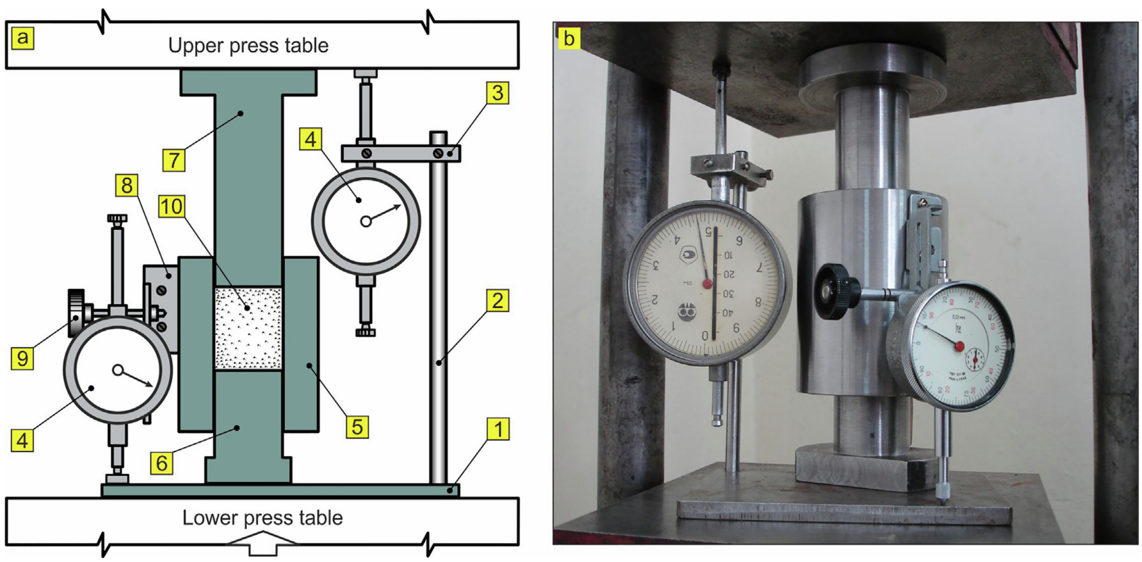

Fig. 3. (a) Scheme and (b) general view of the unit for determination of settlement of press-powders under bilateral compression of ceramic products: 1 – base plate; 2 – guiding pivot-rod; 3 – fixing holder-clamp; 4 – pointer measurer; 5 – matrix; 6 – lower punch; 7 – upper punch; 8 – movable holder-clamp; 9 – tightening screw; 10 – press-powder.

3. Results and discussion

During experimental studies setting up, the determination of settlement of press-powder from loam was carried out in the following sequence:

(1) the inner surface of the mold parts was lubricated to prevent its breakage and easier pushing of the pressed loam from the matrix;
(2) press powder from loam was poured into the mold (Fig. 1) for the entire height of the matrix. The matrix was gently shaken without manual compaction of the powder for its uniform backfill;
(3) the assembled compression unit with press powder (Fig. 3a) was placed on a laboratory hydraulic press. The base plate of the press fell to the contact with the punch mold. At the same time, there was no gap between them and no compaction of the powder was allowed due to excessive mechanical movement of the punch (Fig. 3b);
(4) with help of the holders-clamps, the dial gauges of powder precipitation were adjusted to their stop in the upper and lower plates of the press. After that, the indicator handles were set to zero position;
(5) a video camera was installed on a tripod (Fig. 4, a) for synchronously recording the readings of dial gauges during the pressing process;
(6) the loam was pressed under pressure up to 60 MPa. At the same time, it was provided an adjustable gradual increase of pressure. The increase in compression was carried out in 5–6 times faster compared with further loading of the press stamp at the initial stage. Simultaneously, the recording of dial indicators on a video camera was carried out in a continuous mode. The settlement of press-powder was fixed according to the indications of the press manometer with a step of 0.5–1 MPa with the help of a sound signal;
(7) the experimental results for determining the settlement of punches during the pressing process were processed in table form (Table 1).

They were established the graphical dependences of settlement of press-powder from loam with a moisture content of 9.8% by mass of the applied pressure according to the obtained experimental data. On the Fig. 4b shown the compression curves of separate settlement of press-powder from the pressure of the lower and upper punches and their general value.

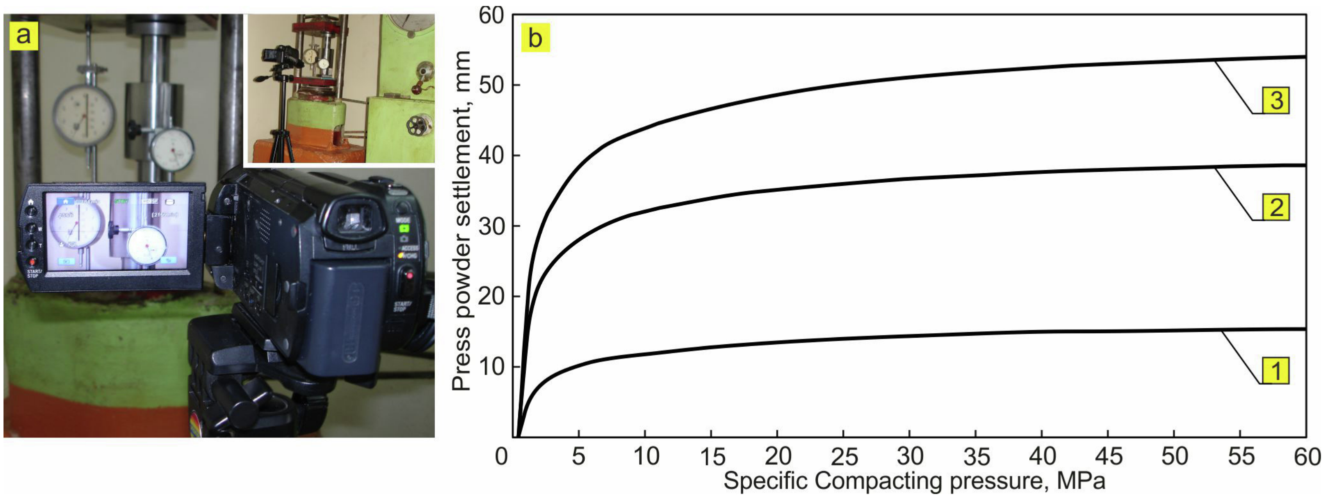

Fig. 4. (a) Videorecording of the settlement process of mold punches under two-sided compression on laboratory hydraulic press and (b) compression curves of loam with humidity 10.2%: 1 – settlement of lower punch; 2 – settlement of upper punch; 3 – general settlement.

Table 1
Measurement parameters of settlement of press-powder under bilateral mold compression.

Parameter name	Serial number of measurement (No, No)										
	1	2	3	4	5	...	71	72	73	74	75
Video recording time, sec	0:00	1:14	1:21	1:26	1:30	...	7:18	7:21	7:24	7:28	7:33
Pressing pressure, MPa	0.0	0.8	1.5	2.3	3.0	...	58.3	59.1	60.1	60.9	61.7
Value of settlement of the lower punch, mm	0.00	5.83	7.52	8.51	9.36	...	15.34	15.35	15.36	15.38	15.40
Value of settlement of upper punch, mm	0.00	17.75	22.15	24.35	26.25	...	38.55	38.57	38.59	38.63	38.65
General value of settlement, mm	0.00	23.58	29.67	32.86	35.61	...	53.89	53.92	53.95	54.01	54.05

The analysis of compression curves showed nearly the same character of dependence of settlement upper and lower punches of mold from pressing (Fig. 4b). That dependence can be expressed as power function: $\Delta h = aP^n \pm bP^m$, where Δh – settlement; P – compacting pressure; a, b, n, m – numerical coefficients.

For the numerical evaluation of the function Δh, it was used the authors' program of data processing by the method of approximating polynomial using the Chebyshev method [20]. Algorithm of the program determines an interrelation and calculates a functional dependence between parameters. The calculation results of function Δh 6th-order for lower, upper and general value of settlement of punches are given in formulas 1–3:

$$\Delta h = 4.942 + 2.144P - 0.311P^2 + 0.025P^3 - 0.001P^4 \quad (1)$$

$$\Delta h = 14.530 + 5.721P - 0.835P^2 + 0.067P^3 - 0.003P^4 \quad (2)$$

$$\Delta h = 19.472 + 7.865P - 1.146P^2 + 0.092P^3 - 0.004P^4 \quad (3)$$

The study of the functional dependence of all compression curves showed that the Δh 6th-order functions have polynomials higher than fourth degree with numerical coefficients close to zero and are not shown in formulas (1–3). The calculated and experimental data in the graphs completely match for equations of the sixth order.

In the investigated range of measurements according to the degree of increase in total precipitation Δh, the interval of pressing pressure can be divided into four sections: the first is 0–3 MPa; the second – 3–10 MPa; the third – 10–25 MPa; the fourth is 25–60 MPa for Δh of the upper and lower punches, the boundaries of the sections shift to the region of smaller values. The first section is characterized by a significant settlement Δh at low pressures due to the removal of air from the press powder and the mechanical convergence of particles – the initial pressing stage. The second section corresponds to a moderate Δh due to plastic irreversible deformation of loam grain – plastic (second stage) pressing. The third section is characterized by a gradual decrease in Δh due to the gradual cessation of plastic deformation of loam, the emergence and development of elastic deformations of particles – the plastic stage and the beginning of the elastic stage of pressing. The fourth section corresponds to the smooth attenuation Δh due to the lack of elastic deformation of the particles up to their brittle fracture – the elastic (third stage) stage of pressing and the beginning of the stage of mechanical destruction of the particles (fourth stage).

The developed unit for the removal of compression curves under bilateral compression of clay powder allows to set the pressure. The plastic and elastic deformations of particles begin and end under influence of this pressure.

4. Conclusion

The mold, laboratory unit and procedure for determining the settlement of press-powder under pressure were developed and tested on standard clay raw materials. Studies have been carried out on the preparation of the press-powder, the pressing of the sample, the fixation of changes in the deformations under bilateral compression, and the making compression curves. The novel design of compression unit and the method for determination of the optimal pressure parameters and moisture of press-powder [16] allow to developed a semi-dry pressing technology for a defectless raw-brick without fracture of delamination and repressing, taking into account the characteristics of the material composition and technological properties of clay raw materials.

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