Completeness of ceramic bricks’ quality control

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Abstract. The method of quality control of building materials is proposed taking into account the indicator of completeness of control. The completeness of the control calculated as the percentage of checked failures. By the example of quality control of ceramic bricks of brand 100, it is shown that the completeness of control of ceramic bricks of grade 100 is from 46.7 to 48.3%. This confirms the requirements of normative document on conducting performance checks (appearance, dimensions, deviations from nominal sizes and shapes, tensile strength in compression and bending, average density) during acceptance tests. Proposed to exclude verification of the width of the brick, which will reduce the complexity of the control.

1. Introduction

The controlled parameters of the ceramic bricks’ quality control following the regulatory documentation are determined and compared with the permissible values. Increased requirements for quality control arise in the assessment of energy-saving properties of masonry [1,2]. Of particular importance is the quality of the brickwork of the exterior walls [3–5]. Restoration of historic brick buildings [6,7] [8] begins with an assessment of the technical condition of the building [9]. Then comes the selection of bricks for the restoration of masonry. Quality control of hand-formed bricks for restoration is particularly difficult. Bricks made with waste [10–15] have their specifics of quality control.

If at least one of the measurement results is outside the boundaries of the tolerance specified for it, then the product is considered defective [16,17].

An important indicator characterizing the reliability of control is the completeness of control [18]. The completeness of control is a component of the reliable method of monitoring the technical condition of the product, characterizing the possibility of detecting failures in this product with the selected method of monitoring its technical condition [19–21]. A quantitative assessment of the completeness of control is determined from the ratio [22,23]

\[ V_k = \frac{N_k}{N} \] (1)

where \( N_k \) is the number of monitored parameters; \( N \) is the total number of parameters of the object.

Therefore, following Russian State Standard GOST 530-2012 “Ceramic brick and stone. General specifications” the quality of products is confirmed by acceptance inspection of finished products. Acceptance control includes acceptance tests and periodic tests. The total number of monitored indicators for testing ceramic bricks is 12, for acceptance tests is 5, for periodic tests is 7. Therefore, for acceptance tests, the assessment of completeness of control is 0.416, and during periodic tests is 0.58.
The completeness of the control is also calculated as a percentage from the controlled parameters according to the formula [24,25]:

\[ P_1 = \left( \frac{G - G_1}{G} \right) \times 100\% \]  

(2)

where \( G \) is the number of all considered parameters; \( G_1 \) is the number of unchecked parameters.

With the increasing complexity of the control object, the number of conditionally checked parameters usually increases. Two more formulas additionally used to assess the completeness of control:

\[ P_2 = \left( \frac{G - (G_1 + \sum_{k=1}^{m_k} G_2)}{G} \right) \times 100\% \]  

(3)

\[ P_3 = \frac{G - (G_1 - G_2)}{G} \times 100\% \]  

(4)

where \( G_2 \) is the number of conditionally checked indicators; \( m_k \) – is the probability of not checking the \( k \)-th parameter from among the conditionally checked.

Estimates \( P_1 \) and \( P_3 \) give the upper and lower boundaries of the possible values of completeness of verification. The value of \( P_2 \) (\( P_3 < P_2 < P_1 \)) is determined taking into account the probabilities of not checking conditionally checked parameters. With a large number of conditionally checked faults, \( P_2 \) can become the main assessment.

Different samples due to technological variation in their manufacture are characterized by a certain dispersion field (range of values) of quality indicators [26–28]. The values of the lower and upper boundaries of such an interval of the \( k \)-th controlled parameter during the \( i \)-th check of a fit product are denoted by \( a_{ik}^i \) and \( b_{ik}^i \), for a product with a possible defect, \( W_k \) are denoted by \( a_k^i \) and \( b_k^i \). The tolerance field for checking the controlled parameter \( W_k \) should include at least part of the interval \([a_0, b_0] \).

Therefore, for the parameter being tested the measure of completeness of control, for the unverified parameter \( m_k = 1 \), then for the conditionally checked parameter \( 0 < m_k < 1 \).

For a conditionally checked parameter on the \( i \)-th test, the probability of not checking the \( k \)-th parameter can be determined

\[ m_k^i = \int_{a_k^i}^{b_k^i} f(x) dx \]  

(5)

where \( f(x) \) is the probability density function of the values \( W_k \); \( a \) and \( b \) are the lower and upper boundaries of the region of common values for suitable and defective products.

The integral in the formula taken over the range of values that are common to healthy and faulty technical conditions. The value \( m_k^i \) is the probability that, if there is a defect in the monitoring object, the measurement result will fall into the interval \([a, b] \).

2. Materials and methods

The tests were conducted in the laboratory of the department "Technology of building materials and woodworking" of Penza State University of Architecture and Construction. For tests, brick of grade 100 of plant LLC "Wall Materials" of the city of Penza was used. The number of bricks was 60 pieces. The following indicators were evaluated: compressive strength, flexural strength, average density, coefficient of thermal conductivity, length, height, width.

Product dimensions were measured with a metal ruler. The compressive strength was calculated by the formula

\[ R = \frac{P}{S} \]  

(6)

\( P \) is the greatest load established during the test of the sample, \( N \);

\( S \) is the cross-sectional area of the sample.

The bending strength was determined as follows. A brick sample was installed on two press supports. The load was applied in the middle of the span. The bending strength was calculated by the formula
\[ R = \frac{3P_l}{2bh^2} \]  \hspace{1cm} (7)

\( P \) is the largest load established during testing of the sample, MN;
\( l \) is the distance between the axes of the supports, m;
\( b \) is sample width, m;
\( h \) - sample height, m.

The average density was calculated by the formula
\[ \rho = \frac{m}{V} \]  \hspace{1cm} (8)

\( m \) is sample weigh, kg;
\( V \) is sample volume, m³.

3. Results and discussions

Let now several checks are carried out and several controlled parameters are measured. If we assume that the values are not correlated, then
\[ m_k = \prod_{i=1}^{k} m_{i,k} \]

The definition of a function \( f(x) \) is usually fraught with significant difficulties. Most often, the controlled parameters are normally distributed random variables with a mathematical expectation that coincides with the nominal value and a given standard deviation \( \sigma \). The maximum permissible deviation from the nominal value is \( \pm 3\sigma \). Then
\[ m_k = \frac{1}{\sigma \sqrt{2\pi}} \int_{a}^{b} e^{-\frac{(x-x_0)^2}{2\sigma^2}} \, dx \]  \hspace{1cm} (9)

The calculations of \( m_k \) are greatly simplified if there assume that there is a uniform distribution law. In this case, the value is the ratio of the length of the interval of values common to the technical states “suitable” and “unsuitable” to the length of the interval of the scattering field in the presence of defectiveness, for example
\[ m_k = \frac{b_k-a_k}{b_{k_0}-a_{k_0}} \]  \hspace{1cm} (10)

The completeness of control on the example of ceramic bricks evaluates using formulas (2-4) following Russian State Standard GOST 530-2012 “Ceramic brick and stone. General specifications”, the quality of products is confirmed by acceptance control of finished products. Acceptance control includes acceptance tests and periodic tests. During acceptance tests, determine the appearance, dimensions, deviations from the nominal dimensions and shape, tensile strength under compression and bending, average density. During periodic tests, determine these same indicators, excluding average density, and additionally the presence of calcareous inclusions, water absorption, initial adsorption rate water, freeze-thaw resistance, voidness, specific effective activity of natural radionuclides. Consider the completeness of control during acceptance tests of brick KR-250 250 65 65 / 1NF / 100 / 2.0 / 50 / GOST 530-2012.

According to the results of acceptance tests, the following results were obtained (Table 1).

The results of the calculation of the assessment of the completeness of control of brick quality indicators are given in Table 2, 3.

Table 1. Values of brick quality indicators during acceptance tests

| Parameters                        | Regulatory interval | Checks |
|-----------------------------------|---------------------|--------|
| Compressive strength [MPa]        | 100-125             | 102-120| 100-115| 95-129| 108-121| 105-129| 108-128|
| Flexural strength [MPa]           | 2.2-2.5             | 2.1-2.4| 2.2-2.6| 2.3-2.5| 1.9-2.5| 2.1-2.4| 2.1-2.3|
| Average density, [kg/m³]          | 1410-2000           | 1600-1800| 1700-1900| 1750-2000| 1800-2100| 1600-1900| 1700-1900|
Using the previously calculated \( m_i \) values for conditionally checked parameters, we determine the value of the completeness of control by the formula (3). The calculation results are given in Table 4.

Analysis of Table 2 indicates that the control completeness indicator for the brick width is \( m_k = 1 \), i.e. during acceptance tests, this indicator can be excluded.

Thus, in the case under consideration \( G = 7 \), the number of unverifiable parameters \( G_1 = 1 \), the number of conditionally verified parameters \( G_2 = 5 \).

Using the previously calculated \( m_i \) values for conditionally checked parameters, we determine the value of the completeness of control by the formula (3). The calculation results are given in Table 4.

Table 2. Brick Quality Control Completeness Values

| Parameters                          | Normal distribution | Uniform distribution |
|------------------------------------|---------------------|----------------------|
| Compressive strength [MPa]         | \( m_k \)           | \( m_k^1 \)          |
| Flexural strength, [MPa]           | \( m_k \)           | \( m_k^2 \)          |
| Average density, [kg/m\(^3\)]     | \( m_k \)           | \( m_k^3 \)          |
| Coefficient of thermal conductivity| \( m_k \)           | \( m_k^4 \)          |
|                                    |                     | \( m_k^5 \)          |
|                                    |                     | \( m_k^6 \)          |

Table 3. Assessment of the completeness of control of brick indicators during acceptance tests

| Parameters                          | Characteristic       |
|------------------------------------|----------------------|
| Compressive strength               | conditionally verifiable |
| Flexural strength                  | conditionally verifiable |
| Average density                    | conditionally verifiable |
| Coefficient of thermal conductivity| verifiable            |
| Length                             | conditionally verifiable |
| Width                              | unverifiable          |
| Height                             | conditionally verifiable |

Table 4. Completeness of brick control during acceptance tests

| Probability distribution          | Completeness of control |
|-----------------------------------|-------------------------|
| Normal distribution               | \( P = \frac{7 - (1 + 0.87 + 0.432 + 0.008 + 0.499 + 0.82)}{7} = 0.483 \) |
| Uniform distribution              | \( P = \frac{7 - (1 + 0.52 + 0.11 + 0.667 + 0.574 + 0.857)}{7} = 0.467 \) |
The analysis of Table 4 shows that the influence of the probability distribution hypothesis is minimal [29]. Assessment of the completeness of control of ceramic brick KR-p-250 250 65 /1NF / 100 / 2.0 / 50 / GOST 530-2012 is 46.7-48.3%. This confirms the requirements of Russian State Standard GOST530-2012 on the verification of these indicators (appearance, dimensions, deviations from nominal sizes and shapes, tensile strength in compression and bending, average density) during acceptance tests. There can be excluded checking the width of the brick, which will slightly reduce the complexity of the control.

4. Conclusions
This study describes the procedure for completing the quality control of building materials using ceramic brick as an example.

1. It is shown that during acceptance tests, the completeness of control of ceramic bricks of grade 100 is 46.7-48.3%.
2. There can be excluded checking the width of the brick, which will slightly reduce the complexity of the control.

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