

Evaluation of measurement uncertainty for the determination of the mechanical resistance of the brick samples by using uniaxial compressive strength test

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Abstract. Clay bricks are the most important engineering materials that can influence the quality of the construction. The quality control of the clay bricks is of prime importance to improve the quality of engineering construction. The qualities of bricks for construction applications should be checked for various types of inspection services. In this article, our inspection service was focused on compression strength test on bricks to determine their mechanical resistance and suitability for construction work. The accurate method for clay brick's production measurements has been elaborated using uniaxial compressive strength testing machine. The method was tested for a rectangular clay brick manufactured with size approximately 250 mm × 250 mm × 200 mm. The measurement method and standard uncertainty estimation of uniaxial compressive strength are briefly described in this article.

Keywords: clay brick's production / inspection services / uniaxial compressive strength / standard uncertainty

1 Introduction

Clay brick materials are the oldest building materials in the world and are still immensely popular [1]. It can be used for a variety of applications such as single-family houses or apartment blocks, office or public buildings, and for all architectural styles.

In the last two decades, many manufacturing companies in Albania have been focused on the production and distribution of brick materials made of clay. Furthermore, Edilcentro Ltd. is one of the leading companies in Albania in the field of bricks' production of high quality. In this company, the phases of clay bricks' production are under automatic control and permanent supervision of the technological process [2]. Figure 1 depicts the technological scheme of clay brick's production.

According to this scheme of the automation process, it is clear that inspection services play an important role in ensuring the quality of the clay brick's production. The

qualities of bricks for construction applications should be checked for various types of inspection services. Some of the inspection services would be related to absorption test, compression strength test, hardness test, shape and size, color test, soundness test, structure of brick, and presence of soluble salts.

Our research work has been focused on compression strength test on bricks to determine their mechanical resistance and suitability for the construction work. One of the basic and most used methods of testing which is performed on brick samples is the determination of uniaxial compressive strength [3]. Similar testing has been performed successfully on other types of materials such as concrete, rocks, and metals with some differences in testing procedures and minimum measurement equipment properties [4–7]. Furthermore, according to the American Society for Testing and Materials (ASTM) specifications, we have performed compression testing for the determination of the properties of clay brick materials.

In this article, we have briefly described the measurement method and standard uncertainty estimation of

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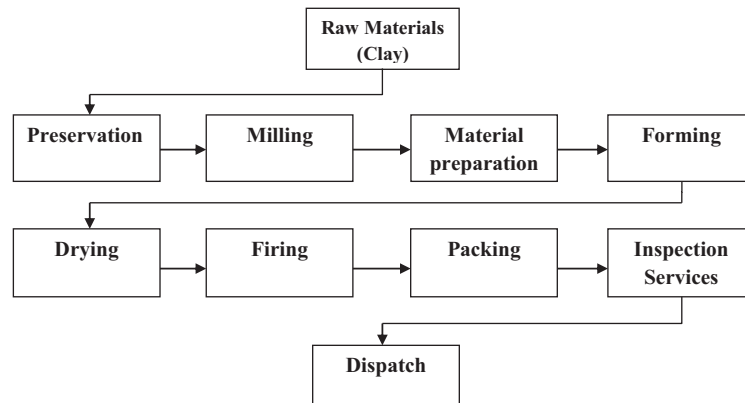


Fig. 1. Technological scheme of clay brick's production.

measured uniaxial compressive strength which would depend on the force applied to the sample.

2 Measurement method

The uniaxial compressive strength machine is located in the laboratory of the manufacturing company Edilcentro Ltd., Albania. The complete range of the uniaxial compression strength machine was designed to meet the demands of our laboratory as shown in Figure 2. Compressive load was applied in displacement control on clay bricks using MTS servo-hydraulic actuator. Load and displacement measurements were recorded in real time using a computer-based data acquisition system.

The measuring range of the uniaxial compression testing machine varied from 0 to 500 kN. The function of the uniaxial compression testing machine consists in applying the load to the surface area of materials that will be tested. The load frame provides the stability required for accurate test results. A small number of indirect compressive strength tests have been developed, primarily in order to allow *in situ* quality control testing of materials. The compression testing was performed according to ASTM and ISO specifications [5–8]. In the present test set-up, 10 specimens of clay bricks were tested for determining their mechanical resistance. The manufactured clay bricks had approximate length, width, and height of 250, 250, and 200 mm, respectively.

In the measurements, the clay bricks were generally placed in-between two plates that distribute the applied load across the entire surface area of two opposite faces of the test sample and then the plates are pushed together by a uniaxial compressive testing machine. A compressed clay brick was usually shortened in the direction of the applied forces, and load measurements were recorded in real time using a computer-based data acquisition system. The uniaxial compressive strength of the test specimens was calculated by dividing the maximum compressive load on the specimen by the initial cross-sectional area. A compressive strength measurement and the surface area of each clay brick are given in Table 1.

3 Uncertainty of uniaxial compressive strength

Uniaxial compressive strength is the quantity that is indirectly determined by the measurement which depends on the force applied to the sample. Sample stress σ of uniaxial compressive strength is evaluated as the ratio of maximum applied force F_{\max} and sample cross-sectional area A in the beginning of the test according to equation (1).

$$\sigma = \frac{F_{\max}}{A}. \quad (1)$$

In accordance with equation (1), the measurement uncertainty of stress will depend uncertainty of the force and the uncertainty of cross-sectional area. A *Guide to the Expression of Uncertainty in Measurement* (GUM) has been used to establish the general rules for identifying sources of uncertainty and evaluating the measurement uncertainty [9]. Before starting an evaluation of uncertainty, the uniaxial compressive strength measurement model has been defined by taking into account influence sources of uncertainty which can be expressed as follows [9–12]:

$$y = x + K_{F1} + K_{F2} + K_{F3} + K_{F4} + K_{F5} + K_{F6} + K_{F7} + K_A, \quad (2)$$

where x is the measurement value of the uniaxial compressive strength, K_{F1} is the correction from calibration of uniaxial compressive strength machine, K_{F2} is the correction that arises from load application rate to sample test, K_{F3} is the correction that arises from the preservation condition effect on compression resistance of a sample, K_{F4} is the correction that arises from the effect of planarity on compression resistance of a sample, K_{F5} is the correction with respect to the angle of the surface plane between the sides, K_{F6} is the correction that comes from sample centering, K_{F7} is the correction from reading of applied load, and K_A is the correction that arises from reading of the sample cross-sectional area.



Fig. 2. Test set-up for compression testing of clay brick.

Based on the law of propagation of uncertainty and uncertainty of input quantities, we can evaluate combined uncertainty as expressed below:

$$u_c^2(y) = \sum_{i=1}^n \left(\frac{df}{dx} \right)^2 \cdot u^2(x_i), \quad (3)$$

where $u(x_i)$ is the standard uncertainty of the input quantities and $c_i = df/dx$ is the sensitivity coefficient.

Table 1. Summary of test results on clay bricks.

Measurement No.	Force (N)	Length (mm)	Width (mm)
1	138592.8	249	249
2	138865.2	250	250
3	138048.0	250	249
4	138592.8	250	250
5	138948.0	249	249
6	138593.4	250	249
7	138079.0	249	250
8	138762.4	249	249
9	138487.0	249	249
10	138072.0	249	249

According to the input quantities, the combined uncertainty could be expressed as follows:

$$u_c^2(y) = c_1^2 \cdot u_{F1}^2 + c_2^2 \cdot u_{F2}^2 + c_3^2 \cdot u_{F3}^2 + c_4^3 \cdot u_{F4}^2 + c_5^2 \cdot u_{F5}^2 + c_6^2 \cdot u_{F6}^2 + c_7^2 \cdot u_{F7}^2 + c_8^2 \cdot u_A^2, \quad (4)$$

where u_{F1} is the calibration uncertainty of uniaxial compressive strength machine, u_{F2} is the uncertainty of the load application rate to sample test, u_{F3} is the uncertainty of the preservation condition effect on compression resistance of a sample, u_{F4} is the uncertainty of the effect of planarity on compression resistance of a sample, u_{F5} is the uncertainty with respect to the angle of the surface plane between the sides, u_{F6} is the uncertainty of sample centering, u_{F7} is the standard uncertainty of the reading of applied load, and u_{F8} is the standard uncertainty of the reading of sample cross-sectional area.

As the calibration uncertainty contribution, the specifications of the uniaxial compressive strength machine are used [8,9,13]:

$$u_{F1} = \sqrt{\left(\frac{U_{F1}}{k} \right)^2 + \left(\frac{F_a}{\sqrt{3}} \right)^2}, \quad (5)$$

where U_{F1} is the expanded calibration uncertainty of the machine which corresponds to 250 N with a coverage factor $k=2$ and F_a is the test device scale which corresponds to 1000 N.

Since it was difficult to quantify more accurately the effect of load application rate on the sample test, we have assumed for simplification of the technical documents that evaluation of the uncertainty will be expressed as follows [6,11–14]:

$$u_{F2} = 2\% \cdot F_{\max} = \frac{2}{100} \cdot F_{\max}, \quad (6)$$

where F_{\max} is the maximum applied force on the clay brick materials. We have used similar assumptions for the

Table 2. Sources of uncertainties associated with their values.

Sources of uncertainties	Standard uncertainty, u_i	Probability distribution	Sensitivity coefficient, c_i	Uncertainty (N/mm ²)
Calibration, u_{F1}	590.4 [N]	Rectangular	1.61×10^{-5} [1/mm ²]	9.49×10^{-3}
Load application rate, u_{F2}	2778.9 [N]	Rectangular	1.61×10^{-5} [1/mm ²]	4.46×10^{-2}
Preservation condition effect, u_{F3}	2084.2 [N]	Rectangular	1.61×10^{-5} [1/mm ²]	3.35×10^{-2}
Effect of planarity, u_{F4}	2084.2 [N]	Rectangular	1.61×10^{-5} [1/mm ²]	3.35×10^{-2}
Angle of surface plane, u_{F5}	138.9 [N]	Rectangular	1.61×10^{-5} [1/mm ²]	2.23×10^{-3}
Sample centering, u_{F6}	694.7 [N]	Rectangular	1.61×10^{-5} [1/mm ²]	1.11×10^{-2}
Reading of applied force, u_{F7}	105.1 [N]	Normal	1.61×10^{-5} [1/mm ²]	1.69×10^{-3}
Reading of sample area, u_A	73.4 [mm ²]	Normal	3.59×10^{-5} [N/mm ⁴]	2.64×10^{-3}
Combined uncertainty $u_c(y)$, $k = 1$				1.39×10^{-1}
Expanded uncertainty U , $k = 2$				2.78×10^{-1}

evaluation of the other sources of uncertainty which can be expressed as follows:

$$u_{F3} = 1.5\% \cdot F_{\max} = \frac{1.5}{100} \cdot F_{\max}, \quad (7)$$

$$u_{F4} = 1.5\% \cdot F_{\max} = \frac{1.5}{100} \cdot F_{\max}, \quad (8)$$

$$u_{F5} = 0.1\% \cdot F_{\max} = \frac{0.1}{100} \cdot F_{\max}, \quad (9)$$

$$u_{F6} = 0.5\% \cdot F_{\max} = \frac{0.5}{100} \cdot F_{\max}. \quad (10)$$

The standard uncertainty due to the reading of indications of applied load is calculated as the standard deviation of the readings of applied loads S_{F7} , expressed as follows [8,9]:

$$u_{F7}^2 = \frac{S_{F7}^2}{n} = \frac{\frac{1}{n-1} \sum_{i=1}^n (x_i - x_m)^2}{n}, \quad (11)$$

where n is a complete set of measurement values, x_i is the individual measurement value, and x_m is the arithmetic mean of individual measurements.

The standard uncertainty due to the reading of indications of the sample cross-sectional area u_A is expressed as follows [15]:

$$u_A^2 = x_W^2 \cdot u_L^2 + x_L^2 \cdot u_W^2, \quad (12)$$

where x_W and x_L are the reading values of the width and length for the sample cross-sectional area which can be evaluated as follows:

$$x_W^2 = w_m^2 + \Delta_w^2, \quad (13)$$

$$x_L^2 = l_m^2 + \Delta_l^2, \quad (14)$$

where l_m is the mean value of length, w_m is the mean value of the width, Δ_l is the correction from readings of length, and Δ_w is the correction from readings of width which are $\Delta_l = \Delta_w = 0$.

The standard uncertainties of the length u_L and width u_W are evaluated as follows:

$$u_L^2 = u_l^2 + u_{\Delta_l}^2, \quad (15)$$

$$u_W^2 = u_w^2 + u_{\Delta_w}^2, \quad (16)$$

where u_l and u_w are the standard deviations of the readings of length and width, respectively, and u_{Δ_l} and u_{Δ_w} are the relative uncertainties of length and width, respectively, which are $u_{\Delta_l} = u_{\Delta_w} = 0.05$ mm.

The final evaluation of equation (12) can be expressed by equation (17):

$$u_A^2 = (w_m + \Delta_w)^2 \cdot (u_l + u_{\Delta_l})^2 + (l_m + \Delta_l)^2 \cdot (u_w + u_{\Delta_w})^2. \quad (17)$$

The sensitivity coefficient of the applied force and cross-sectional area were calculated from equation (1).

In the end, we can evaluate combined standard uncertainties according to equation (6), and expanded uncertainty U is obtained through multiplication by coverage factor $k = 2$, as expressed in the following equation:

$$U = k \times u_c(y). \quad (18)$$

Furthermore, using the above equations, we can summarize in Table 2 all the sources of uncertainties associated with their values.

According to equations (1) and (18), the estimated results of the sample stress of uniaxial compressive strength have shown that expanded uncertainty of 2.23 N/mm² (estimated value) was 0.28 N/mm².

As can be seen, the larger uncertainty components arise from load application rate to sample test, preservation condition effect on compression resistance of a sample, effect of planarity on compression resistance of a sample, and sample centering.

The difficulties in quantifying more accurately the effect of a load application rate to sample test, preservation condition effect on compression resistance of a sample, and effect of planarity on compression resistance of a sample have influenced the uncertainty measurement results. The alignment in manual way of the sample centering has also influenced the uncertainty measurement results. Therefore, further research work will be focused on the improvement of the largest uncertainty components.

4 Conclusions

This article describes measurement method and contributions to uncertainty of results obtained by testing of clay brick's production. The accuracy of clay brick's production results can be extracted through evaluation of measurement uncertainty. Our measurement model can be used for most of the rectangular types of clay brick's production measured by uniaxial compressive testing machine at good accuracy. The method was tested for a rectangular clay brick manufactured with size approximately 250 mm × 250 mm × 200 mm. The expanded uncertainty of 2.23 N/mm² was 0.28 N/mm². The thorough uncertainty analysis has shown that larger uncertainty arises from load application rate to sample test, preservation condition effect on compression resistance of a sample, effect of planarity on compression resistance of a sample, and sample centering.

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