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The influence of deformation of the frame of testing device to the accuracy of Brazilian test

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Abstract. This article deals with determination of mechanical properties based on indirect measurements of brittle building materials like stones using portable device. Due to the fact, that the material samples may change their properties during transportation, it is preferred to test samples on site. For these reasons, portable testing device was developed. The testing machine operates on the split test principle. The device also shall to serve for estimation of other mechanical characteristics of the tested material, such as Young's modulus, compressive strength or flexural strength, etc. This paper concentrates on the effect of deformation of frame on the accuracy of indirect determination of mechanical properties.

Introduction

Direct assessment of elastic modulus E, tensile strength σUT or fracture toughness KIC of brittle materials represent a difficult problem for experimental instrumentation. Therefore alternative solutions have been proposed [1,2]. One of these alternative solutions, called the Brazilian test, has been popular for determining tensile strength for brittle building materials due its simplicity mainly. The Brazilian test is performed by compression with diametrically opposite concentrated loads on a disc specimen. When the the specimen dimensions and maximum force at the moment of the fracture of sample is known, it is possible to calculate the tensile strength of material. If we know the relationship between load and displacement/deformation, it is possible to estimate other parameters of the material.

Experimental device

The testing device is primarily intended for split tests of core samples. Weight of the device is approximately 25 kg, see Fig. 1.. The loading is performed by moving the lower grips upward. The lower grip is lifted by wedge mechanism. Linear movement of the wedge is implemented by screw rotation. Maximal loading force is limited by 100 kN. Loading force is registered by logger from measuring bolt. Force data are imaged by data-logger display and can be recorded by a computer in digital form. Loading displacement data are obtained directly by measuring instruments based on optoelectronics sensors and by non-directly by counting of the loading screw revolutions, both types of data can be recorded by a computer in digital form. Interchangeable jaws with different ratios Rjaw/Rspecimen are installed in the testing machine. The custom written software is used to control the test equipment, see Fig. 2. The software stores the measured data from sensors to a file in *.txt format. The software can also draw a graph of the loading forces and deformations. The graph has a variable size, so it adjusts automaticaly to the measurement range. The user can also zoom for him interesting part of graph. This software allows calculation of tensile strength RT, compressive strength RC and flexural strength RF using data obtained from the test device, without further operator intervention.

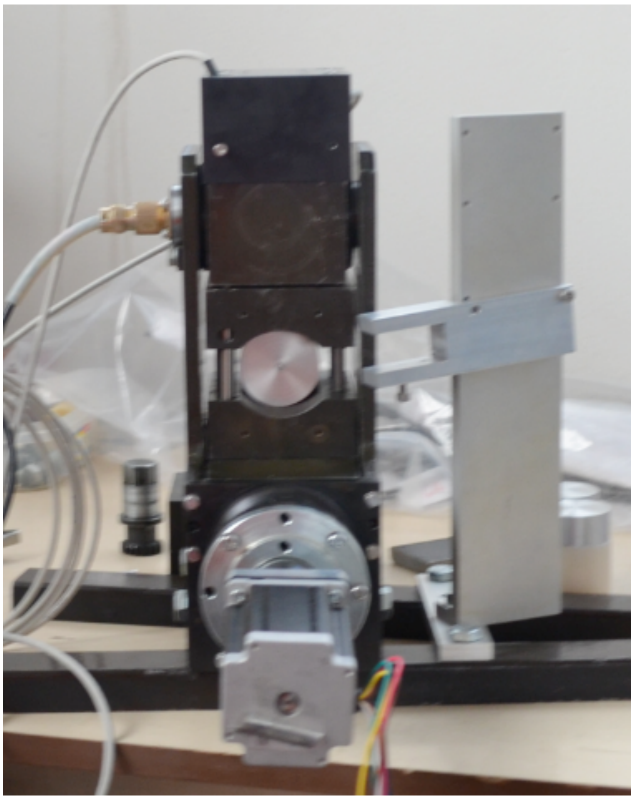

Fig.1 Portable device for split test

Fig.2 Window of software used for control of portable device and for calculation of material propertise. The software draws a graph of the loading forces and deformations.

Brazilian test and calculation of tensile strength.

Theoretical basis for the split test is analytical solution developed by Hondros for determination of elastic modulus and Poisson's ratio [1]. Complete stress solution linear contact between grips and specimen is expressed by equitons

$$\sigma_x = \frac{2P}{\pi L}\left(\frac{\cos\theta_1 \sin^2\theta_1}{r_1} + \frac{\cos\theta_2 \sin^2\theta_2}{r_2}\right) - \frac{2P}{\pi DL},$$
$$\sigma_y = \frac{2P}{\pi L}\left(\frac{\cos^3\theta_1}{r_1} + \frac{\cos^3\theta_2}{r_2}\right) - \frac{2P}{\pi DL}, \quad (1)$$
$$\tau_{xy} = \frac{2P}{\pi L}\left(\frac{\cos^2\theta_1 \sin\theta_1}{r_1} + \frac{\cos^2\theta_2 \sin\theta_2}{r_2}\right),$$

where P is the line load [N/m], L is the thickness of the disc and D is the diameter of specimen. Meaning of Θ_1, Θ_2, r_1 and r_2 is obvious from the Fig. 3. That failure is expected to initiate at the center of disc. The tensile strength R_T is expressed as

$$R_T = \frac{2F_{\max}}{\pi LD},. \quad (2)$$

where P is line load [N/m], L is thickness of the disc, and D is diameter of the specimen. When using jaws with the radius, a more accurate solution proposed by Koukoulis can be used.

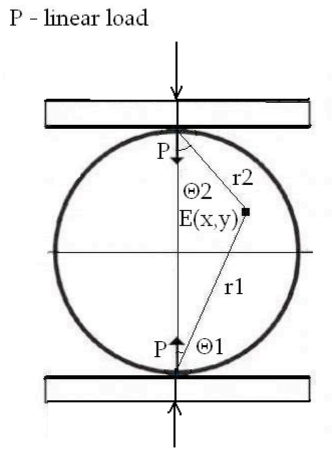

Fig. 3 Brazilian test: parameters Θ_1, Θ_2, r_1 and r_2 .

Estimation of Young modulus.

In the case of the known relationship between displacement and load, other mechanical properties such as Young modulus can be determined. Estimation of Young modulus can be based on following relationships

$$A(\Delta x) = \Delta x \cdot F(\Delta x),. \quad (3)$$

$$\sum_{i=1}^{i_{macx}} \left(F_{measured}(x_i) - F_{simulated}(x_i)\right)^2 = \psi\left(E_{simulation}, \sigma_{simulation}\right),. \quad (4)$$

where A is deformation work, Δx, resp x_i are the displacement, F is loading force, and E is Young modulus. Subscription indicates values measured directly by sensors. Subscription simulation indicates simulated values.

Experiments and effect of frame deformation

Specimens were prepared from sandstone by core drilling. The specimens were made from sandstone, marlite and limestone. The specimens were obtained in dry condition. Diameter of the specimens was 47-50 mm and length was from 35mm to 70 mm. Specimens were loaded to final rupture by the portable loading device developed. Result of split test show that the tensile strength σ_{UT} differs only a little from obtained by other methods. In the case of other variables such as E, however, are significant differences (order of 10 or more), which do not allow practical use of measurements of E. This behavior can be explained by the growing influence of deformation of the devices frame on indirect measurements. Measusered relationship between loading force to deformation of brazilian disc is showen in Fig. 4. The graph is contains two parts: a) Brazilian disc was loaded to the final fracture (Fig. 4 a); b) the (theoretically) linear region in the beginning of the test (Fig. 4 b).

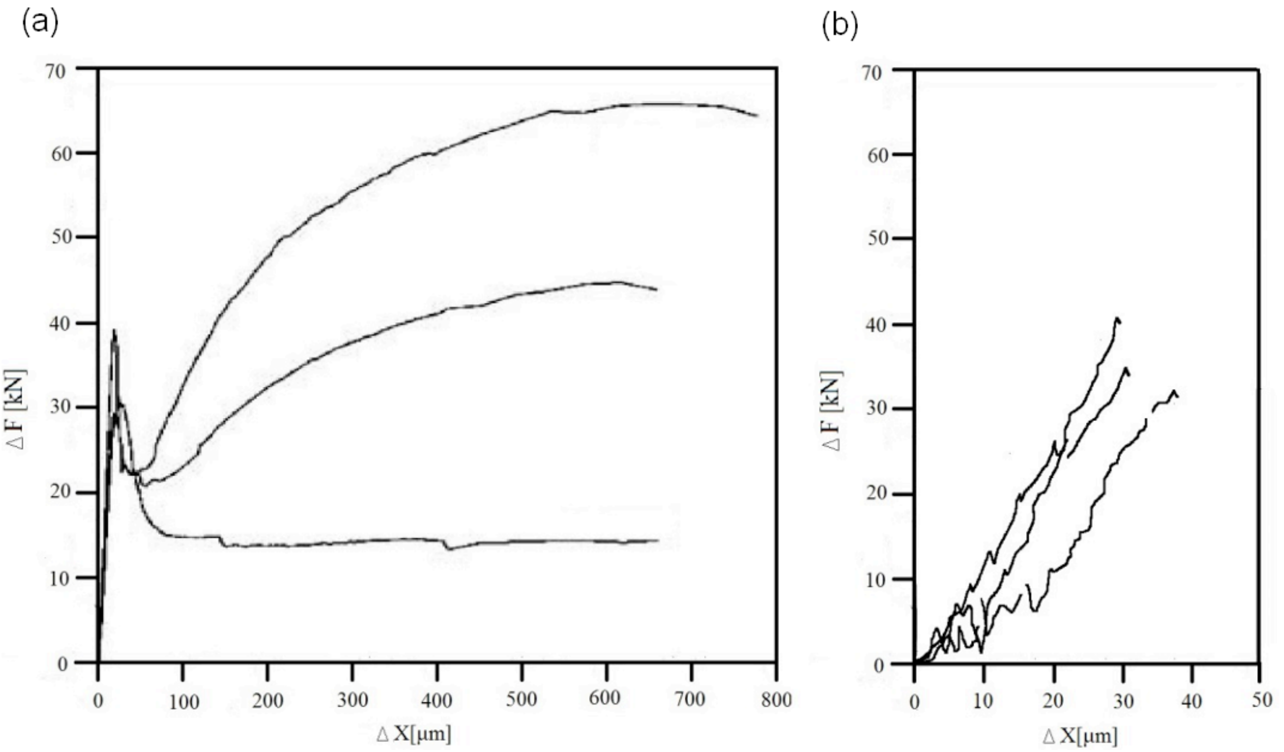

Fig. 4 Experimental graph shows relationships between loading force and aesured deformation:a) loading to the final fracture; b) linear region at the beginning of the test.

If the model based on the relationships Eq.2 and Eq.3 will corrected by deformation of whole device, the results will be better. For further practical use it is necessary to implement further measurements to create a table of corrections. Then these corrections must be implemented to the control software. The problem, however, is gaining generally valid correction because results differ for tests carried out for only one type of material (error between 30-150% depending on the sample). To estimate the effect of deformation measurement accuracy measurements were made of materials with precisely defined properties such as metals or plastics. Frame deforamation in order of μm. In order to further refine results, it is necessary to implement additional measurements.

Finite element model of testing device.

Deformation of the frame, jaws and the samples can be simulated by Finite Element Method. Finite element model of whole assembly was prepared in the SolidSoftware. This model was meshed and solwed. Meshed FEM model of whole asembly of testing device is shown in Fig. 5 a. First results show that the Frame deforamation in order of μm, and the same deviation can caused mistake of the calculated values of the order of 100%. The separate FEM model of the Brazilian disk and jaws were prepared for ANSYS software, where it was meshed and solwed. This model of Brazilian disk and jaws was used for analysis of contact angle. This model of the Brazilian disc and jaws is shown in Fig. 5 b. For this model were tetrahedral elements SOLID187 used. The contact angle varied between 2-8 for brittle building materials, 2-24 for metals and plastics.

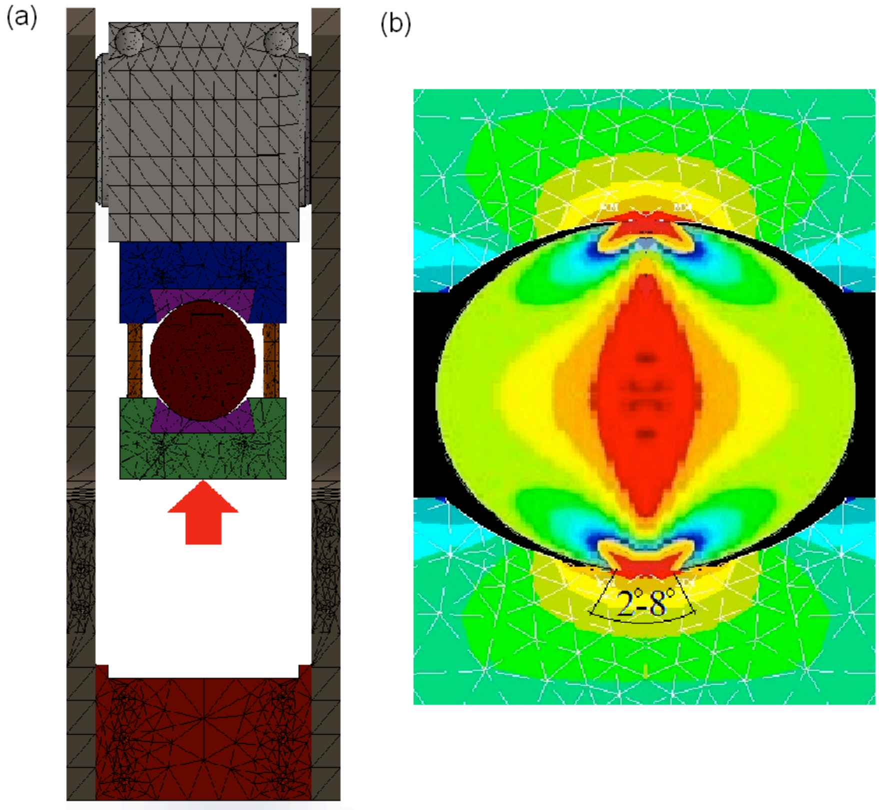

Fig. 5 a) FEM model of portable device; FEM model of contact between jaws and specimen.

Experiments: Materials with known mechanical properties

Another ser of measurements was taken for specimens made from materials with precisely defined mechanical properties. This materials were steel, bronze, duralium and plastics. Poisson constanst, Tensile strength and Young modulus are well known for this materials. For all materials were prepared specimens of length L = 10; 20; 30; 50; 60; 70mm and diameter 48 mm and 35 mm.The calculated value of Young modulus E depends on the length of specimen for short specimens (shorter then 50 mm) and it is independent for longer sample (over 50 mm) Calculated Young modulus exhibits systematic deviation from the values determined by other measurements.

For example duralium has knowen Young modulus $E = 73$ GPa and Poisson ratio $i = 0.333$ and the steel of jaws has Young modulus $E = 200$ GPa and Poisson ratio $i = 0.31$. From data obtained from measurements on the portable device the Analytical solution gives for long specimens with length L = 50-70mm Youngus modulus E = 114 GPa for beginning of loading (loading force 15 kN) and for higher forces the error incraises. The Young modulus obtained from Eq. 2 and Eq.3 is about 120 GPa according to length of specimen. The difference between Hooks law and exerimental curve obtained from portable device is shown in Fig. 6. This results can be corrected by some corellation function.

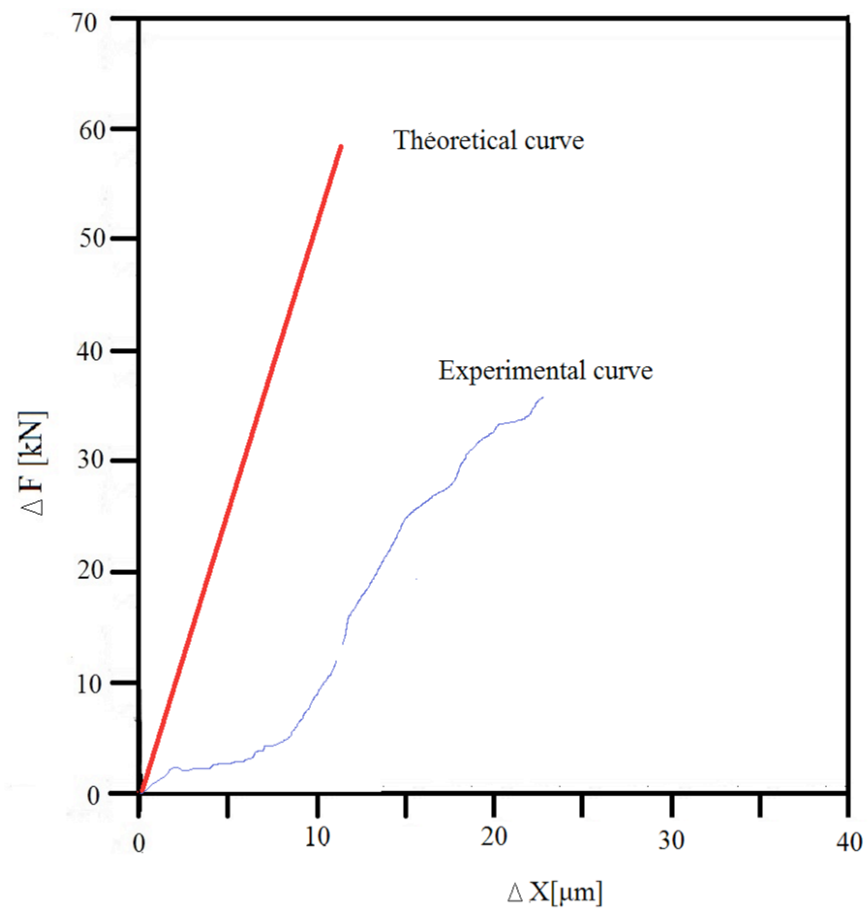

Fig. 6 a) Comparison of experimental and theoretical graph of Loading –Deformation

Results

1. Corrections based on the relationships Eq. 2 and Eq. 3 improve results of measurement.
2. Implementation of the corrections to the control software improves accuracy of the measurement.
3. In order to futher refine results, it is necessary to implement additional measurements.

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