Experimentální Analýza Napětí 2011
Experimental Stress Analysis

Portable Testing Device for In-situ Testing of Building Material

Daniel Vavřík[1] & Ivan Jandejsek[1]

Abstract: Examination of brittle buildings materials using mechanical tests requires sampling of studied elements and materials (stones, bricks or concrete). In case of existing integral structures the best suitable sampling method is core drilling. It is preferred to test samples in situ in all cases where it is possible to avoid changes of the material properties during transportation and storing. Moreover it is possible to prepare other samples operationally wen some uncertainty occurred if in situ testing is possible. For such a purpose, a portable testing device has been designed and manufactured. This device is primary devoted for so called split test technique which is based on well know testing of Brazilian disk. Analytical equation used for evaluation of the split test is based on several assumptions which have to be verified. For such verification Digital Image Correlation technique was used in our work.

Keywords: Experimental, Stress, Analysis

1. Introduction

Beyond technological effect and variations of the material composition, the mechanical characteristics of building materials are dependent on moisture content. However, the moisture content and its distribution can vary during time between sampling and testing if it is delayed. It is preferred to test samples in situ from this reason to avoid changes of the material properties during transportation and storing. It is desirable to minimize number of specimens tested on other hand. So, specimens should be sampled from carefully selected places. If some specimen point out critical material characteristic, detailed examination of its sampling place should be done. In situ testing of building materials is preferred from these reasons. Therefore a portable testing device has been designed and manufactured [1]. This device is primary devoted for so called split test technique which is based on well know Brazilian test.

Analytical equations describing related Brazilian disk which are used for evaluation of the split test suppose, that tensile stresses are constant in axis symmetric plane of the specimen, which laying in the loading axis. So, effect of the contact between specimen and loading grips should be negligible. This assumption was verified in our work using non-contact Digital Image Correlation (DCT) method. It was proven that mentioned assumption was not fulfilled in our experiments as will be shown in this paper.

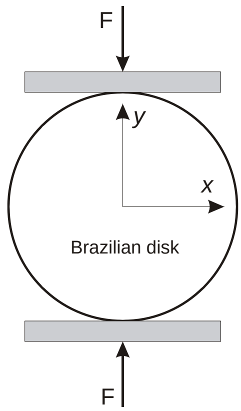

Fig. 1. Schema of the Brazilian/Split test

[1] *Daniel Vavřík; Ivan Jandejsek, Institute of Theoretical and Applied Mechanics, v. v. i ; Prosecká 76,190 00 Prague, Czech Republic; vavrik@itam.cas.cz*

2. Split test

Split test [2] which is recommended for measurement of the tensile strength of a brittle materials is based on the Brazilian test. A related disc specimen is compressed with diametrically opposite and symmetric line loads [3], see Fig. 1. The theoretical basis for the Brazilian test is the analytical solutions that have been obtained by many researches for isotropic or transverse isotropic materials under concentrated loads, loads that are distributed over a small arc of the disc's circumference [4–7]. Fairhurst [8] discussed the validity of the Brazilian test, and concluded that failure is expected to initiate at the center of disc, but actually the failure sometimes initiates at the loading points.

The formula, which is used for calculation of the tensile strength f'_{st} according to ASTM [2]:

$$f'_{st} = \frac{2F}{\pi l d} \tag{1}$$

supposes loading with point like contact. Where F is the maximum load at failure, l and d are the length and diameter of the cylindrical specimen, respectively. Applicability of this relation is based on assumption, that stresses σ_x and σ_y are constant in the vertical central plane of the specimen in accordance with analytical equations for this plane:

$$\sigma_x = \frac{2F}{\pi l d} \tag{2}$$

$$\sigma_y = \frac{2F}{\pi l}\left(\frac{d^2-1}{d^2}\right) \tag{3}$$

3. Testing device

Testing device [1] is mainly intended for tensile (split) testing of core samples, even though it is sufficiently flexible for universal testing (compression, bending). Device was designed as portable, durable and independent of external electricity supply. Its weigh is approximately 25 kg with outside dimension of 290x290x155 mm, see Fig. 2 for its scheme. Core sample /1/ should have diameter 48-52 mm and maximal length of 100 mm. Core sample is compressed between flat surface of top head /2/ and support bed /3/ (it is flat in the realized device). Smaller sample diameter then 48 mm is possible if support bed is replaced. Bending test is possible if support bed is replaced as well and top head /2/ gives a half turn: top head can be equipped by two or one pin bearing /4/ alternatively with respect of requirement of four or three point bending test. Bending sample dimensions are limited by 70x40 mm. Sample length is not limited although bearing pins distance is limited by 100 mm.

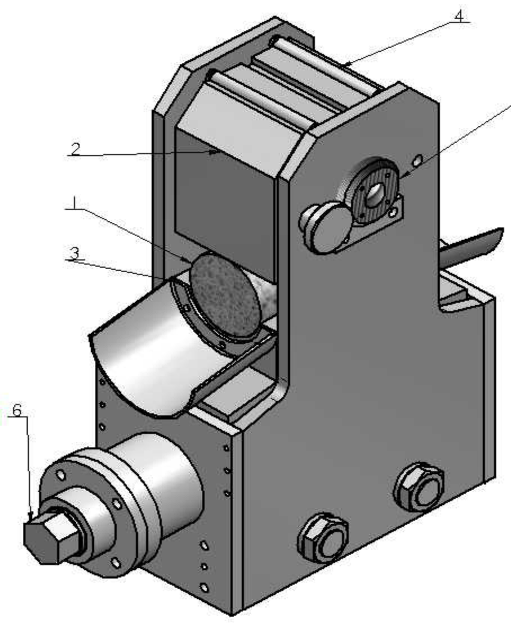

Fig. 2. Portable testing device

Maximal loading force is limited by 100 kN. Loading force is read by logger from measuring bolt /5/. Force data are imaged by logger display and can be recorded by a computer in digital form.

Loading by screw rotation /6/ is realized manually or by stepper engine alternatively. Loading displacement data are obtained non-directly by counting of the loading screw revolutions: one screw revolution corresponds to 0.16 mm of grip displacement. Maximal displacement velocity is 1 mm/min in the case of stepper engine in use. Accessory gear-box with transmission coefficient of 20 is inserted between stepper engine and loading screw in this case. Stepper engine has ability of 200 steps per one revolution. So, it is possible control loading displacement with precision of 0.125 μm. Revolutions of the stepper engine are controlled by the computer and serve as time/displacement reference axis for loading force data after multiplying by the transformation coefficient. It is possible because device was designed as very stiff in comparison with potential loading conditions.

4. Digital Image Correlation

The Digital Image Correlation (DIC) method [9] as nowadays technique is commonly applied for full field measurement of the displacement fields. DIC tracks self-similar regions (subsets) in an image sequence, acquired during the measurement. Fine structure has to be presented in images for DIC applicability. This structure can be natural or it can be prepared artificially.

The search of self-similar places is mathematically based on the well-known cross correlation calculation. The implementation of advanced numerical methods [10] makes possible to reach high accuracy for displacement field measurement.

5. Experimental

Core drill specimens were prepared from Calcareous Marly Limestone. Diameter of the specimens was 50 mm and length was 50 mm. Influence of two contact surfaces were tested: flat grip was directly in contact with the specimen in first case and soft plastic plate was inserted between flat grip and the specimen in second case.

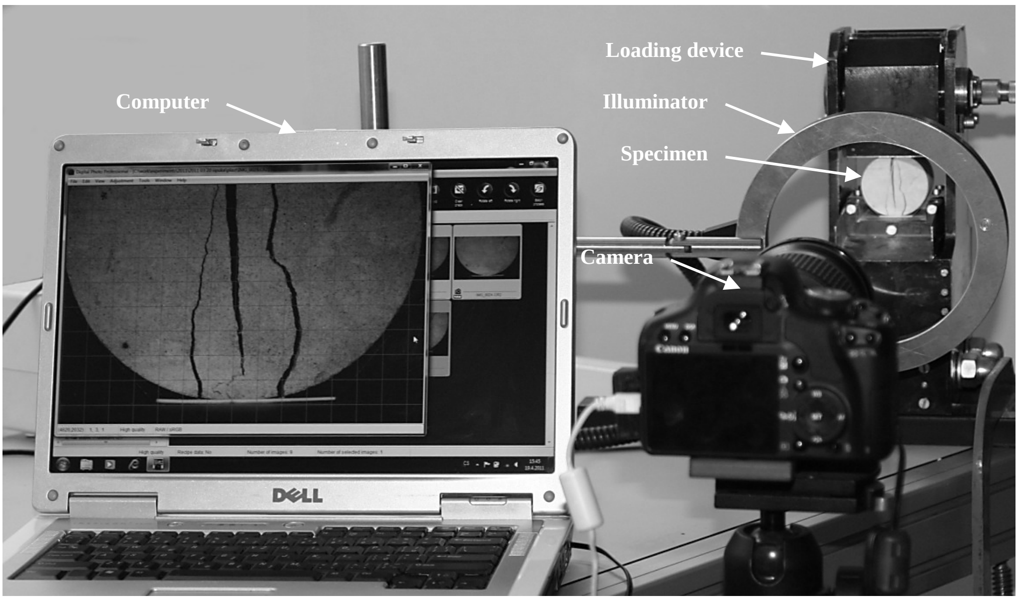

Fig. 3. Experimental setup. Cracked specimen is imaged on the notebook screen. Primary crack in the centre and secondary cracks are on the sides.

Specimens were loaded by above descripted loading device. Front side of the specimen was recorded using Canon camera EOS 500 D equipped by the macro lens. Data were recorded directly into computer using appropriate Canon software for remote camera control. Overview image of the experimental setup is depicted in Fig. 3. Set of acquired images was processed using our DIC software [10].

6. Results

Specimen rupture was exactly in the horizontal symmetric plane in both cases of the contact realized. It appeared that split test was processed in right conditions without any information about strain field on the specimen front surface. However it was proven that strain field is not constant in the central vertical plane as supposed by the theory when images acquired during loading were processed using DIC, see Fig. 4 for strain fields ε_x and ε_y before rupture of the specimen.

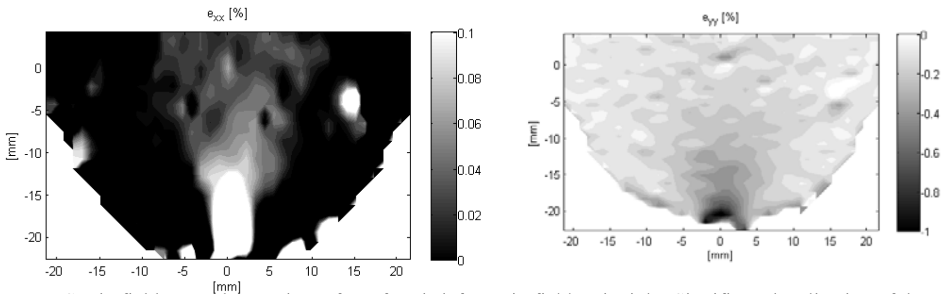

Fig. 4. Strain field σ_x on the specimen front face is left, strain field σ_y is right. Significant localization of the strain intensity is 5 mm above contact surface (contact surface is 2 mm below bottom border of the images).

It was found that microcracks occurred in the region near to the contact point looking on related image, see Fig. 5.

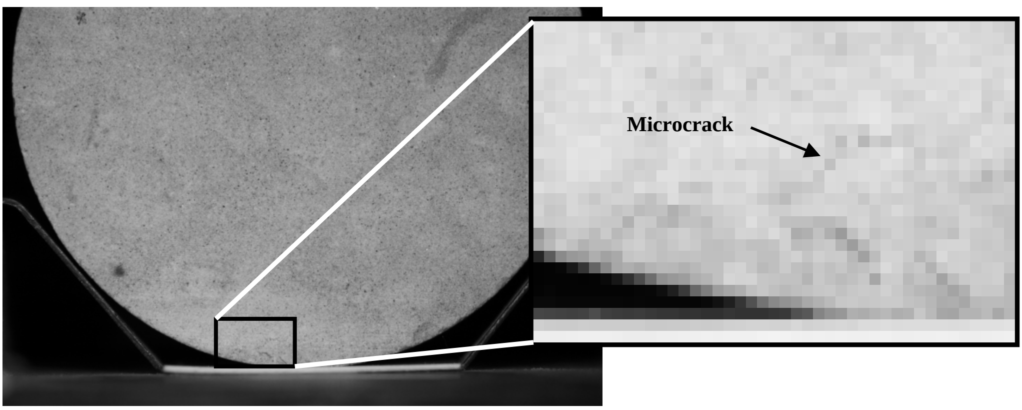

Fig. 5. Optical image of the front face of the specimen left. White PP sheet in the contact is visible on the bottom of the specimen. Detail where the microcrack is visible is right.

The equation (1) lost meaning for evaluation of our experimental results, since strain field is significantly non-homogenous in the central vertical plane. Tensile strength f'_{st} would be significantly underestimated from this reason.

Above described behaviour of the specimen was observed for all loading levels processed regardless of contact type studied in this work.

7. Conclusions

It was proven for contact types studied, that although global behaviour of the specimen satisfied conditions of the split test, detailed study of the strain field on the specimen surface showed that strain distribution didn't satisfied theoretical assumptions. Using maximal loading force for the tensile strength would conclude underestimation of the tensile strength f'_{st} if the influence of the contact between the specimen and grip is significant for the specimen behaviour during loading.

Other types of the contact will be under study in future work to find optimal solution for which split test will be valid.

Acknowledgement

This work has been supported by the Project DF11P01OVV001 of the Ministry of Education, Youth and Sports of the Czech Republic.

References

[1] Drdácký, Miloš ; Slížková, Zuzana ; Vavřík, Daniel. Identification of historic materials using tests on small samples. In Proc. of 2nd international conference on: Vulnerability of 20th century cultural heritage to hazards and prevention measures. Firenze : CICOP, 2005. S. 29-37. ISBN 960-87851-2-X

[2] ASTM C496 Splitting Tensile Strength of Cylindrical Concrete Specimens

[3] Y.Jianhong et al. International Journal of Rock Mechanics & Mining Sciences 46 (2009) 568–576.

[4] Hondros G. The evaluation of Poisson's ratio and the modulus of materials of a low tensile resistance by the Brazilian (indirecttensile) test with particular reference to concrete. Aust J Appl Sci 1959; 10: 243–68.

[5] Muskhelishvili H. N. Some basic problems in mathematic elastic mechanics. Beijing: SciencePress;1958.

[6] Claesson J, Bohloli B. Brazilian test: stress field and tensile strength of anisotropic rocks using ananalytical solution. Int J Rock Mech Min Sci 2002; 39: 991–1004.

[7] Chen C S, Pan E, Amadei B. Determination of deformability and tensile strength of anisotropic rock using Brazilian tests. Int J Rock Mech Min Sci 1998; 35:43–61.

[8] Fairhurst C. On the validity of the ''Brazilian'' test for brittle materials. Int J Rock Mech Min Sci 1964;1:535–46.

[9] S. S. Russell and M. A. Sutton (1989) Experimental Mechanics, Vol. 29, pp. 237-240

[10] Jirousek, Ondrej ; Jandejsek, Ivan ; Vavrik, Daniel. Evaluation of strain field in microstructures using micro-CT and digital volume correlation. Journal of Instrumentation, 2011, Vol. 6, January, p. 1-5. ISSN 1748-0221. Available at: http://iopscience.iop.org/1748-0221/focus/extra.proc10