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NON-DESTRUCTIVE METHODS OF FAILURE ANALYSIS OF ROCK MATERIAL IN LABORATORY CONDITIONS.

NEDESTRUKTIVNÍ METODY ANALÝZY PORUŠENÍ HORNINOVÉHO MATERIÁLU V LABORATORNÍCH PODMÍNKÁCH.

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Abstract:

The presence of interconnected discontinuities such as cracks, fractures and joints significantly affects both elastic and transport properties of rocks and rock masses. Non-destructive methods of failure analysis of rock material are described in this paper. Measurement of elastic and transport properties has been realised on the test specimens. The test specimens after the loading were analysed by two methods - computer tomography and measurement of elastic wave velocity. The ultrasonic wave velocity is influenced by various type of loading. Computer tomography appears as a sensitive method for distinct irregularities.

Keywords: velocity of ultrasonic wave, computer tomography, discontinuity

1. Introduction

Laboratory measurements of stress and strain properties of rock samples are counted among basic destructive tests necessary for assessment of behaviour of rock massif especially due to anthropogenic activity in this environment – constructing of engineering constructions, extracting mineral raw materials, constructing of underground storage etc.

The presence of interconnected discontinuities such as cracks, fractures and joints significantly affects both elastic and transport properties of rocks and rock masses. Where the discontinuities are randomly oriented and the state of stress is hydrostatic, the rock might be expected to exhibit isotropy in physical properties. A rock or rock mass containing a system or systems of interconnected, aligned cracks will behave in an anisotropic manner in its elastic and transport properties [4]. An effect of stress or temperature on rock may arise new discontinuities whose orientation is influenced by new stress – strain state [8] or affect existing discontinuities.

2. Methodology of measurement and analysis

Elastic and transport properties have been studied not only during loading of test specimen, but also after peak strength, both in uniaxial or triaxial state of stress or after heating and cooling at present. The test specimens after the loading were analysed by various methods - computer tomography, measurement of elastic wave velocity, optical microscopy.

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2.1.Characteristics of tested material

Cylindrical test specimens (with a diameter of 48 mm and a height of 96 mm) were used in these tests. The samples were homogenous, intact.

The material selected for the tests:

- medium-grained biotite granodiorite from quarry Erlich (sample No. 7176) and quarry Nový (Žulová) (sample No. 9164)
- medium-grained quartz glauconitic sandstone from quarry Řeka (Cretaceous) (sample No.7197)
- coarse-grained greywacke sandstone from borehole Darkov 257 (Carboniferous) (sample No.7567)
- olivine basalt from quarry Bílčice (sample No. 7273)

2.2.Stress – strain tests with measurement of gas permeability

The universal mechanical press ZWICK 1494 with maximum force output of 600 kN and servo control and triaxial cell KTK 100 for measurement in triaxial state of stress with maximum confining pressure of 100 MPa was used for stress-stain tests. Triaxial cell is adapted to inserting into ZWICK press and to gas passage experiments. The triaxial cell KTK 100 was used for the laboratory tests for simulation of stress conditions in rock massif and for measurement of gas permeability [1,5]. Confining pressure in the triaxial cell was applied by the hydraulic pressure of oil. The compressed nitrogen was applied as a reference gas. Upstream pressure of the gas was 3 MPa and it was constant during the measurement. The volume rate of the gas was measured by the flowmeters with the range from 5 to 600 $cm^3 \cdot min^{-1}$. Confining pressure was constant during experiments (5 MPa) and axial stress increased up to the failure or up to the determined limit. Longitudinal and transverse deformation, gas permeability and acoustic emissions were continuously registered in course of stress measurement [6,7].

2.3. Thermally treatment

In order to avoid provoking thermal shock, the test specimens were heated from 20°C to maximum temperature at a rate of 20°C min^{-1} up to 600°C, and of 8 °C min^{-1} to 800°C. A maximum temperature was maintained for 1hr. Different specimens were thermally treated to 200°C, 400°C, 600°C, 800°C and then put into a desiccator until they were tested.

2.4. Measurement of ultrasonic wave velocity

The digital ultrasonic tester CH-48S of MARUTO Company was used for measurement of longitudinal ultrasonic wave tests. Frequency of ultrasonic wave used by this tester is 50 KHz, range of measuring time from 0.1 to 10000µs.

2.5. Computer tomography

Computer tomograph SOMATOM STAR of Siemens company was used for analysis of test specimen.

The observed rock density is close to density of bone tissue (this is 1.9 $g \cdot cm^{-3}$). Therefore X-ray radiation for depicting of rock structure can be applied [10]. There is electromagnetic wave motion within wavelength range of 10^{-9}- 10^{-12}m. The computer tomography (hereafter CT) operates with densitometric procedure. CT detects and registers a weakening of X-ray radiation after passage across the tested sample.

The “high resolution” technique was used for depicting of structure changes of rock samples. This method enable to recognise very thin layers (1 – 2 mm). Another method of data recording - helical (spiral) CT – was also applied for depicting of structure of rocks. Advantage of such technique is including total volume of observed sample with possibility of subsequent processing of gained data by so called postprocessing methods. The 3D reconstruction is the most important advantage of this method.

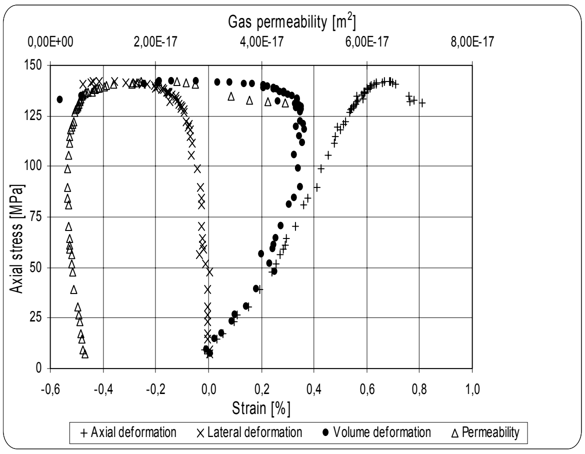
3. Discussion of results

a. The velocity of ultrasonic wave is influenced by material in which the wave propagate and by nehomogenities in this material. Influence of one artificially made joint with different orientation was measured. The original velocity was measured on intact test specimens No. 9164/6 ($v_p = 4{,}68$ km s^{-1}), No. 9164/3 ($v_p = 4{,}68$ km s^{-1}). The sample No. 9164/6 was cut parallel with longitudinal axis of specimen and sample No. 9164/3 perpendicular to longitudinal axis of specimen. In the case of sample No. 9164/6 the discontinuity was parallel with direction of propagating ultrasonic wave and the velocity was not expressively influenced ($v_p' = 4{,}4$ km/s). The velocity of ultrasonic wave in the sample No. 9164/3 with perpendicular orientation of discontinuity to propagating ultrasonic wave decreased ($v_p' = 3{,}63$ km s^{-1}).

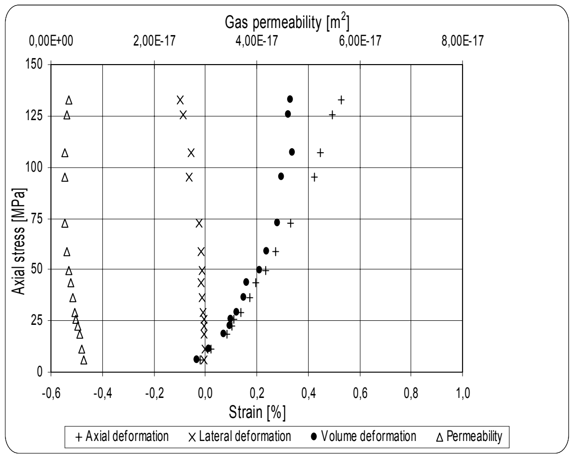
b. The stress – strain curves with longitudinal, transverse and volumetric deformation are shown for test specimen No. 7567/2 and No. 7567/18 in Fig. 1 a, b. Except of these curves the course of permeability during the loading were recorded. The loading of the specimen No. 7567/2 was finished after a failure. The finished permeability in this case increased expressive (from 6.3E-18 m^2 to 42E-18 m^2). The loading of the specimen No.7567/18 was finished in moment when the permeability after beginning decrease started to increase but the value of finished permeability (3.27E-18m^2) did not reach the started value (5.89E-18m^2).

Further tested specimens were loaded by this mode:

- No.7567/7 was loaded up to the failure and the permeability increase from 5.6E-18 to 48E-18 m^2.
- No. 7567/9 – loading was finished before the failure close to peak strength. Permeability increase cca twice (from 5.9E-18 to 9.8E-18m^2).
- No. 7567/24 – loading was finished before the failure close to peak strength. Permeability increase cca twice (from 6.7E-18m^2 to 14E-18m^2).



a) No. 7567/2



b) No. 7567/18

Fig.1 Dependence of strain and gas permeability on axial stress at confining pressure 5MPa.

The velocity of longitudinal ultrasonic wave was determined for all specimens after loading tests. In Fig. 2 there is recorded relationship between permeability rate and velocity rate. The values of rates are calculated as quotient values after experiment and before experiment.

It is evident that the failure test specimens (No.7, No.2) have expressive lower velocity of ultrasonic wave. But the orientation of this failure zone is skew to direction of ultrasonic wave in these cases (angle with longitudinal axis of specimen cca 30°). It is important fact as was mentioned above.

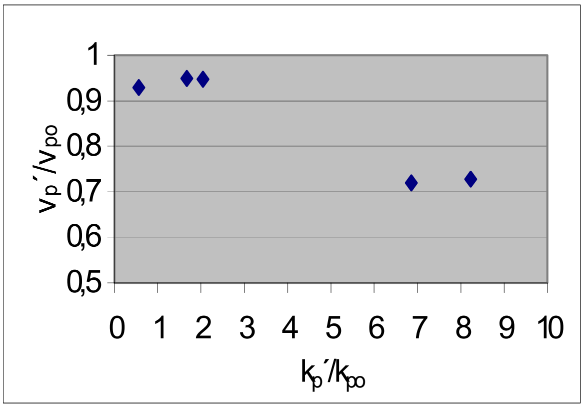


Fig.2 Relationship between permeability rate and velocity rate

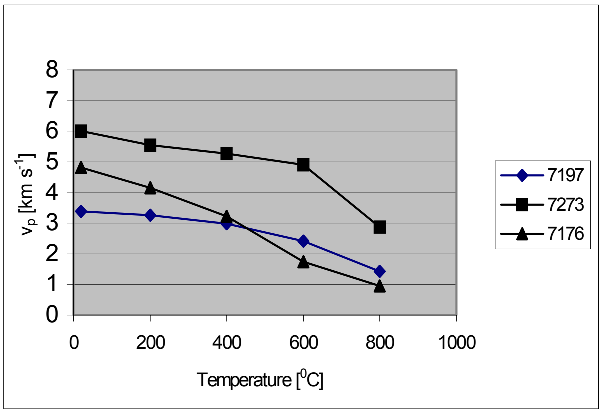
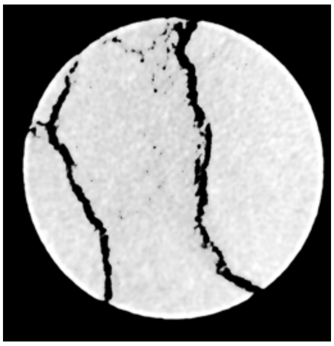
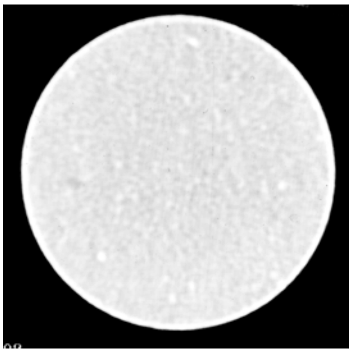


Fig.3 Relationship between temperature and velocity of longitudinal ultrasonic wave

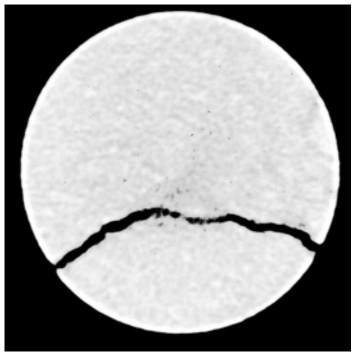
c. The thermally treatment samples were analysed both physical and petrograpfical methods. Measurement of physical parameters proved the influence temperature on these parameters. The increase of temperature caused the decrease of velocity of longitudinal ultrasonic wave (Fig.3), strength, elastic modulus [9]. The decrease of velocity of ultrasonic wave is due to arise of new discontinuities (intragrain, intergrain) in the rock material [2,3].



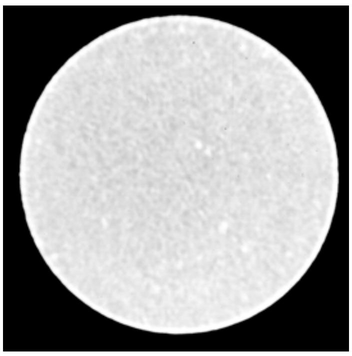
a) No. 7567/2



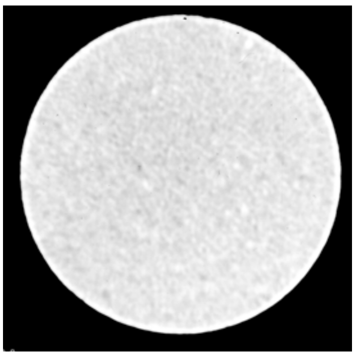
b) No. 7567/18



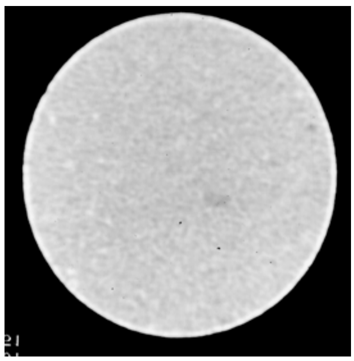
c) No. 7567/7



d) No. 7567/9



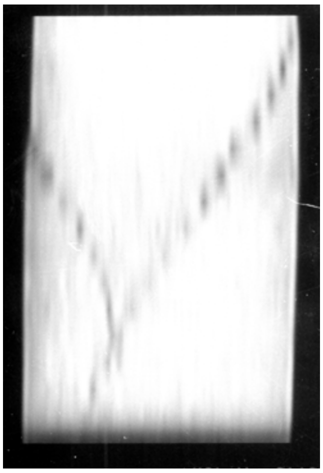
e) No. 7567/24



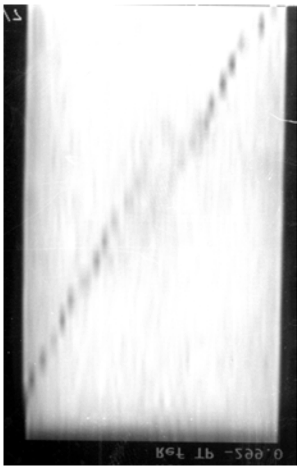
f) No. 7567/19

Fig. 4 Cross-sectional CT images of specimens after the tests and origin material

d. The test specimens of sample No. 7567 were analysed before and after experiment by computer tomography in sections perpendicular to longitudinal axis of test specimen. The difference of sections was 4 mm and from these transversal sections it is possible to construct the sections parallel to longitudinal axis of sample. In Fig. 4 a, b, c, d, e, f there are shown transversal sections in the middle of each test specimen and original material (No.19). It is evident that the failure was recorded only in the samples loading after peak strength. In the middle part of specimen No. 9 was recorded arising joint. The parallel sections of failure samples are shown in the Fig. 5a,b.



a) No. 7567/2



b) No. 7567/7

Fig. 5 Parallel section CT images of failure specimens

4. Conclusion

- measurement of ultrasonic wave velocity is very sensitive method for detection of discontinuities in the sample. However, the sensitivity is strongly influenced by orientation of the cracks.
- utilisation of CT as a non-destructive method for discontinuity detecting is possible, too. The distinct irregularity must be present in the sample to obtain a zone with changed density. This zone could be well recognised by CT without reference to orientation of this zone.

Acknowledgement

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