EXPERIMENTS ON ROCKS UNDER HIGH PRESSURE CONDITIONS IN GTA 20-32 TRIAXIAL PRESS

EXPERIMENTY NA HORNINÁCH VE VYSOKOTLAKÉM TRIAXIÁLNÍM LISU GTA 20-32

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Abstract

The paper describes the methodology of measurements in the GTA 20-32 triaxial press. The deformation behaviour of two different types of rocks was compared:

- gypsum with plastic deformation even at lower confining pressure,
- Carboniferous sandstone with brittle failure even at the highest confining pressure.

The influence of gypsum layering was studied as well. The experimental results show that the deformation and strength properties of the gypsum in the triaxial state of stress do not significantly depend on the orientation of axial stress to the observed layering.

Abstrakt

V příspěvku je popsána metodika měření na triaxiálním lisu GTA 20-32. Je porovnáno deformační chování dvou rozdílných typů hornin:

- sádrovce, který se deformuje plasticky už při nízkých plášťových tlacích,
- karbonského pískovce, porušujícího se křehce i při nejvyšších plášťových tlacích.

Autoři studovali také vliv vrstevnatosti sádrovce. Experimentální výsledky ukazují, že přetvárné a pevnostní vlastnosti sádrovce v trojosém stavu napjatosti nezávisí výrazně na orientaci osového napětí k pozorované vrstevnatosti.

Key words: triaxial stress, deformation, rocks.

1 INTRODUCTION

Rocks are affected by stress and temperature under natural conditions at great depths; their plastic deformation can occur. The corresponding stress relations are experimentally implemented in triaxial presses (see, e.g., [1]; [3]; [4]; [6]). Triaxial tests enable to recognize the mechanical and deformation properties of the rock under conditions corresponding to great depths. The principle of the experiment is illustrated in Fig. 1. The maximum stress (σ_1) is applied to the sample in the direction of the longitudinal axis of a cylindrical sample (it is caused by the pressure of the press piston). The so-called confining stress affects the surface of the cylindrical sample ($\sigma_2 = \sigma_3 = p$), caused by the pressure of oil in the chamber of the press.

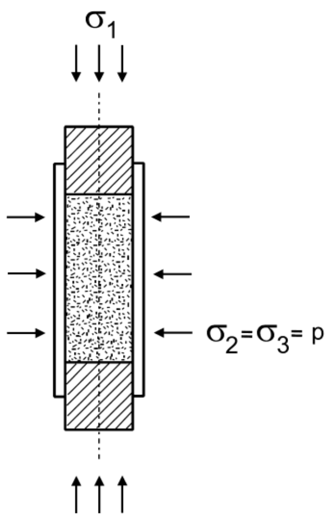

Fig. 1 Schematic illustration of the sample loading during the triaxial test

Fig. 2 Triaxial press GTA 20-32 with a maximum confining pressure of 400 MPa

2 METHODOLOGY OF MEASUREMENTS

2.1 Apparatus for testing rock samples in a triaxial state of stress.

The apparatus GTA 20-32 was used in experiments (Fig.2). This is an apparatus for testing rock samples in a triaxial state of stress, made in the High Pressure Research Centre Unipress, Polish Academy of Sciences [2]. The apparatus is intended for testing cylindrical samples of a diameter up to 32 mm and a slenderness ratio 2. Samples with a diameter of 22.5 mm were used in experiments. The loading is realized in a high pressure chamber (Fig. 3) by means of oil at pressures up to 400 MPa (confining pressure) and by means of a chamber piston causing the axial compression on the sample. The confining pressure is constant during the experiment. The axial deformation of the sample is calculated from the displacement of the piston. The displacement of the piston is measured with an induction gauge with a measuring accuracy of 0.01 mm [8].

Fig. 3 Pressure chamber

The diagram of the equipment is displayed in Fig. 4.

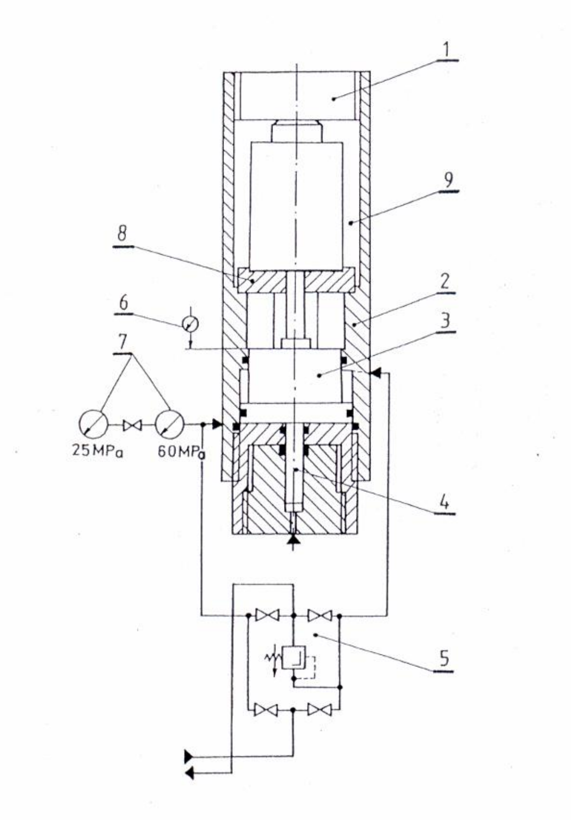

Fig. 4 Diagram of the operating unit of the GTA 20-32 triaxial press. The sample is located inside the working chamber (9).

1 – closing screw, 2 – press frame, 3 – piston body, 4 – compensating chamber , 5 – hydraulic distribution, 6 – axial deformation sensor, 7 – pressure sensors, 8 – working chamber beds, 9 – operating chamber

2.2 Calculation of the axial stress and deformation

For the axial stress in the tested specimen the following equation is valid [7]:

$$\sigma_1 = \sigma_3 + \frac{4.(27549.p - F_t).(1-\varepsilon)}{3{,}14.D^2}$$

where:

F_t – friction force [N],

σ_1 – axial stress [MPa],

σ_3 – stress caused by confining pressure [MPa],

D – specimen diameter [mm],

p – piston pressure [MPa],

ε – relative axial deformation

The numeric coefficient 27549 (mm^2) in the above mentioned equation is the working area of the piston which makes axial loading. If the pressure under the piston is measured in MPa and the area of the piston is in mm^2, the force affecting the piston is in N.

The deformation curves are constructed so that the vertical axis contains a so-called differential stress $\sigma_1 - \sigma_3$. The deformation curves are coming to the origin of coordinates in this case.

The expression (1 - ε) corrects the stress to a cross section of the tested specimen during its plastic deformation (during the plastic deformation the tested specimen is deformed into the shape of a cask). In deriving the above-mentioned relation it is supposed that during the plastic deformation the volume of the tested specimen is constant. The relation omits the compressibility during the elastic part of the deformation. It is

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possible to suppose this for most solutions as decimal percentages up to one percent and this error is comparable with some other errors of measurement.

The relative axial deformation is calculated according to the equation:

$$\varepsilon = \frac{l - 0{,}064079.p}{L_O} + \frac{F_t}{430000 L_O}$$

p – piston pressure [MPa],

l – measured piston displacement [mm],

L_0 – original height of tested specimen [mm],

F(t) – friction force [N],

ε – relative axial deformation

The numeric factor 430000 is the rigidity of the press construction expressed in $N.mm^{-1}$. The force 430 000 N will prolong the construction by 1 mm. The numeric factor 0.064079 (in $N^{-1}.mm^3$) is the ratio of the piston area for the axial loading to the rigidity of the press.

2.3 Tested specimen

A cylindrical specimen about 43 mm in height and 22,5 mm in diameter is used. The specimen is placed between the anvils before the experiment and coated by rubber. The coating prevents the oil penetration into pores of the specimen.

3 TESTED MATERIAL

Rocks with supposed significantly different deformation properties were selected for the experiment; gypsum and Carboniferous sandstone with a high degree of diagenesis. Gypsum from the Kobeřice quarry is a homogenous sediment with significant layering. It is evident from the detailed microscopic analysis that the rock does not consist of sharp limited laminas. Optically visible layering is caused by the presence of orientated but dispersed lenses of coal substance (Fig.5) with occasional non sharp rich clay matter laminas (the thickness ~ 0.3 to 0.4 mm). The occurrence of calcite was ascertained from infrared spectroscopic and differential thermal analyses.

The sandstone was taken from the exploration field in Paskov – west (the Upper Silesian Basin), from the borehole NP 866, at a depth of 1507 m, from the Petřkovice Member. It is the grey fine-grain sandstone; in some places with coal substance. It contains clastic and newly-created quartz (65%), non-proportionally located feldspars (10 %), mica (2%), groundmass (20 %) and cement (3 %).

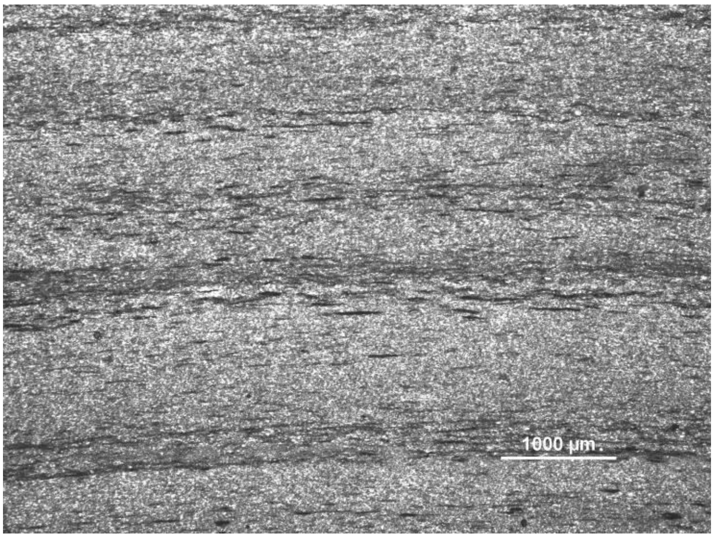

Fig. 5 Oriented lenses of coal matter in gypsum. Transmitted light, crossed nicols.

4 EXPERIMENTAL RESULTS AND DISCUSSION

The deformation curves (differential stress versus relative axial deformation, $\sigma_1 - \sigma_3$ vs. ε_1) of the rocks at constant confining pressures are presented in Fig. 6 and 7.

The specimens of gypsum are deformed linearly at first, further the compression leads to an inelastic deformation. At a low confining pressure the curve shows a defined peak strength and a gradual strength decrease in the post-failure region until the final deformation occurs at approximately constant axial stress σ_1 referred to as a residual strength.

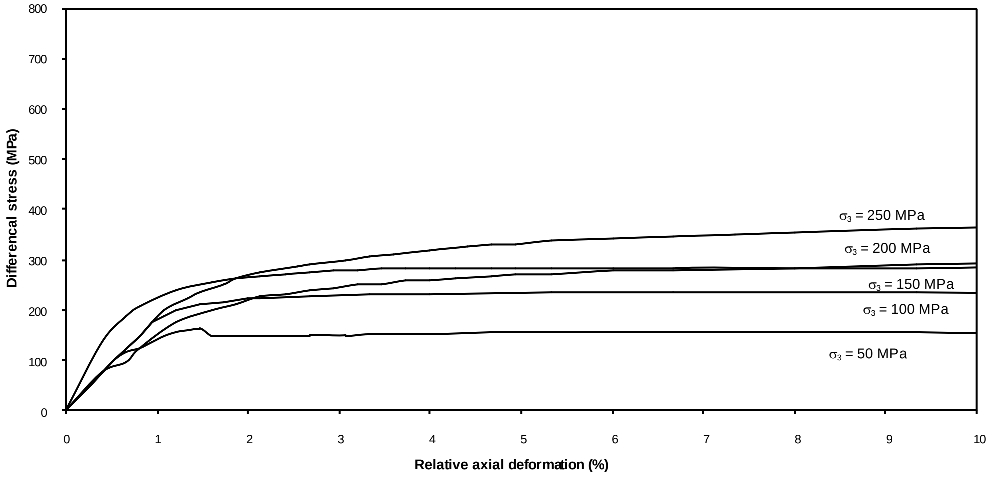

Fig.6. Deformation curves – sample of gypsum

The above-mentioned texture of the gypsum enables a significant deformation of specimens during the triaxial compression test – see Fig.8. The character of the deformation and failure for the sandstone was significantly different, the tested specimens were broken diagonally through a shear zone.

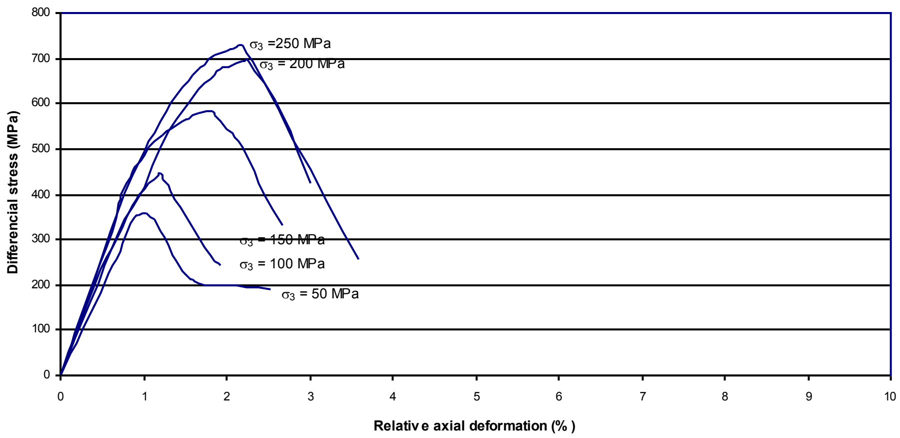

Fig.7 Deformation curves – sample of sandstone

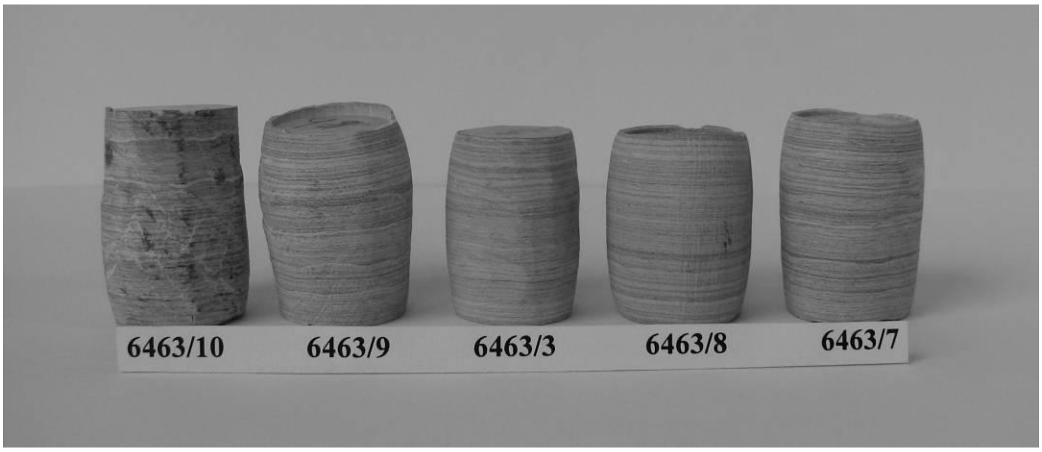

Fig. 8 Tested gypsum specimens after the experiments (loading parallel to layering), confining pressure σ_3=50MPa (No.10), 100 MPa (No. 9), 150 MPa (No. 3), 200 MPa (No. 8), 250 MPa (No. 7)

The deformation and failure of specimens are displayed in detail in Fig. 9 and Fig. 10. The plastic deformation of layering in gypsum and the diagonal zone of failure in sandstone are visible.

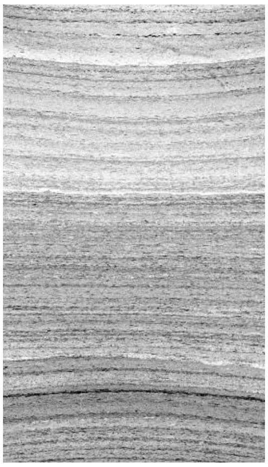

Fig. 9 Gypsum specimen after the test (σ_3 = 150 MPa) - a thin section along the axial axis, magnification 2x

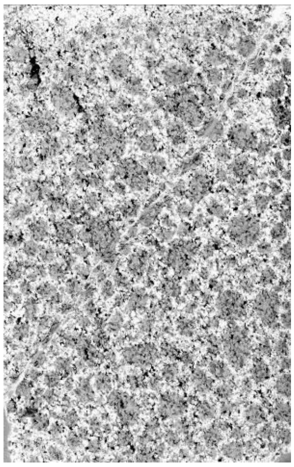

Fig. 10 Sandstone specimen after the test (σ_3 = 250 MPa) - a thin section along the axial axis, magnification 2x

During triaxial tests of gypsum specimens the influence of the orientation of the axial force to the layering was studied as well. The specimens of gypsum were loaded parallelly and perpendicularly to the layering. This factor has no significant impact, the values of the triaxial strength in the case of confining pressure 50 MPa, 100 MPa and 150 MPa are comparable (see Table 1). The strength stated in Table 1 corresponds to the maximum achieved axial stress during the deformation. In the case of confining pressures of 200 MPa and 250 MPa the plastic behaviour of the gypsum sample causes that no strength point was observed. Therefore, in these cases it is not possible to evaluate the triaxial strength and we do not indicate this in the table.

Tab. 1 Triaxial strength of the tested specimens at various confining pressures.

Confining pressure [MPA]	Triaxial strength [MPA]		
	Gypsum		Sandstone
	Axial stress perpendicular to layering	Axial stress parallel to layering	
50	210	219	410
100	335	363	541
150	440	441	727
200	-	-	888
250	-	-	970

The visible shearing failure areas were marked only for gypsum specimens tested at the confining pressure of 50 MPa. This also corresponds to the character of the deformation curves where the decrease of the force after the achievement of the strength point is evident – see Fig. 6. In the case of higher confining pressures, the gypsum specimens were plastically deformed without the origination of a visible shear failure. Experiments were performed so that the relative deformation does not exceed 20% with the aim to keep the cohesion of the material for a possible analysis of failed specimens after the experiment.

The failure of the sandstone on the other hand has a brittle character even at the highest confining pressure. The tested specimens are failed in a narrow shear zone (Fig.10). This fact is in accordance with the results of other authors (e.g., [3]; [5]; [9]).

5 CONCLUSION

The methodology of measurement in the high pressure triaxial press GTA 20-32 is described in detail in the paper. The experiments for two types of rock material with considerably different deformation behaviour were presented:

- Gypsum with plastic deformation even at lower confining pressure,
- Carboniferous sandstone with brittle failure even at the highest confining pressure.

The influence of gypsum layering was studied as well. The experimental results show that the deformation and strength properties of gypsum in the triaxial state of stress do not significantly depend on the orientation of the axial stress due to significant visually observed layering. It is apparent that it is caused by the structure of the tested material where the layering is significantly expressed by the occurrence of oriented lenses of the coal substance and not sharp restricted laminas of different materials which could cause anisotropic behaviour of the rock during loading.

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REFERENCES

[1] COATES, D. F. *Rock mechanics principles.* Ottawa. 1965: Mines Br. monograph 874. Department of Mines and Technical Surveys.

[2] DLUGOSZ, M., GUSTKIEWITZ, J. & WYSOCKI. Apparatus for investigation of rocks in a triaxial state of stress. Part I. Characteristics of the apparatus and of the investigation method. *Archiwum gornictwa*. 1981, Tom 26, Zeszyt 1, pp. 17 – 28.

[3] JAEGER, J. C. & COOK, N. G. W. *Fundamentals of rock mechanics*. 2^{st} ed. London: Chapman and Hall, 1976.

[4] KONEČNÝ, P. Jr. & KOŽUŠNÍKOVÁ, A. Measuring of gas – permeability of coal and clastic sedimentary rocks at triaxial state of stress. *Coalbed Methane and Coal Geology, Gayer, R. & Harris, I. (ed.), Geological Society Special Publication No. 109*, 1996, pp. 227-229.

[5] MENENDEZ, B., ZHU, W. L. & WONG, T. F. Micromechanics of brittle faulting and cataclastic flow in Berea sandstone. *Journal of structural geology*. 1996, Vol.18. Nr. 1, pp. 1-16.

[6] PATERSON, M. S. & WONG, T.F. *Experimental Rock Deformation – The Brittle Field*. 2st ed. Berlin, Heidelberg, New York: Springer-Verlag, 2005.

[7] POLÁČEK, J. *Chování hornin v podmínkách trojosého zatížení*. Ústav geoniky ČSAV, 1995.

[8] RAMBOUSKÝ, Z. *Vývoj snímače pro triaxiální komoru.* Ostrava: HOÚ ČSAV, 1990.

[9] SANTARELLI, F. J.. & BROWN, E.T. Failure of 3 sedimentary-rocks in triaxial and hollow cylinder compression tests. *International Journal of Rock Mechanics and Mining Sciences & Geomech. Abstract*. 1989, Vol 26XXVI. Nr. 5, pp. 401-413.

RESUMÉ

V příspěvku je popsána metodika měření na triaxiálním lisu GTA 20-32. Je porovnáno deformační chování dvou rozdílných typů hornin:

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Autoři studovali také vliv vrstevnatosti sádrovce. Experimentální výsledky ukazují, že přetvárné a pevnostní vlastnosti sádrovce v trojosém stavu napjatosti nezávisí výrazně na orientaci osového napětí k pozorované vrstevnatosti. Tato skutečnost je způsobena strukturou zkoumaného materialu, v němž je vrstevnatost zvýrazněna orientovanými čočkami uhelné hmoty a ne ostře ohraničenými laminami rozdílného materiálu, který by způsobil anizotropní chování během deformace.