Moravian greywacke – evaluation of fracture, strength and deformability properties

Martin Závacký[1,*], *Tomáš* Majda[2], *Iva* Rozsypalová[3] and *Jan* Štefaňák[1]

[1] Institute of Geotechnics, Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic
[2] Institute of Structural Mechanics, Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic
[3] Institute of Building Testing, Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic

Abstract. This contribution brings overview of mechanical properties of greywacke with focus on fracture mechanics parameters. Investigated rock type is clastic sediment, relatively widespread in Moravia region. The rock type is significantly utilized in construction industry. For purposes of this study, Kobeřice quarry was selected as sampling locality. Mechanical properties were investigated by deformation controlled 3-point bending test. Chevron notch was created on specimens in order to study fracture mechanics parameters. Moreover, deformation controlled uniaxial compression tests were carried out, as well. Specimens were equipped with strain gauges; thus, elastic modulus and the Poisson's ratio could be determined. Splitting tensile test was employed in order to determine tensile strength. Mean value of fracture toughness K_{IC} was determined to 1.85 MPa·m$^{0.5}$. Mean value of uniaxial compressive strength was observed at level of 211 MPa and tensile strength reached 19.4 MPa. Hence, the tested greywacke was considered as high strength rock. Brittle type of failure occurred during the tests. The obtained results were compared with values reported for clastic sediments from several localities in the Czech Republic. Moravian greywacke reached significantly high strength in comparison to other clastic sedimentary rocks and can be considered as valuable raw material for purposes of construction industry.

Keywords: clastic rock, chevron bend test, fracture toughness, correlation of fracture parameters

1 Introduction

This contribution deals with rock properties evaluation, particularly mechanical properties. Strength is one of the most common of the examined parameters of rock. Especially uniaxial compressive strength and tensile strength, which is usually determined by indirect method of splitting tensile test. The deformability parameters as elastic modulus and the Poisson's ratio are commonly investigated as well. Further group of properties are fracture

* Corresponding author: zavacky.m@fce.vutbr.cz

properties. They are less often investigated but they are not less interesting. Fracture parameters can be utilized in various practical applications, in geotechnical issues e.g. assessment of rock slope stability in case of toppling failure [1] or rock cutting [2].

One of the most widespread type of fracture test is 3-point bending test with notch in specimen. The testing procedure is detailly described by Ouchterlony in suggested methods of International Society for Rock Mechanics (ISRM) [3]. It is possible to determine more fracture parameters by this testing procedure, but advanced analysis of the recorded data is necessary, like for example in [4, 5].

Some correlations between fracture toughness and other parameters of rock are discussed in previous studies [6, 7]. Hence, comparison of rock properties from several localities within the Czech Republic was done in this study in order to evaluate probable correlations within local geological conditions.

This study is focused primarily on complex evaluation of fracture, strength and deformability properties of greywacke as one of the most widespread rock types in Moravia region. Greywacke is kind of compact sandstone with a matrix content of more than 15 %. The matrix material consists mostly of clay minerals, chlorite and silt. The sand-size grains composed of quartz, feldspar, mica and rock fragments [8].

2 Methods

Greywacke for purposes of this study was sampled in Kobeřice quarry in Prostějov district, the Czech Republic. The investigated greywacke had fine grained structure. No bedding planes were recognized; thus, the rock was considered as homogenous and isotropic from petrographic point of view. The sampled rock was not influenced by weathering.

3-point bending test was carried out in order to determine fracture mechanics parameters. Cylindrical specimens were prepared with chevron notch in the middle of span as a stress concentrator (Fig. 1). Diameter of the specimens was 53 mm and length approximately 200 mm, span of supports during 3-point bending test was 160 mm. The test was performed on a very stiff LabTest 6.250 multipurpose mechanical testing machine with controlled deformation with rate of 0.02 mm/min up to load of 1 kN. Then the deformation rate was decreased to 0.01 mm/min in order to record more data during unstable crack growth occurring after reaching of peak load. Dependence of the force versus deflection in the middle of the span was recorded during the test. The force-deflection diagrams were adjusted using academic software GTDiPS [9]. Afterwards, fracture toughness K_{IC} was determined according ISRM methods [3] from the maximal force reached during each test.

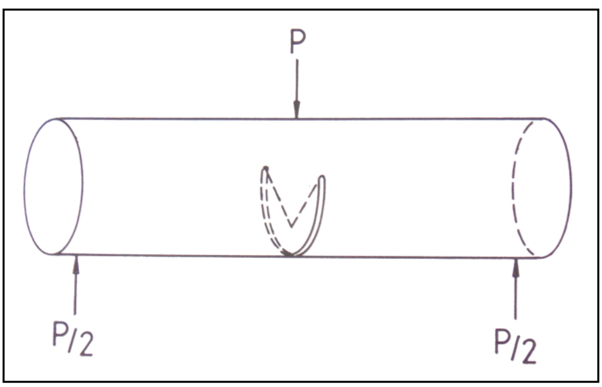

Fig. 1. Rounded bar specimen in 3-point bending test with chevron notch [10].

Rests of the specimens after the bending tests were used to prepare specimens for uniaxial compression and splitting tensile tests. Specimens for 3-point bending test were prepared from one block of rock. Additional specimens for compression tests were prepared from two further blocks (distinguished by notation of specimens - see results).

The uniaxial compression test was carried out on cylindrical specimens with diameter 53 mm and length to diameter (L/D) ratio varied from 1.8 to 2.1. Three of the specimens were equipped by strain gauges (two axial and one circumferential sensor) in order to determine modulus of elasticity and Poisson's ratio. The test was conducted in axial deformation control mode with rate 0.5 µm/s. The elastic modulus was determined as secant modulus between 15 and 50 MPa. The Poisson's ratio was determined in the same interval of axial load.

Tensile strength was determined by splitting tensile tests (Brazilian tests). Disc specimens with L/D ratio 0.5 were employed. The tests were carried out as force controlled with loading rate of 200 N/s [11]. Loading frame with Advantest Rock servo-hydraulic control console by CONTROLS company was employed to carry out the described uniaxial compression tests and splitting tensile tests.

3 Results

Force-deflection curves of the 3-point bending tests are presented in Fig. 2. All the curves have similar shape. The curves are characteristic by steep increasing of the force to the peak level. Then decreasing trend follows which is even slower after deflection ca. 0.1 mm. Gaps between points in the decreasing part of the curves was caused by rapid unstable crack grow which indicates brittleness of the tested rock.

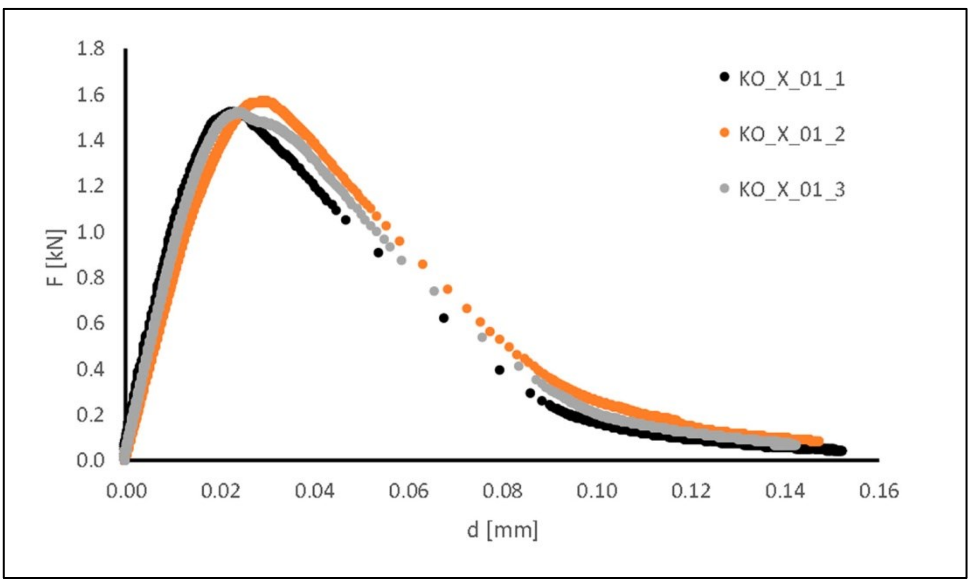

Fig. 2. Force-deflection curves obtained by the 3-point bending tests.

Fracture toughness K_{IC} was determined from the peak force and the values are listed in Table 1. and the average is 1.85 MPa·$m^{0.5}$. Coefficient of variation (CoV) is relatively low (1.8 %). The low variation within specimens from one block of the rock is in accordance with the assumption of homogenous isotropic rock behaviour noted in the previous chapter.

Table 1. Summary of the determined fracture toughness.

Parameter	**Symbol**	**Unit**	**KO-X-01/1**	**KO-X-01/2**	**KO-X-01/3**	**Mean value**	**CoV [%]**
Fracture toughness	$\mathbf{K_{IC}}$	$MPa \cdot m^{0.5}$	1.82	1.89	1.85	**1.85**	1.8

Stress-strain diagrams are plotted in Fig. 3 and Fig. 4. The strain components are distinguished: axial strain, radial strain and volumetric strain. The axial strain tended to follow linear trend during whole test. Only negligible strain softening appeared close to failure in case of KO-X-01/A and KO-X-5/1 specimen. Harmed strain gauge caused soar of the radial strain and consequently volumetric strain above 200 MPa in case KO-X-5/1 (Fig. 4). Damage of the strain gauge was caused by a crack developed through the sensor.

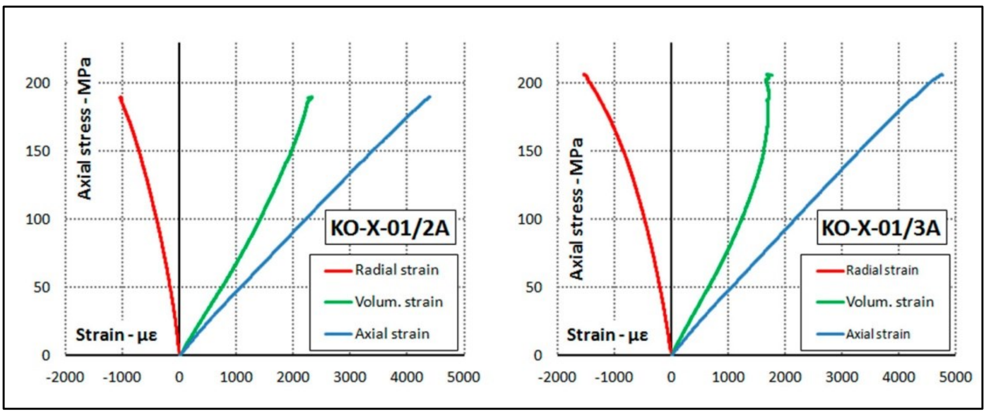

Fig. 3. Stress-strain diagram obtained from uniaxial compression test of KO-X-01/2A and KO-X-01/3A specimens.

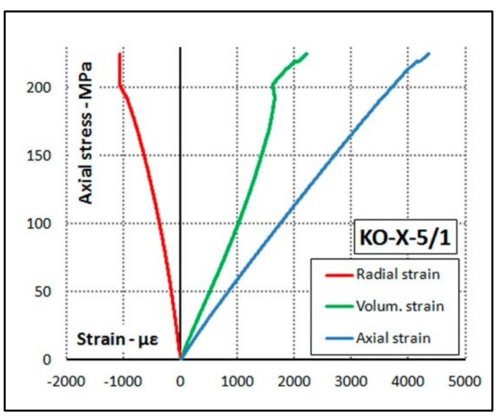

Fig. 4. Stress-strain diagram obtained from uniaxial compression test of KO-X-5/1.

The determined uniaxial compressive strength and deformability parameters (E, ν) are listed in Table 2. The specimens KO-X-01/2A and KO-X-01/3A were prepared from samples used in the bending tests. Remaining tested specimens were prepared from further sampled blocks of rock in order to widespread amount of the results. There were not installed strain gauges on specimens KO-X-4/1 and KO-X-5/2, thus, the modulus of elasticity and Poisson's ratio were not determined. The splitting tensile strength, listed in Table 3, was determined on specimens prepared from rests of bending test samples, as well.

The tensile strength reached the lowest variability (3.2%) from the strength and deformability properties, while the modulus of elasticity showed the highest variability (14.9%).

Table 2. Summary of uniaxial compression testing – strength and deformability parameters.

Parameter	Symbol Unit	KO-X-01/2A	KO-X-01/3A	KO-X-4/1	KO-X-5/1	KO-X-5/2	Mean value	CoV [%]
Uniaxial compressive strength	σ_c [MPa]	190.2	206.4	231.2	225.2	203.1	**211.2**	7.9
Modulus of elasticity	**E** [GPa]	45.2	46.0	-	58.4	-	**49.9**	14.8
Poisson's ratio	**ν** [-]	0.16	0.19	-	0.19	-	**0.18**	9.6

Table 3. Results of the splitting tensile strength tests.

Parameter	Unit	KO-X-01/2 B-1	KO-X-01/2 B-2	KO-X-01/2 B-2	KO-X-01/3 B-1	KO-X-01/3 B-2	KO-X-01/3 B-3
Tensile strength - σ_t	[MPa]	18.7	20.5	19.3	19.0	19.6	19.2
Mean value	[MPa]	**19.4**					
CoV	[%]	3.2					

4 Discussion

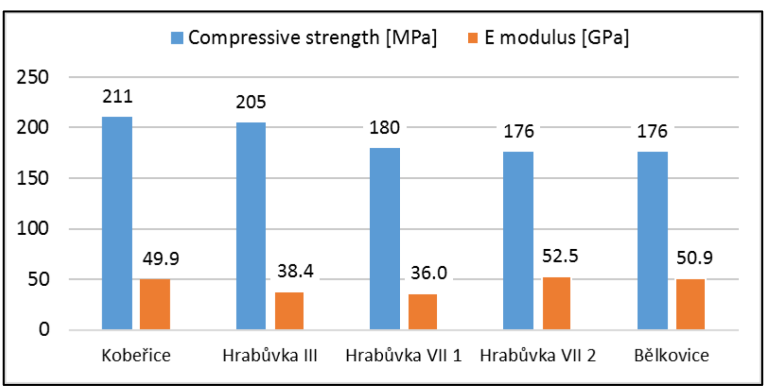

Fig. 5. Comparison of the uniaxial compressive strength and modulus of elasticity of greywacke from Kobeřice with another reported localities within Moravia region (the data taken from [12]).

The parameters determined by the described laboratory investigation were compared with another previously published data [12]. The greywacke as a rock type showed in general relatively high uniaxial compressive strength in range from 176 to 211 MPa (Fig. 5), thus, all belongs to grade "R5 – Very strong rock" (100-250 MPa) according ISRM classification [13]. Samples from Kobeřice performed compressive strength 211 MPa, what is slightly higher than strength reported from the further listed localities in Moravia region. Modulus of elasticity E varied within range from 36.0 to 52.5 GPa. Value from Kobeřice is also on the upper bound of the range.

Fracture toughness of the tested greywacke reached value 1.85 MPa·m$^{0.5}$, what is significantly higher than values determined on another clastic sedimentary rocks from the Czech Republic. There were compared 6 sandstones from the Bohemian Cretaceous Basin and 2 sandstones from the Carpathian Flysch belt (Fig. 6) [5, 14]. Fracture toughness of the sandstones from Bohemian Cretaceous Basin reached less than 1.0 MPa·m$^{0.5}$ in all reported cases. Higher values, within range of 1.0 ÷ 1.5 MPa·m$^{0.5}$ reached sandstones from the Carpathian flysch belt. The flysch belt sandstones are Cretaceous age, as well [15]. However, these sandstones were influenced by Alpine orogeny, while the Bohemian ones were not affected by orogenic processes after their formation.

The studied greywacke from Koběřice belongs to Moravian-Silesian Zone of the Bohemian Massif and this sedimentary rock was formed in Carboniferous period [15]. Hence, the greywacke is the oldest from the compared rocks. The greywackes in Moravia were also affected by orogenic processes and anchimetamorphism – early phase of metamorphism [16]. Consequently, we can assume some correlation between mechanical properties, particular fracture toughness in this evaluation, and geological history of rock.

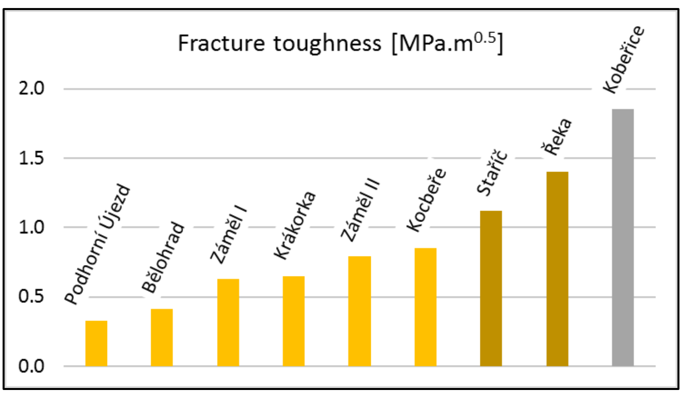

Fig. 6. Comparison of the fracture toughness among several sandstones from the Czech Republic (the data taken from [5, 14]). Yellow – the Bohemian Cretaceous Basin, brown – Carpathian flysch belt, grey – Moravian-Silesian Zone of the Bohemian Massif.

Furthermore, there was done comparison of fracture toughness with density and uniaxial compressive strength (Fig. 7). Some correlation between the properties occurred in both cases. Linear approximation of the trend was done by least squares method. Coefficient of determination is higher in case of compressive strength (R^2=0.783) (Fig. 7 – right). However, the coefficient of determination for density (R^2=0.719) is only 6 % lower. Amount of the evaluated data is relatively constrained and focused on clastic sedimentary rocks only; thus, we cannot generalize that fracture toughness is more dependent on the uniaxial compressive strength than on density of a rock.

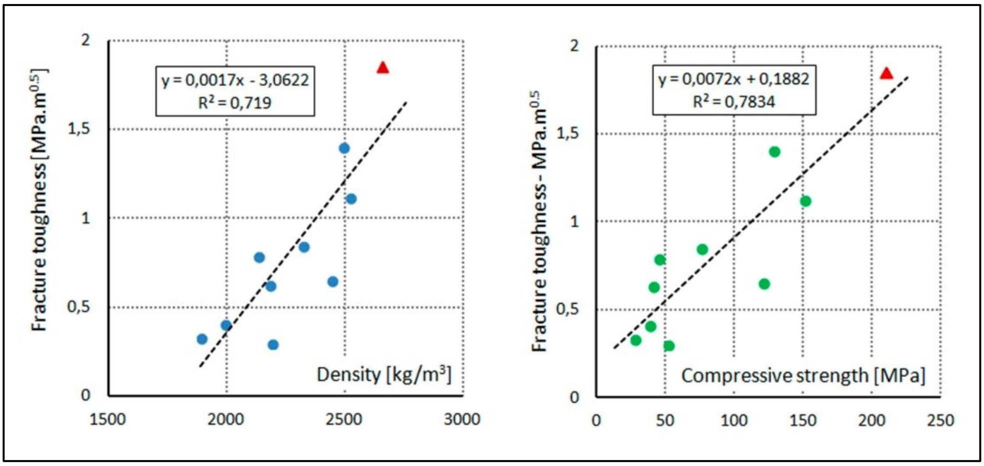

Fig. 7. Dependency of the fracture toughness on density (left) and uniaxial compressive strength (right) with highlighted the studied locality – Kobeřice (the data taken from [5, 14]).

5 Conclusions

Laboratory tests of Moravian greywacke from sampling locality Kobeřice were carried out and fracture, strength and deformability parameters were determined. The obtained results were compared with values reported for another clastic sedimentary rocks in the Czech Republic. Following features were observed:

- The greywacke reached the highest uniaxial compressive strength and fracture toughness among the compared rocks. All of the listed greywackes reached "R5 – Very strong rock" grade in ISRM classification of uniaxial compressive strength. Brittle failure occurred during all types of the conducted tests.
- Some correlation occurred between fracture toughness and density, as well as between fracture toughness and uniaxial compressive strength. Simple linear regression has similar coefficient of determination in both cases (R^2= 0.719 resp. 0.783).
- Influence of geological history of rock to its mechanical properties, particularly fracture toughness, is assumed according the comparison carried out among the clastic sedimentary rocks.

According the summarized observation, we can assume that Moravian greywacke from other localities could reach similarly high values of mechanical properties. However, this assumption and figured correlations should be verified by further investigation. Nevertheless, mechanical properties of the examined greywacke are appropriate for various applications in civil engineering. Hence, the greywacke is valuable raw material for construction industry.

This contribution has been worked out under the project No. LO1408 "AdMaS UP - Advanced Materials, Structures and Technologies", supported by Ministry of Education, Youth and Sports under the „National Sustainability Programme I" and under the project No. FAST-S-19-6031 "Fracture mechanics properties of greywacke in context of another properties of the rock" supported by Brno University of Technology. Thanks are also expressed to colleagues from Institute of Structural Mechanics at Brno University of Technology: Prof. Keršner to his consultations and advices, as well as to Miroslav Friedl for preparation of the specimens to the fracture tests.

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