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Behaviour of Multicomponent Geomaterials: Pilot Experimental Study in Rock Mechanics

Lukáš Krmíček[a,b,]*, Vladislav Horák[a], Simona Kuboušková[c], Matěj Petružálek[b]

[a]*Brno University of Technology, Faculty of Civil Engineering, AdMaS Centre, Veveří 95, 602 00 Brno, Czech Republic*
[b]*Institute of Geology of the CAS, Rozvojová 269, 165 02 Prague 6, Czech Republic*
[c]*Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic*

Abstract

Rock massifs traditionally used for the construction of foundations, tunnels or as a source of crushed stone, frequently contain compositionally (texturally, mineralogically, geochemically) contrasting inclusions – xenoliths. The presence of xenoliths is a commonly overlooked fact which may, however, significantly affect the total strength of the massifs. The most frequent xenoliths in igneous massifs are mafic microgranular enclaves occurring as ellipsoidal inclusions with the size varying from centimetre to metre scales in the host rocks. Our pilot experimental study brings a complex assessment of strength properties (e.g., rebound hardness, uniaxial compressive strength, rock tensile strength) of multicomponent geomaterials, i.e., host-rocks and their enclaves, sampled both from quartz-rich (granitoid) and quartz-poor (syenitoid) massifs.

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1. Introduction

Rock mechanics is a dynamically developing scientific discipline integrating a range of modern geological and geotechnical approaches [1, 2]. This discipline is absolutely irreplaceable in the study of the behaviour of geomaterials and rock massifs affected by civil engineering works.

* Corresponding author. Tel.: +420 541 147 230; fax: +420 549 245 147.
E-mail address: l.krmicek@gmail.com

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Rock massifs frequently contain compositionally (texturally, mineralogically, geochemically) different parts generally described under the term **xenoliths** (from ancient Greek: “foreign rock”) [3]. The presence of xenoliths is a commonly overlooked fact in rock mechanics that, nevertheless, can significantly affect the total strength of the massifs [4].

2. Mafic microgranular enclaves

The most frequent xenoliths in igneous rocks are mafic microgranular enclaves occurring both in quartz-rich (granitoid) and quartz-poor (syenitoid) massifs [4–7]. The shape of mafic microgranular enclaves is mostly ellipsoidal with the size varying from centimetre to metre scales. The name “mafic microgranular enclaves” reflects their high contents of dark (mafic) minerals (dark micas, amphiboles) and fine- to medium-grained, equigranular texture (Fig. 1A).

Genetically, the mafic microgranular enclaves represent relatively rapidly chilled “drops” of more basic (mafic) melt which was variably mingled with the surrounding felsic melt characterized by higher content of SiO_2 [8–11]. Thus, mafic microgranular enclaves are usually preferentially oriented (stretched) in the flow direction of the host magma.

3. Multicomponent geomaterials

From the perspective of rock mechanics, we can consider the host rocks enclosing mafic microgranular enclaves as multicomponent geomaterials. These materials are multicomponent on several scales:

- on elemental scale – mafic enclaves geochemically differ from their host rocks;
- on mineral scale – mafic enclaves contain different minerals than their host rocks;
- on textural scale – mafic enclaves are usually more fine-grained than their host rocks.

4. Multicomponent geomaterials in civil engineering

The correct understanding of strength properties of multicomponent geomaterials is very important for several reasons:

- Rock massifs containing mafic microgranular enclaves are frequently used for both foundation engineering and tunneling.
- Rock massifs containing mafic microgranular enclaves are mined for the production of crushed stone. Depending on the abundance of mafic microgranular enclaves, individual fractions of crushed stone can contain a substantial proportion of multicomponent geomaterials.
- Rock massifs containing mafic microgranular enclaves are preferably exploited for fine stone production (Fig. 1B).

5. Samples and methods

Samples of mafic microgranular enclaves and their host rocks were collected both from the Brno Massif (enclave-granitoid system) and from the Třebíč Massif (enclave-syenitoid system). For detailed petrographical characterisation of studied samples and for principles of estimation of the proportions of enclaves via geochemical modelling as briefly suggested in the chapter 7 see the work by Krmíček (2015) [12].

The Brno Massif located on the eastern margin of the Bohemian Massif is a Cadomian batholith approximately 600 km^2 in area, divided by the Central Basic Belt into the Western Granitoid Complex and Eastern Granitoid Complex [13]. Mafic microgranular enclaves concentrate in the Eastern Granitoid Complex [14].

The Třebíč Massif is the largest (~500 km^2) syenitic body in the Bohemian Massif. Rocks of the Třebíč Massif were formed by intensive mixing of basic (mantle-related) and acidic (crust-related) types of melts, and are characterised by abundant occurrences of mafic microgranular enclaves [15].

Laboratory testing of rock specimens included measurements of ultrasonic wave velocities (using 1-MHz Panametrics transducers), rebound hardness (using L- and N-type Schmidt hammer), uniaxial compressive strength and indirect tensile strengths – Brazilian test (both using MTS 815 loading frame).

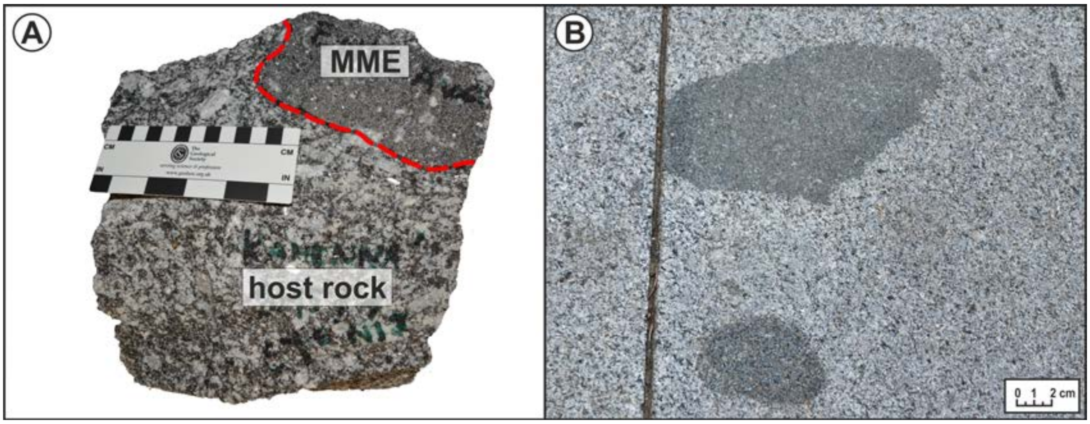

Fig. 1. Examples of multicomponent geomaterials. (a) a raw sample of the host rock enclosing a mafic microgranular enclave (MME); (b) outdoor stone pavement containing multicomponent geomaterials (a view in front of the main entrance to the Faculty of Civil Engineering, Brno University of Technology).

6. Results

6.1 Rebound hardness

Field testing of the rebound hardness using a Schmidt hammer (N-type) provided interesting results (Fig. 2). The enclaves in both granitoids and syenitoids show higher rebound hardness values than their host rocks: on average by 11–13 % and by up to 20 %, respectively.

More sensitive laboratory testing of sliced rock specimens using L-type Schmidt hammer provided similar results with a clearly visible trend of increasing contrast between the rebound hardness of enclave and host rock from a quartz-rich system towards a quartz-poor system.

Fig. 2. Field study of the rebound hardness of multicomponent geomaterials using the N-type Schmidt hammer.

6.2 Uniaxial compressive strength and indirect tensile strengths

Laboratory testing of uniaxial compressive strength and indirect tensile strength characterized the strength properties of multicomponent geomaterials. Testing of more than one hundred rock specimens yielded the following results:

- Contacts between the enclaves and their host rocks do not represent predisposed zones with a significant weakening of mechanical properties.
- Mafic microgranular enclaves, compared to their host rocks, show systematically higher values of uniaxial compressive strength and rock tensile strength.
- Stress-strain diagrams (Fig. 3A, Fig. 3B) together with static and dynamic elastic moduli (Table 1) show a significant difference in deformability of mafic microgranular enclaves and their host rocks.
- The positive strength effect connected with the presence of mafic microgranular enclaves clearly increases from granitoid massifs towards syenitoid massifs.

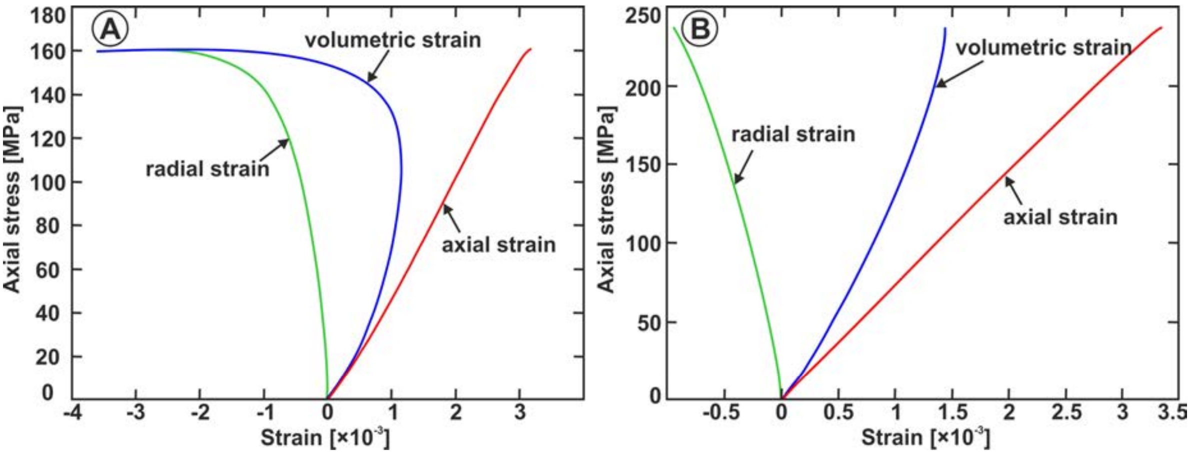

Fig. 3. Stress-strain diagrams of uniaxial compressive testing of multicomponent geomaterials. (a) an example of relative deformation curves in syenite; (b) an example of relative deformation curves in mafic microgranular enclave.

Table 1. Mechanical properties of syenite and mafic microgranular enclave. Symbols: v_p and v_s – P a S wave velocity; ρ – density; UCS – uniaxial compressive strength; E – Young's modulus; μ – shear modulus; ν – Poisson ratio; K – bulk modulus.

rock type	v_p [km/s]	v_s [km/s]	ρ [g/cm^3]	UCS [MPa]	E [GPa]	μ [GPa]	ν	K [GPa]
syenite	4.93	2.93	2.68	160.8	DYNAMIC ELASTIC MODULI			
					56.5	23.0	0.229	34.7
					STATIC ELASTIC MODULI			
					54.80	21.70	0.26	38.20
mafic microgranular enclave	5.869	3.377	2.802	236.7	DYNAMIC ELASTIC MODULI			
					80.0	31.9	0.253	53.9
					STATIC ELASTIC MODULI			
					73.25	29.31	0.25	48.74

7. Quantification of overall strength effect of multicomponent geomaterials for quartz-rich and quartz-poor rock massifs

The exact quantification of the positive impact associated with the presence of mafic microgranular enclaves is not trivial. The proportions of enclaves vary widely among the individual sites. We propose a method combining the results of laboratory testing of uniaxial compressive strength with the results of geochemical modelling based on the general mixing equation of Langmuir et al. (1978) [16]. Based on the results obtained for the individual sites of this pilot study, the rocks were formed by mixing of ca 50 to 80 % of the mafic member (now occurring in the form of mafic microgranular enclaves) with felsic melts. It can be thus concluded that the overall strength is ideally higher by up to 3 % in the quartz-rich (graniotid) massif and by up to 10 % in the quartz-poor (syenitoid) massif.

8. Conclusions

The presence of xenoliths is a commonly overlooked fact which may, however, significantly affect the total strength of the massifs. Mafic microgranular enclaves show, compared to their host rocks, systematically higher values of uniaxial compressive strength and rock tensile strength. Positive strength effect associated with the presence of microgranular enclaves increases from granitoid massifs towards syenitoid massifs.

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