A high potential of the micro-Deval test in rock quality assessment

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Abstract: The micro-Deval test which determines the micro-Deval coefficient is preferentially aimed at quality control assessment of aggregates being used in road construction. In first part of the study, the existing accessible database of rocks properties from 146 sites of Slovakia was used and the micro-Deval coefficient was analyzed in connection to other rock properties. Among others findings, the analysis indicated that the rock strength represented by the Uniaxial Compressive Strength is not conclusive for the micro-Deval coefficient values. In experimental part of the study, three types of rocks have been examined. In aim to evaluate rock quality for the use in aggregate production the micro-Deval test and other selected tests as magnesium sulphate test and freeze-thaw test have been realised. Additional quick tests as Point load test and Slake durability test, routinely used in the rock testing, as well as modifications of the micro-Deval test in dry version have been also performed. It was confirmed that the micro-Deval test provides a high predicative values, gives conformable results in comparison with other tests for aggregates and so it can serve as a good and reliable tool on the rock quality determination. Very good relationship was shown between the results of Slake durability test and micro-Deval test. The realization of micro-Deval test performed on aggregates, which have previously passed an accelerated weathering tests, point out to broader possibilities of the use of micro-Deval tests, mainly their utilization for the monitoring of changes in aggregates quality after some other tests.

Key words: micro-Deval test, resistance to wear, aggregates quality control testing, UCS, Point load test, Slake durability test, aggregate tests feasibility analysis

1. INTRODUCTION

The micro-Deval test is one of a large number of standardized tests in aggregates quality evaluation, predominantly used in road and railway construction. The test began to use in France during the 1960s and in 1996 was established and approved by the European Committee for Standardization as European standard test (EN 1097-1) in a group of normative documents for mechanical and physical properties of aggregates. Many research carried out since this date confirmed the importance and justification of the using of the test (Cooley et al, 2002; Arm, 2003; Rangaraju, 2006; Hossain et al., 2007; Erichsen et al., 2011; Török, 2015; Atac et al., 2016; Czinder & Török, 2017). The testing of natural aggregates but also of materials similar to aggregates (e.g. slags, concrete or recycled aggregates from construction and demolition sites) in micro-Deval apparatus is applied now not only in Europe but worldwide. It was confirmed that the micro-Deval test is representative and provides very good repeatability and reproducibility of results (Meinenger, 2004; Cuelho et al., 2007; Durmeková, 2009) and therefore is responsible method in a control of aggregates quality.

The referred-to laboratory method determines the micro-Deval coefficient M_{DE} which is expressed as a loss percentage of original aggregate specimen with grain size in the range of 10–14 mm caused by abrasion and grinding with steel balls in the presence of water after the rotation in robust steel drum in time duration of about 2 hours. The loss is the amount of material passing the 1.6 mm testing sieve. Through the test is specified the resistance of aggregates to wear by abrasion and polishing in the presence of water what it is in close connection with the keeping of a surface roughness of roads, ways and pavements and related to the skid resistance in usual climatic conditions. The skid resistance of road surfaces is essential to ensure traffic safety (Wang et al., 2015). The realization of the micro-Deval test is even more easily than the realization of the test on the determination of the polished stone value according to EN 1097-8. In regard to scope of the test, its realisation finds application predominantly in road construction with intended use of aggregates into upper layers of roads and other traffic areas, but also in railway construction in the evaluation of aggregates quality for the railway ballast.

In Slovakia, the micro-Deval test has been yet relatively a new method in aggregates testing, and experiences with the test carried out on own domestic produced aggregates are insufficient up to now. Results from the micro-Deval test realisation are mentioned in Slovak research literature only sporadically (Grünner & Romancová, 2005; Romancová, 2005; Durmeková, 2009; Holzer et al., 2009). Scientific background of the test and its position between testing methods are obtained predominantly from foreign studies. The most research with content of the micro-Deval testing are available for us from U.S. (Woodside & Woodward, 1988; Cooley et al, 2002; Appa Rao Hoare, 2003; Rangaraju, 2006; Cuelho et al., 2007; Hossain et al., 2007) which are all really very extensive with a high number of aggregates samples and huge laboratory works and measurements. However, the use of results of mentioned researches and results comparison are problematic due to the different testing conditions and parameters as the different grain size in specimen, different specimen amount in the test, different size sieve for the loss calculated after the test, and so on.

From the mentioned reasons, in the paper our own research on three types of rocks taken from the territory of Slovakia is presented. The research was realised in the frame of a student

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diploma thesis with a main goal to confirm a high potential of the micro-Deval test in aggregates testing also on rocks from Slovakia.

2. METHODS AND ROCK MATERIAL

As an initial step of the study, analyses of data from the Engineering Geological Atlas of Rocks of Slovakia (Holzer et al., 2009) were done and relations between the micro-Deval coefficients and another physical properties and technical parameters of rocks were compared. The most remarkable findings are interpreted in correlation graphs.

Three types of magmatic rocks were taken for own experimental study – paleobasalt, granite and mylonitic granodiorite. Basic physical properties of studied rocks were determined using standard methodology. Specific gravity, bulk density and total porosity were determined according to the standard EN 1936 and water absorption according to the EN 13755. The strength of rocks was determined by the Point Load Test (PLT) what is the method suggested by the International Society for Rock Mechanics (ISRM) as standard indirect test on the determination of the uniaxial compressive strength (UCS) of rocks. A result of the PLT is the Point load index $I_{s(50)}$ and correlated relation between both strength is formulated as $UCS = K \, . \, I_{s(50)}$. The correlation coefficient K was used 22 (EN 1926). As additional test was carried out the Slake durability test (SDT) that is similarly as the PLT included in suggested methods register of the ISRM as suitable test on determination of the index durability and resistance of rocks to weathering (Ulusay & Hudson (eds.), 2007). The result of the SDT is the Slake durability index I_d. Both methods, PLT and SDT are very convenient, practicable and quick and do not require the preparation of specimens of geometrical shapes (cubes or rollers) and in doing so declare the quality of rocks reliably.

The main realised method in own laboratory research was the test in apparatus micro-Deval with two drums (Fig. 1). The test was carried out in standard concept according to the European norm EN 1097-1 (a total mass of 500 g aggregates of fraction 10 /14 mm; 5 kg of stainless metal balls; 2.5 l tap water; 12 000 revolutions in duration about 2 hours) but also in modification version with using drying aggregate specimen and its rotation in the drums without water. In both test versions minimal 2 samples of each lithological type were used.

In the next step of the research, another laboratory tests on determination of thermal and weathering properties of aggregates according to European norms were realised, named the test on determination of resistance to freezing and thawing with 10 cycles (EN 1367-1) and magnesium sulphate test with 5 cycles (EN 1367-2). After these tests, standard micro-Deval tests were realised on the same aggregate specimens that were submitted to the accelerated weathering tests.

All examined rocks were strong igneous rocks suitable in a production of crushed aggregates of different size fractions and thus for use for various construction purposes. Two lithotypes of them, paleobasalt and granite, were taken from active quarries Sološnica and Devín, both situated in western part of Slovakia. Third rock type, granodiorite, was obtained from the muck dumps created from the excavation of the tunnel Višňové – Dubná Skala current built on the D1 highway in north part of Slovakia. Rock samples were obtained from mentioned sites in form of irregular blocks or in the nature of coarse aggregates.

3. RESULTS

3.1 Findings from the rock database analyses

The database Engineering Geological Atlas of Rocks of Slovakia (EGARS) includes the characterization of rock masses of 146 sites over the all geological formations of the Western Carpathians (Holzer et al., 2009; Holzer, Bednarik & Laho, 2014). It was created and complemented during 30 or up to 40 years in several stages. The atlas also contents values of essential physical and technical properties of each rock material taking from these rock masses, between them the micro-Deval coefficient. In the same final stage of the data collection, tests as PLT, SDT and micro-Deval tests were realised on the same sample files and therefore results of these tests are comparable together. It is pity that the database does not include another very important properties predicative about the stone quality and suitability for aggregates production, such as results of Los Angeles abrasion tests, impact tests, magnesium sulphate test or freezing-thawing

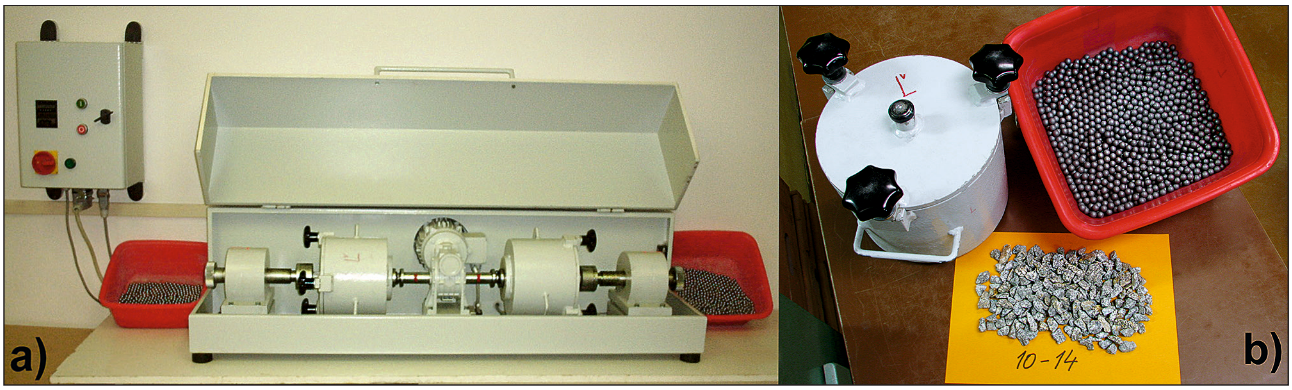


Fig. 1 a – Micro-Deval apparatus with two drums; b – Aggregate specimen with grains between 10 and 14 mm size of mass 500 g in comparison with 5 kg steel ball with diameter ca 10 mm.

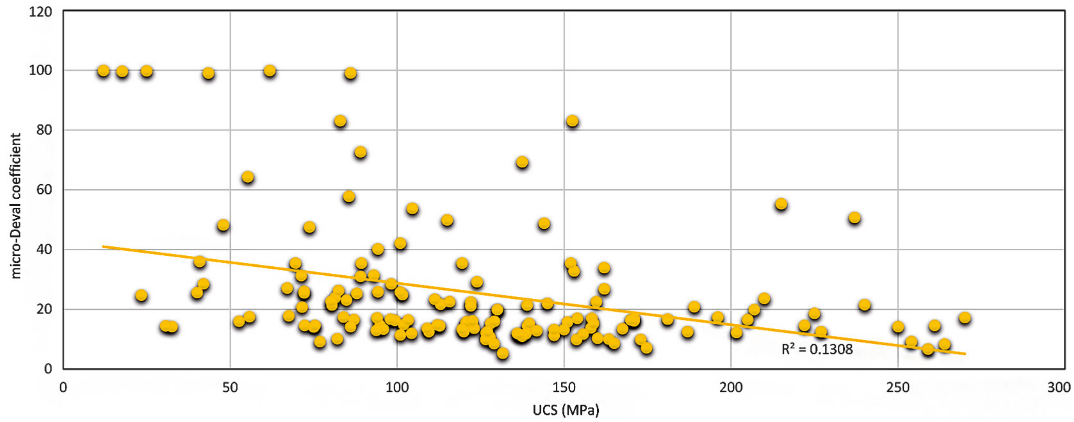


Fig. 2 Relationship between uniaxial compressive strength and micro-Deval coefficient of rocks of Slovakia, data source: EGARS (Holzer et al., 2009).

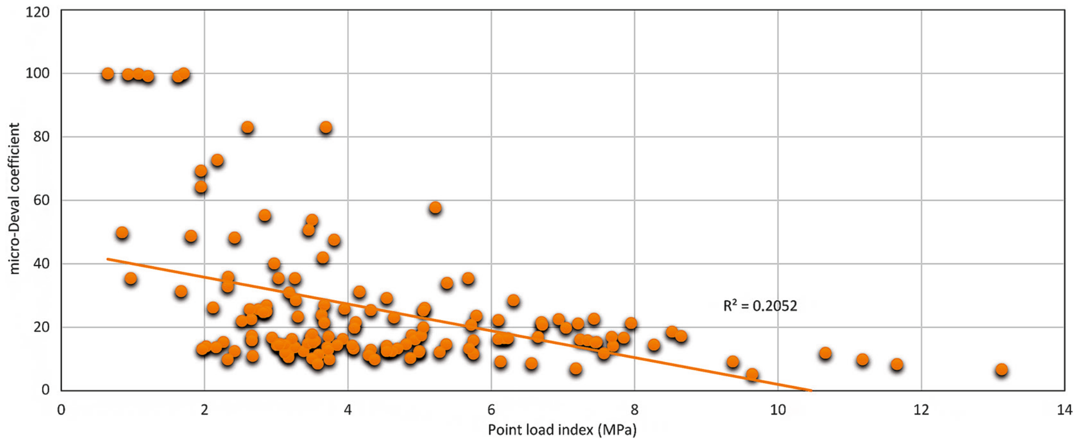


Fig. 3 Relationship between Point load strength and micro-Deval coefficient of rocks of Slovakia, data source: EGARS (Holzer et al., 2009).

tests what would be very suitable for another comparative analysis. From strength properties the uniaxial compressive strength and the strength measured at point load were used. From other parameters, results of Slake durability tests were analysed, predominantly by reason of the similarity of both tests.

The relation the UCS and the micro-Deval coefficient M_{DE} was not confirmed (Fig. 2). This fact can be partly justified by the factor that the EGARS compiled gradually over a long time period and the sampling as well as the laboratory testing was carried out in several stages.

The comparison of the PLT and micro-Deval test results turned out to be very similar. In this comparison the correlation between test methods remains poor with R^2 value about 0.20. The relationship between these properties were analyzed in a set of all rock types in Slovakia (gneiss, amphibolite, granite, granodiorite, limestone, dolomite, quartzite, sandstone, conglomerate, andesite, rhyolite, basalt, but also tuffs and travertine, it means all 146 sites together) and the linear relationship between Point load index $I_{s(50)}$ and the micro-Deval coefficient M_{DE} showed be not very close (Fig. 3). Analyses of these properties in parts with regard to the rock type and its genesis showed better dependencies of variables, predominantly for granitoids, carbonate rocks, sandstones and volcanic rocks without tuffs and pyroclastic types (Fig. 4).

Very good relationship has been shown between values of the Slake durability index I_d determined by the SDT and the micro-Deval coefficient M_{DE} of atlas rocks, how is presented on dolomites and sandstones in Fig. 5. Similarly, tight relation between mentioned tests has been found in the case of studied rock types in the own experimental part of the research, how it will be presented in the next part of the paper. This is certainly due to the fact that the nature of both tests is the same (rotation in drums, presence and action of water), although at the SDT miss abrasive steel balls, the size of the rock grains used in the tests is different, and the duration of both tests is also significantly different.

3.2 Results of the experimental study

The basic physical properties of the studied rocks are given in Tab. 1. According to results of the realised strength tests, the strongest rock from them is the fine-grained paleobasalt from

Tab. 1 Basic physical characteristics of rocks used in the experimental study

Property / Number of samples	Paleobasalt Sološnica	Granite Devín	Granodiorite (tunnel muck) Višňové
Specific gravity (g.cm^{-3}) / 5	2.808	2.683	2.713
Bulk density (g.cm^{-3}) / 10	2.73	2.63	2.67
Total porosity (%) / 10	2.78	1.98	1.58
Water absorption (%) / 10	0.45	0.73	0.40
Point load index (MPa) / 15 to 20	3.57	3.13	2.58
Uniaxial compressive strength *calculated* (MPa) / 15 to 20	78.5	68.9	56.8

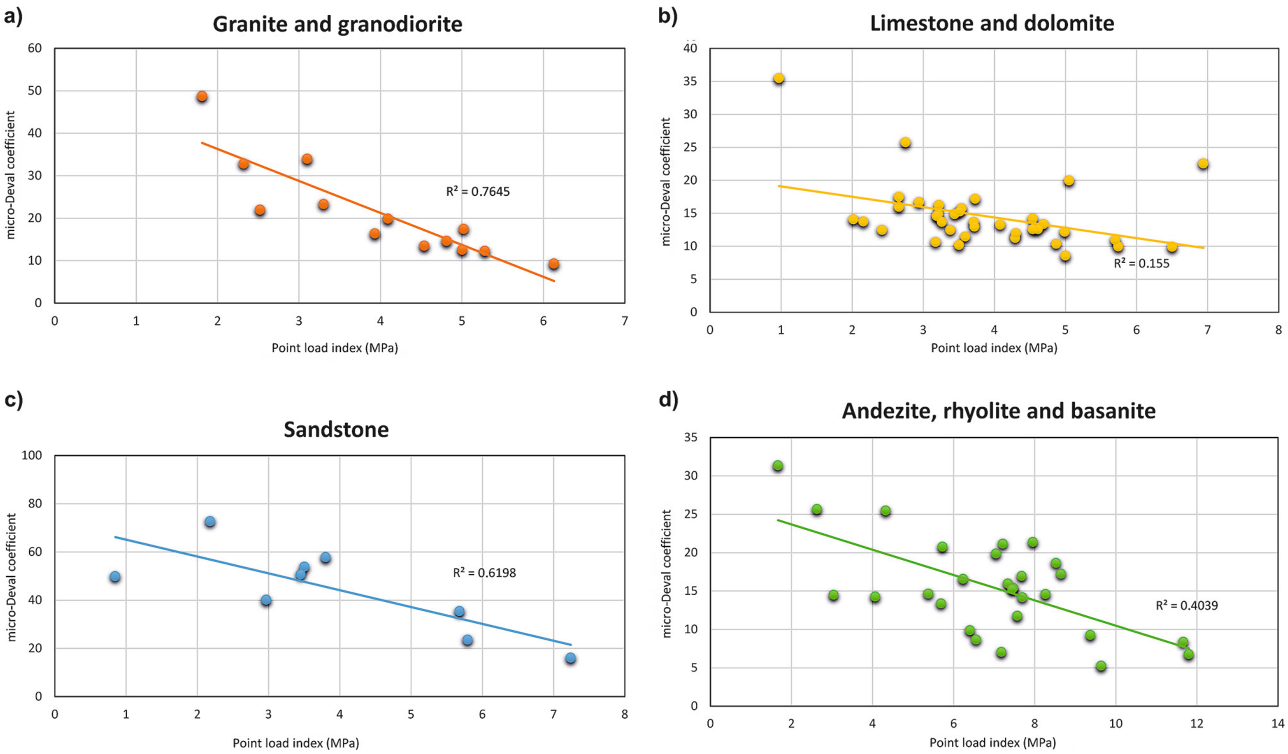


Fig. 4 Relationship between Point load strength and micro-Deval coefficient of some rock types of Slovakia. a – granitic rocks, b – limestone and dolomite, c – sandstone, d – effusive rocks, data source: EGARS (Holzer et al., 2009).

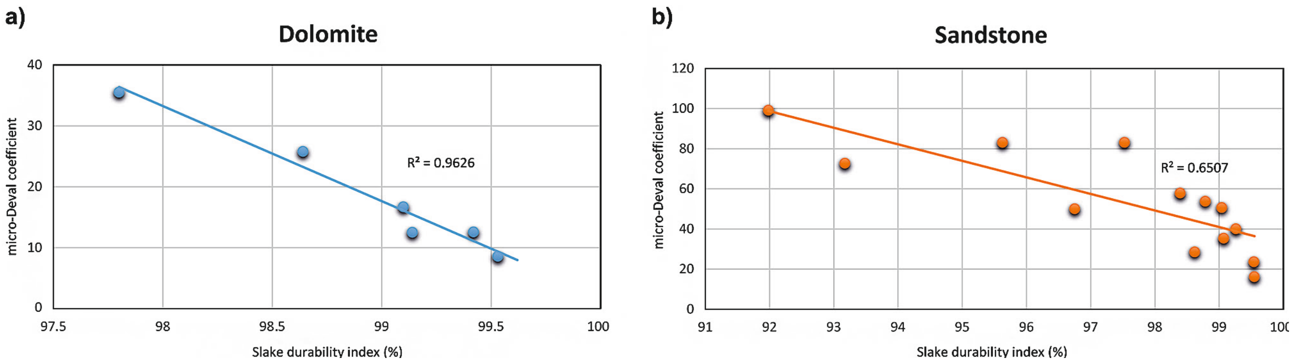


Fig. 5 Relationship between Slake durability index and micro-Deval coefficient of rocks from the database. a – dolomite, b – sandstone, data source: EGARS (Holzer et al., 2009).

Sološnica quarry, the second in line is medium-grained granite from Devín quarry and at the end is the partly mylonized, slightly lineated medium-grained granodiorite, excavated from the realised highway tunnel. The paleobasalt with amygdaloidal structure has also the highest values of specific gravity, bulk density and total porosity. The water absorption which partially reflects an effective or open porosity changes the order of rocks and points to the highest absorption of granite compared to other rocks. The lowest value of water absorption shows the granodiorite.

In Tab. 2 are presented results of the realised tests that assess the quality of the rock for its use as a crushed aggregate. The mechanical properties of rocks were evaluated by the micro-Deval test only and the resistance to climate influences was determined

Tab. 2 Results of realised tests for mechanical and physical properties of aggregates

Parameter	Paleobasalt Sološnica	Granite Devín	Granodiorite (tunnel muck) Višňové
M_{DE} standard	11.2	16.6	14.8
M_{DE} dry	1.6	5.6	7.3
Freeze-thaw test – loss (%)	0.21	0.66	0.43
Sulphate test $MgSO_4$ – loss (%)	16.9	22.1	19.1
SDT index – 20 minutes (%)	99.4	98.5	98.8
SDT index – 2 hours (%)	98.3	96.2	96.7

by accelerated weathering tests as freeze-thaw test, sulphate soundness test with $MgSO_4$ and Slake durability test. These tests were performed according to current European norms. From these tests, the SDT only is not a standard test.

Based on the results of realised tests, it can be assessed that the paleobasalt aggregate from Sološnica is the highest quality, followed the granodiorite aggregate from the driving tunnel, and finally is placed the granite from Devín quarry. The Slake durability test confirms these conclusions (see Tab. 2). The results of the aggregate tests are not entirely correlated with the strength tests (see Tab. 1). The relation between the Point load strength and the micro-Deval coefficient M_{DE} of tested rocks is no significance. The value of the coefficient of determination R^2 is 0.366 and says about marked relationship between analysed variables. The basalt from Sološnica quarry, however, retains the primacy according to all performed tests and therefore has the highest resistance to loading, wear or abrasion, freezing-thawing, salt crystallisation and ageing by the weathering.

The relationship between the Slake durability index I_d and the micro-Deval coefficient M_{DE} was showed almost optimally linear with very high closeness (Fig. 6). The similarity in the nature of both tests inspired an idea to monitor the relationship between these tests not only in standard regime (two 10 minutes cycles at the SDT) but also after following time intervals up to the same time what is used at the micro-Deval test. And so, besides the exerted Slake durability test with 2 cycles, each in duration of 10 minutes (Fig. 6a) were realised another cycles on the same aggregates up to total time of 120 minutes, as well as it is in the case of the micro-Deval test. The results of this experiment and the influences of testing time on the Slake durability index value are presented in Fig. 7. The linear relationship between monitored parameters is retained, the coefficient of determination R^2 is near to 1 (Fig. 6b).

The comparison of results of standard micro-Deval test with water (wet version) and its modification in dry version is also very interesting. The test carried out without water, changes the order of study rocks from the point of view of their resistance to wear or abrasion. It means that water presence has significant influence on testing rock types. Results of the micro-Deval test in dry version tend to the results of strength tests that are similarly realised on dried rock specimens (see Tab. 1 and Tab. 2).

Results of realised weathering tests in comparison with micro-Deval test results are illustrated in relation graphs in Fig. 8. Both long-term cyclic tests are in very good correlation with the

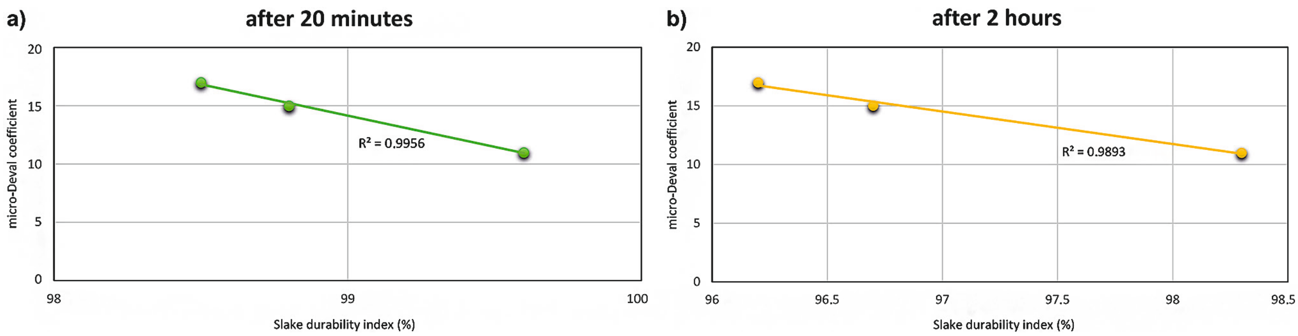


Fig. 6 Relationship between Slake durability index and micro-Deval coefficient of tested rocks. a – after two cycles, each in duration of 10 minutes; b – after seven cycles in duration of 2 hours.

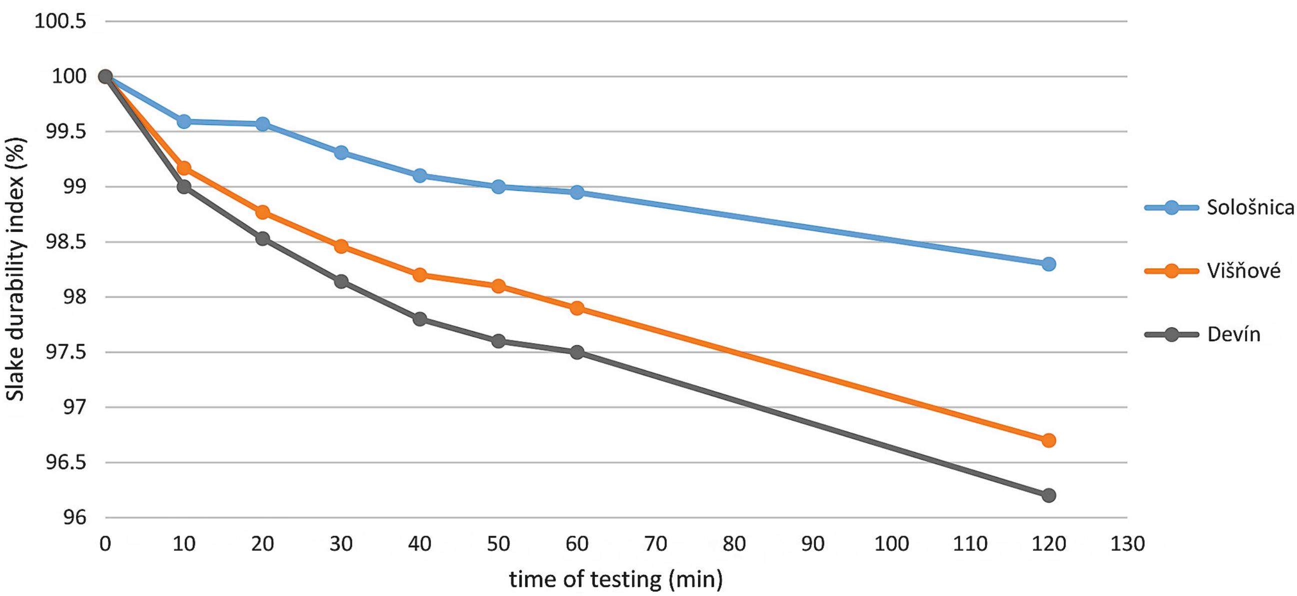
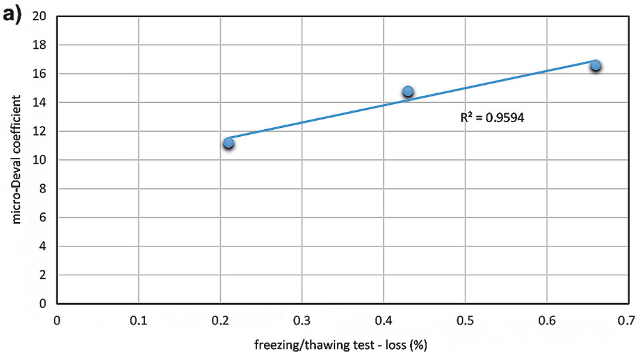


Fig. 7 Results of different time duration of Slake durability test.



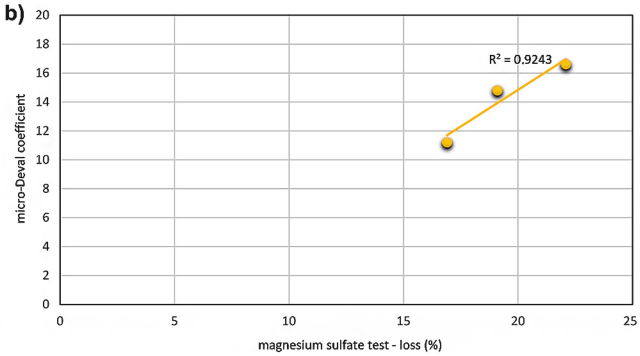


Fig. 8 Realised weathering tests in relation to micro-Deval coefficient. a – freezing and thawing test; b – magnesium sulfate test.

micro-Deval test, R^2 values are in the range from 0.92 to 0.96.

At the end of the study, standard micro-Deval tests were performed on the same aggregate specimens that were previous tested by the freeze-thaw test and magnesium sulphate test. Results of these tests are summarized in Tab. 3. Influence of the accelerated weathering tests on the aggregates such can be expressed, except the mass loss, also by the way the changes of micro-Deval coefficients values. Values of the micro-Deval coefficients M_{DE} can be compare together. Lower quality of aggregates after weathering tests is evident. In all rock types it is also evident that the freeze-thaw testing is less destructive on the aggregates how the magnesium sulphate testing. The use of the micro-Deval test is thus significantly broader.

4. DISCUSSION

Despite the existence of the high capacity database of rock properties in the Engineering Geological Atlas of rocks in Slovakia, conclusions of relation properties analyses are not convincing. The difficulties are stemming from the long way of creating the database and from gradually the step by step updating the information about the properties of rocks from individual sites and this fact do not allow make clear and responsible conclusions about the correlations between particular rock properties. The dependence between the uniaxial compressive strength and the micro-Deval coefficient of rocks was not confirmed, neither in own experimental study. Genetic factors of rocks, their mineral composition, structural and textural characteristics such as grain size and grain arrangement, matrix, size and distribution of pores influence results of both tests. The different nature of these tests influencing from the different loading on rock specimens, as well as conditions of the execution of tests (in the dry and wet state of the rock) also affect the results.

Existing large experimental studies over the world about micro-Deval tests and with them associated a quantity of knowledge in this area tend to the satisfaction that it is not necessary to realise another research. The big heterogeneity of rock types as source material in production of natural crushed aggregates, however, the application of results from foreign tests makes more difficult. To adapt the results and findings from other research projects generally is not always very suitable also for a reason of different test procedures and requirements on the test realization. Gökalp et al. (2016) compared EN and ASTM micro-Deval method on some types of natural aggregates and other materials and their test results showed that both methods produce different mass losses with different aggregate type and grain size. The necessity to test each rock type is evincible from the fact that our tested rocks according to their petrological scope belong to the group of magmatic rocks and show very similar basic physical properties (density, porosity and water absorption). As well as according to their strength values, all rocks belong to the same class of strength, all three types are strong rocks with the UCS in the range from 50 to 100 MPa (Tab. 1). Results of the micro-Deval tests are different for each rock type and this fact influencing their usage as a crushed aggregate.

The quality assessment of used building materials with one test and one parameter would be very practical, but in the case of rocks as a source material for the production of aggregate it turns out that this is absolutely not sufficient. The high variety of lithological types and often a big structural and weathering heterogeneity also in the range of the same rock type exists.

Tab. 3 Values of micro-Deval coefficients M_{DE} of aggregates after weathering tests in comparison with values determined on intact aggregate specimens

	M_{DE} standard	Test 1 Freeze-thaw test loss (%)	Test 2 Magnesium sulfate test loss (%)	M_{DE} after test 1	M_{DE} after test 2
Paleobasalt Sološnica	11.2	0.21	16.9	11.7	12.1
Granite Devín	16.6	0.66	22.1	19.1	23.5
Granodiorite (Višňové)	14.8	0.43	19.1	15.0	15.9

Influences that the aggregate is subjected to in the roadway are several (mechanical loading static, dynamic and friction, climatic factors such as precipitation, cyclical temperature changes, frost, chemical pollution, etc.). The advantage of the micro-Deval test is fact that it takes into account adverse mechanical and weather effects which are included in the conditions of its realization. By this but also by a different way of mechanical stress, it differs from the test on determination of the uniaxial compressive strength. And in particular, this could be the reason the tests are not in a good correlation (Fig. 2).

The frequent question of many researches over the world is which laboratory tests are able to predict the aggregate behaviour in field performance in construction objects the best and in addition the same for various usage purposes (Meinenger, 2004; Grünner & Romancová, 2005 and others). It is not simple to choose only one or two objective suitable tests which should be uniquely declared as the aggregate quality and durability from the point of view of its use in construction of roads, pavements, highways or railway tracks. One of the criteria for choosing of suitable methods may be the feasibility of the tests. The micro-Deval test is certainly advantageous from the point of view its simple realization. From the comparison with other aggregates tests can be conclusive that the micro-Deval test is very easily realized method which is done in relatively small apparatus with a small quantity of aggregates and, after obtaining the skills also relatively quick. The method gives the results after 2–3 days, what is a big advantage in comparison with long-term cyclic tests and therefore comes to be as routine test on the evaluation of aggregate. In comparison with Los Angeles (L.A.) abrasion test is less noisy, in wet version almost absolutely dust-free and also less heavy work. Sulphate tests are cyclic tests and therefore they are long-term tests and their realization requires chemicals handling. The preparation of salt solutions requires a strict observance of temperature condition in defined time relations and realization of procedures on the control of their density. The test on the determination of the frost resistance of aggregates (freeze-thaw test) is also very simple but is long-term and its responsible realization is required an expensive climatic chamber with automatic regulation of temperature. Analysis of the feasibility of aggregate tests results of them is the mass loss, is presented in Tab. 4. It was taken into consideration so things as special apparatus requirement, eventually other needs and tools that are no basic equipment of laboratories, need of the chemical handling, difficulty of realization of test and requirements on the physical condition of the person done the test and time realization of the test. All tests mentioned in Tab. 4 are realized on the aggregate with stated size fraction. And so the level or difficulty of specimen preparation is considered as the same for all tests. Although, more attention and work is certainly required in the tests with need of 5000 g of aggregates in comparison with 500 g for the micro-Deval test or SDT.

From this review, the micro-Deval test, together with Slake durability test follows very well. However, the SDT is not a normative test.

In this study area, another problem is what values of the micro-Deval coefficient are good or suitable for the usage of aggregates

Tab. 4 Feasibility study for selected aggregate tests

Test	Apparatus requirement	Other special tools and support	Chemicals handling	Special requirements	Realization time minimal	Difficultness of test realization
Los Angeles fragmentation resistance test	yes	non-type sieves: 1.6; 10; 11.2 (or 12.5); 14 mm; big steel balls; a great deal of specimen; noise protection	no	physical condition of the person performing the test	2-3 days	high
Micro-Deval abrasion test	yes	non-type sieves: 1.6; 10; 11.2 (or 12.5); 14 mm; steel balls	no	physical condition of the person performing the test	2-3 days	middle
Impact test	yes	non-type sieves: 0.2; 0.63; 5; 11.2 and 12.5 mm; a great deal of specimen; noise protection	no	physical condition of the person performing the test; assure safety at work	2-3 days	very high
Crushing value test	yes	non-type sieves: 12.5; 10 and 2.36 mm; steel cylinder mould, plunger and others	no	physical condition of the person performing the test	2 days	high
Magnesium sulphate test 5 cycles	no	wire baskets; densimeter	yes	cyclic test	12 days	high
Freeze-thaw test 10 cycles	yes	no	no	cyclic test	15 days	low
Slake durability test 2 cycles	yes	no	no	no	4 days	low

for some relevant purpose. Technical requirements in various countries are different. Kandhal & Parker (1998) of National Center for Asphalt Technology (NCAT) reported that tests with 16 aggregates of varying field performances from across the U.S. showed that the micro-Deval and magnesium sulfate soundness tests were the two best indicators of aggregate performance for hot-mix asphalt. Losses of 18 % for both tests appeared to separate good and fair aggregates from poor aggregates. Along with tests, the special attention is need to pay to aggregate mineralogical composition (Kandhal & Parker, 1998). Mass loss of 18 % after the test for the accepting of aggregate as a suitable material also recommended Williamson (2005) in Gökalp et al. (2016). Also from another published research is apparent that maximal loss of mass 15 % until above 18 % is considered as acceptable value on the classification of rock as user convenient aggregates (Rangaraju, 2006). At loss of mass 18 up 24 % is recommended to control of aggregate quality by another test. As alternative test are suggested the L.A. abrasion test or magnesium or sodium sulfate soudness test (Cuelho et al., 2007). For bituminous road layers in Ontario in U.S. the highest mass loss of any aggregates is 15 %, for cement concrete surfaces is 13 % (Jayawickrama et al., 2006 in Cuelho et al., 2007). Taking into account mentioned requirements, from our studied rocks only the paleobasalt from Sološnica quarry with M_{DE} value 11 would be absolutely suitable in aggregates production for various purposes.

In Slovakia, technical requirements on the micro-Deval value of aggregates are less hard and less strict. In the case of aggregates into bituminous layers of roads, aerodrome area and other traffic areas is allowed maximal loss mass of 20 or 25 % in dependence on the category of a traffic loading. For the aggregates into cement concrete surfaces is required the values of the micro-Deval coefficient also with regard to the loading from 15 to 30. Logically, higher class of the traffic loading requires lower value of the micro-Deval coefficient. The most strictly criteria is for the high strength concrete, where is allowed the maximal loss of 15 %.

5. CONCLUSIONS

The modest own experimental research realised only in the range of the diploma thesis indicates that the micro-Deval test really has a great potential in the rock testing and gives predictable value about rock quality also for the rocks from the territory of Slovakia.

The micro-Deval test is preferentially used in aggregates testing quality for construction purposes, but the usage of this method can be certainly more widely. The similarity of the test results with results of other test methods, predominantly with Slake durability test tends to possibility to use the micro-Deval apparatus also in the rock testing for many another geotechnical purposes. The paper presents the micro-Deval test also as a beneficial control test for the monitoring of changes in aggregate quality after accelerated weathering tests.

The feasibility analysis of the aggregate tests introduced in the paper shows that the micro-Deval test is a simple and relatively quick method in comparison with other similar aggregate tests and can be used as a routinely test for aggregates.

The relation between the uniaxial compressive strength and the micro-Deval coefficient of rocks was neither confirmed from the analysis of the high volume rock properties database from the territory of Slovakia nor from the own experimental study. On the other side, it was showed very tight relationship between the Slake durability test and the micro-Deval test.

According to results of the realised tests in experimental part of the study (micro-Deval test, freeze-thaw test and magnesium sulphate test), the order of the tested aggregates starting with one of the highest quality is following: 1. paleobasalt Sološnica, 2. granodiorite tunnel muck Višňové, 3. granite Devín. According to some foreign requirements on the micro-Deval coefficient value, only the paleobasalt from Sološnica quarry stands as a good aggregate for various use purposes. The muck from the tunnel tubes in Višňové is also suitable almost for all purposes according to Slovak technical requirements, but no according to international requirements. Finally, the granite aggregate produced in Devín quarry is limited in the utilization and it is suitable for less strength concrete only.

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References

Arm M., 2003: Mechanical Properties of Residues as Unbound Road Materials. Doctoral Thesis, Stockholm, Sweden, 148 p.

Appa Rao Hoare B. E., 2003: Feasibility of using the micro-Deval test method as an aggregate production quality control tool. A thesis in Civil Engineering. Faculty of Texas Tech University, U.S.A., 110 p.

Atac B., Deniz A., Serkan T. & Alp B. S., 2016: Study of the optimal aggregate blending model for quarries. *Environmental Earth Sciences* (2016) 75:1304. https://doi.org/10.1007/s12665-016-6126-z.

Cooley L. A., Huner M. S. & James R. H., 2002: Micro-Deval Testing of Aggregates in the Southeast. NCAT Report No. 02–09, Auburn University, Alabama,USA, 28 p.

Cuelho E., Mokwa R., Obert K. & Miller A., 2007: Comparative Analysis of Coarse Surfacing Aggregate Using Mikro-Deval, L.A. Abrasion and Sodium Sulfate Soundness Tests. Final Report, Western Transportation Institute College of Engineering Montana State University – Bozeman, 39 p.

Czinder B. & Török Á., 2017: Long-term durability tests of andesite aggregates from Hungary. *Central European Geology*, Vol. 60/3, 333–343.

Durmeková T., 2009: Hodnotenie odolnosti kameniva proti obrusovaniu skúškou mikro-Deval. *In:* XIV. Seminár I. Poliačka: Geotechnika v cestnom staviteľstve, Kongres management: Bratislava, pp. 177–183. [in Slovak with English abstract]

EN 1926, 2006: Natural stone test methods. Determination of uniaxial compressive strength.

EN 1936, 2006: Natural stone test methods. Determination of real density and apparent density, and of total and open porosity.

EN 1097-1, 2011: Tests for thermal and weathering properties of aggregates. Part 1: Determination of the resistance to wear (micro-Deval).

EN 1097-2, 2010: Tests for thermal and weathering properties of aggregates. Part 2: Methods for the determination of resistance to fragmentation.

EN 1097-8, 2009: Tests for mechanical and physical properties of aggregates. Part 8: Determination of the polished stone value.

EN 1367-1, 2007: Tests for thermal and weathering properties of aggregates. Part 1: Determination of resistance to freezing and thawing.

EN 1367-2, 2009: Tests for thermal and weathering properties of aggregates. Part 2: Magnesium sulfate test.

EN 13755, 2008: Natural stone test methods. Determination of water absorption at atmospheric pressure.

Erichsen E., Ulvik A. & Sævik K., 2011: Mechanical degradation of aggregate by the Los Angeles, the Micro-Deval and the Nordic test methods. *Rock Mechanics and Rock Engineering*, 44, 333–337.

Gökalp I., Uz V. E. & Saltan M., 2016: Testing the abrasion resistance of aggregates including by-products by using Micro Deval apparatus with different standard test methods. *Construction and Building Materials*, 123, 1–7.

Grünner K. & Romancová I., 2005: Európske normy z oblasti kameniva. *In*: Grünner K. (Ed.): Zborník z odb. seminára Vlastnosti kameniva z pohľadu konečného použitia v stavebníctve. Dom techniky ZSVTS Košice, pp. 29–34. [in Slovak]

Holzer R., Laho M., Wagner P. & Bednarik M., 2009: Inžinierskogeologický atlas hornín Slovenska. [Engineering Geological Atlas of Rocks of Slovakia]. Štátny geologický ústav Dionýza Štúra, Bratislava, 533 p. [in Slovak with English summary]

Holzer R., Bednarik M. & Laho M., 2014: Sú horniny z Brezovských Karpát vhodné na stavebné a dekoračné účely? [Are there rocks of the Brezovske karpaty Mts. Suitable for construction and decoration purpose?]. *AGEOS*, 6, 1, 13–27. [in Slovak with English summary]

Hossain M. S., Lane D. S. & Schmidt B. N., 2007: Use of the Micro-Deval Test for Assessing the Durability of Virginia Aggregates. Research Report. VTRC, Commonwealth of Virginia, 30 p.

Kandhal P. S. & Parker F., 1998: Aggregate Tests Related to Asphalt Concrete Performance in Pavements. National Cooperative Highway Research Program, Report 405. National Academy Press, Washington D.C., U.S.A., 103 p.

Meinenger R., 2004: Micro-Deval vs. L.A. abrasion. [Online]. Available on Internet: http://rockproducts.com/mag/rock_microdeval_vs_abrasion [accessed 2009-04-29].

Rangaraju P., 2006: Evaluation of South Carolina Aggregate Durability Properties. The RD&T Newsletter, Volume XII, No. 1, 3.

Romancová I., 2005: Obrusnosť kameniva zabezpečujúca trvanlivosť stavebných konštrukcií. *In*: Grünner K. (Ed.): Zborník z odb. seminára Vlastnosti kameniva z pohľadu konečného použitia v stavebníctve. Dom techniky ZSVTS Košice, pp. 49–56. [in Slovak]

Török Á. 2015: Los Angeles and Micro-Deval values of volcanic rocks and their use as aggregates, examples from Hungary. *In*: Lollino G., Manconi A., Guzzetti F., Culshaw M., Bobrowsky P. & Luino F. (Eds): Engineering Geology for Society and Territory, Vol. 5. Springer International Publishing, Basel, Switzerland, pp. 115–118.

Ulusay, R. & Hudson, J. A. (Eds.), 2007: The complete ISRM suggested methods for rock characterization, testing and monitoring: 1974–2006. Kozan Ofset Matbaacılık San. ve Tic. Şti. Ankara, Turkey, 628 p.

Wang D., Wang H., Bu Y., Shulze Ch. & Oeser M., 2015: Evaluation of aggregate resistance to wear with Micro-Deval test in combination with aggregate imaging techniques. *Wear*, 338–339, 288–296.

Woodside A. R. & Woodward W. D. H., 1988: Assessing the wear characteristics of aggregate exposed at the road surface. *In*: Latham J.P. (Ed.): Advances in Aggregates and Armourstone Evaluation. Geological Society, London, Engineering Geology Special Publications, 13, pp. 149–157.