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# Long-term durability tests of andesite aggregates from Hungary

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The Micro-Deval test method is used for testing of aggregate durability. The present paper focuses on two Hungarian andesites obtained from the quarries of Recsk (Mátra Mountains, Hungary) and of Nógrádkövesd (Cserhát Mountains, Hungary). The aim of this study is to find a simple test method based on the original Micro-Deval test method to assess the long-term durability of aggregates. An additional part of the research was to develop suitable mathematical models that can describe the behavior of the andesite aggregates under continuous abrasive impact. The relevant standard (EN 1097-1:2012) recommends 12,000 rotations to determine the Micro-Deval coefficient required for classification of the aggregates. Within the framework of this research, a modified Micro-Deval test was applied: the number of rotations was increased in several steps and the degree of abrasion was measured afterwards. Regression analyses were used to outline mathematical forms which characterize the dependence between the number of rotations and the degree of abrasion. According to the results, the long-term Micro-Deval tests significantly modify the assessed durability and thus provide information on the long-term abrasive impact. The degree of change depends on the studied material: the ratio of the long-term Micro-Deval coefficients of the two studied andesite types is larger than 3. The regression analyses of the measured Micro-Deval coefficients revealed that quadratic curves are suitable to describe these tendencies for both andesite aggregates.

**Keywords:** andesite, aggregate, durability, long-term properties, regression analysis

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## Introduction

Igneous rocks are frequently used as aggregate in Hungary. Volcanic rocks such as basalt and andesite are the most common types found in Hungary and utilized in the construction industry as aggregates (Gálos and Kárpáti 2007; Török 2007), whereas sedimentary rocks in Hungary are mostly used as building or decorative stones (Török et al. 2004; Török 2007). The favorable properties of andesite (high uniaxial compressive strength and resistance to abrasion) make it suitable for use in road and railway construction in the form of aggregate or armor stone and as blocks in hydraulic engineering.

Several test methods exist to determine the aggregate properties of rock materials: the polished stone value test (Đokić et al. 2015), the slake durability test (Mišćević and Vlastelica 2011), the Nordic test (Krutilová and Příklad 2017), aggregate crushing and aggregate impact value tests (Palassi and Danesh 2016), and Washington degradation tests (Liu et al. 2017). The most common methods, such as Los Angeles (LA) and Micro-Deval (MDE) tests, usually focus on the determination of durability (Erichsen et al. 2011). The LA and MDE test results are taken as the basis of the different classification systems (Czinder and Török 2015; Palassi and Danesh 2016).

Long-term durability is also important for the description of the behavior of the various rocks undergoing continuous abrasive impact. Erichsen (2015) tested the long-term durability of jasper and greenstone by LA tests; the samples were subjected to different numbers of rotations. The alteration of the slake durability index (Id), according to increasing number of test cycles of Dalmatian (Croatia) marls (Mišćević and Vlastelica 2011) and clay-bearing rocks from Turkey (Gökceoğlu et al. 2000), was also analyzed.

Relationships could be found between rock mechanical parameters and aggregate properties. According to Rigopoulos et al. (2013), the MDE test results correlate with uniaxial compressive strength in the case of ophiolite complexes from Greece. A dependence has been found between the polished stone value and the Nordic abrasion value of various igneous rocks (Krutilová and Příklad 2017). Schmidt hammer rebound values and point load tests were correlated with LA values (Kahraman and Gunaydin 2007). Recently, Török (2015) revealed the relationship between the LA and MDE test results of Hungarian andesite and basalt, whereas Czinder and Török (2015) compared the ultrasonic pulse velocity, the strength parameters, and aggregate properties of the Gyöngyössolymos andesite (Hungary).

The present paper focuses on aggregate properties and does not provide a detailed petrographic description of the studied andesite. However, it is important to note that mineralogical properties of the igneous rocks influence the mechanical and aggregate properties (Tugrul and Zarif 1999; Příklad 2001; Yilmaz et al. 2011). The uniaxial compressive strength is affected by the relative abundance of the phenocrysts in andesitic rocks (Ündül 2016). The mineral composition of the rocks also has a great influence on aggregate durability (Pang et al. 2010); the average crystal size and the Mohs hardness correlate with the Micro-Deval values (Wang et al. 2015).

The current research takes a different approach. It focuses on the description of long-term behavior of aggregates using extended abrasion. The standardized Micro-Deval test requires 12,000 rotations, whereas in this paper the andesite aggregates were subjected to up to 10 times more rotations (120,000, respectively) to assess the behavior of wear durability. This intense wear and the detection of material loss allowed us to apply suitable mathematical models to describe the material loss.

## Materials

Andesites from two quarries in the northern part of Hungary were used to prepare aggregate samples for the laboratory tests (Fig. 1). The andesite from Nógrádkövesd (Cserhát Mountains, Hungary) was formed during the Miocene volcanism and the andesite from Recksk (Mátra Mountains, Hungary) was formed in the Eocene. Both rock materials show quite homogenous fabrics.

The rock mechanical parameters of the studied materials were determined previously (Table 1; Czinder and Török 2015, 2017).

## Methods

The durability of the studied andesites was described by Micro-Deval tests (the relevant standard is EN 1097-1:2012). The aggregate samples were made from two fractions representing two ranges: 150 g of 10.0–11.2 mm and 350 g of 11.2–14.0 mm in size, respectively. The aggregate samples were tested in steel drums (Fig. 2). The abrasive impact was provided by 5,000 g of steel balls and 2,500 ml of water in the



Fig. 1  
Location of the studied quarries in Hungary

Table 1  
The mean rock mechanical parameters of the studied andesites

Rock mechanical parameters	Conditions	Recsk	Nógrádkövesd
Uniaxial compressive strength (MPa)	Air-dry	270.8	85.4
	Water saturated	265.7	76.0
	Freeze–thaw subjected	244.8	78.0
Modulus of elasticity (GPa)	Air-dry	48.7	22.5
	Water saturated	48.2	28.8
	Freeze–thaw subjected	47.0	23.8
Tensile strength (MPa)	Air-dry	9.8	7.9
	Water saturated	6.4	6.4
	Freeze–thaw subjected	8.3	5.8



Fig. 2  
The Micro-Deval test equipment with four drums

drums which are rotated during the tests (100 rotations per minute). According to the relevant EN standard, the result of the Micro-Deval test is the Micro-Deval coefficient ( $M_{DE}$ ) which is the ratio of the abraded mass after 12,000 rotations and the original

mass of the sample. In the evaluation, a smaller Micro-Deval coefficient indicates more favorable aggregate properties. The Micro-Deval tests were made in pairs; thus, two test results were obtained for each set of experiments.

To determine the long-term aggregate properties of the samples, additional rotations were made with increments of 12,000 rotations. Two series of measurements were made. In the first set (called test 'A'), the aggregate samples were washed, dried, and measured after the total number of rotations. For test 'A', different aggregate samples were needed for each experimental setting. The number of rotations was increased by 12,000 rotations to 120,000 and an additional stage (6,000 rotations) was also investigated. The other series of measurements (called test 'B') describes the tests where MDE values were measured after each 12,000 rotations, until reaching 120,000 rotations.

The long-term Micro-Deval coefficients (MDE) of both test types were calculated (similarly to the standardized Micro-Deval coefficient) as the ratio of the abraded and the original mass measured after the increased number of rotations. According to the results of test 'B', a modified or relative coefficient ( $MDE'$ ) was also calculated at every stage of the increasing number of rotations:

$$MDE'_n = \frac{m_{n-1} - m_n}{m_{n-1}} \times 100 (\%)$$

where  $m_n$  is the mass of the aggregate and  $MDE'_n$  is the relative Micro-Deval value at the  $n$ th stage of the increasing number of rotations. The measurements of test 'B' required only two aggregate samples, i.e., the tests were made on the same pair of samples throughout.

Regression analyses were used to find suitable statistical models which can describe the correlation between the number of rotations and the Micro-Deval coefficients. The adequacy of the models was described by the Pearson's coefficient of correlation ( $R^2$ ).

The notations of the different Micro-Deval values:

- $M_{DE}$ : the Micro-Deval value determined after 12,000 rotations according to the relevant EN standard;
- $MDE$ : the long-term Micro-Deval value;
- $MDE_A$  or  $MDE_B$ : the long-term Micro-Deval values determined after test 'A' or 'B';
- $MDE'$ : modified or relative Micro-Deval value.

## Results and discussion

The long-term Micro-Deval tests caused significant loss in mass of the studied andesite aggregates (Table 2). The number of rotations was increased to 120,000 in 11 steps. The grains became smaller and more subspherical with the increasing number of rotations (Fig. 3).

Table 2  
The long-term Micro-Deval coefficients of the studied andesites

Number of rotations	$MDE_A$ value		$MDE_B$ value	
	Recsk		Nógrádkövesd	
6,000	3.3	–	8.7	–
12,000	4.9	4.9	15.6	14.6
60,000	12.2	11.7	49.7	44.6
120,000	18.9	17.1	70.6	66.1



Fig. 3  
The grains after 0 (a, d), after 60,000 (b, e), and 120,000 rotations (c, f), respectively. Top row displays andesite from Recsk (images: a, b, c); bottom row shows andesite from Nógrádkövesd: (images: d, e, f)

The test results of test ‘A’ fit well to quadratic curves (Fig. 4); the coefficient of correlation reached 0.9 for both andesites. The functions of the fitted curves do not contain any constant member, since in the mathematical representation, the initial phase (when the number of rotations and the MDE were 0) was considered as a fixed point. When a constant member is kept in the functions, the Pearson’s coefficient is even slightly higher: 0.998 and 0.98 for the andesites from Nógrádkövesd and Recsk, respectively. The MDE test results that represent the standardized 12,000 rotations are

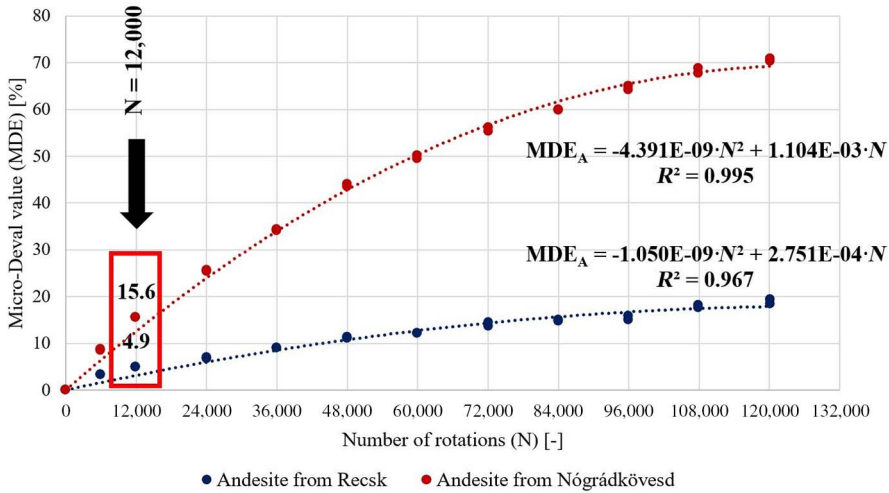


Fig. 4 The MDE values according to the number of rotations, test ‘A’ (see explanation of test ‘A’ in the text)

highlighted by a red rectangle (Fig. 4). It is clear that long-term abrasive impact reduces the durability of andesite aggregates and decreases the MDE values, similarly to previous findings on greenstone (Erichsen 2015). These results suggest that the standardized Micro-Deval test provides information on aggregate durability but does not allow precisely assessing the long-term behavior of andesites (Fig. 4). In other words, 12,000 rotations do not necessarily represent the material durability.

The comparisons of the test results of ‘A’ and ‘B’ also brought new insights. The differences between test ‘A’ and test ‘B’ are shown in Figs 5 and 6 for the andesites from Recsk and Nógrádkövesd, respectively. The Micro-Deval coefficients obtained in test ‘B’ ( $MDE_B$ ) are smaller at higher number of rotations. This is caused by the fine-grained mass of the abraded aggregates which increased the abrasive impact during test ‘A’ (the differences between  $MDE_A$ ,  $MDE_B$ , and  $MDE'$  values at 12,000 rotations are negligible, so the data points uncover each other. Both figures contain data points of each series of measurements).

The mass reductions of the aggregate samples from the different quarries show significant differences: the MDE value of the andesite from Recsk is 17.1 (Fig. 5), whereas the andesite from Nógrádkövesd provided  $MDE = 66.1$  after 120,000 rotations (Fig. 6).

In both cases, the plots of the modified  $MDE'$  values follow decreasing trends. The reason is that the material of the aggregates did not change during the long-term tests, but the shape of the grains became smaller and more subspherical by the abrasion of the vertices and the edges of the grains. However, although the quadratic model provides satisfying  $R^2$  values for  $MDE'$ , it was not feasibly to apply it: at higher

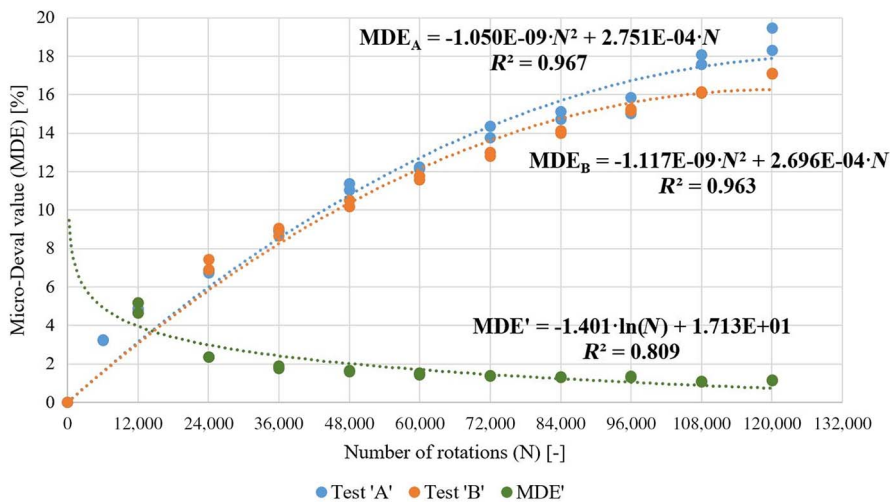


Fig. 5 Long-term Micro-Deval test results of the andesite from Recsk

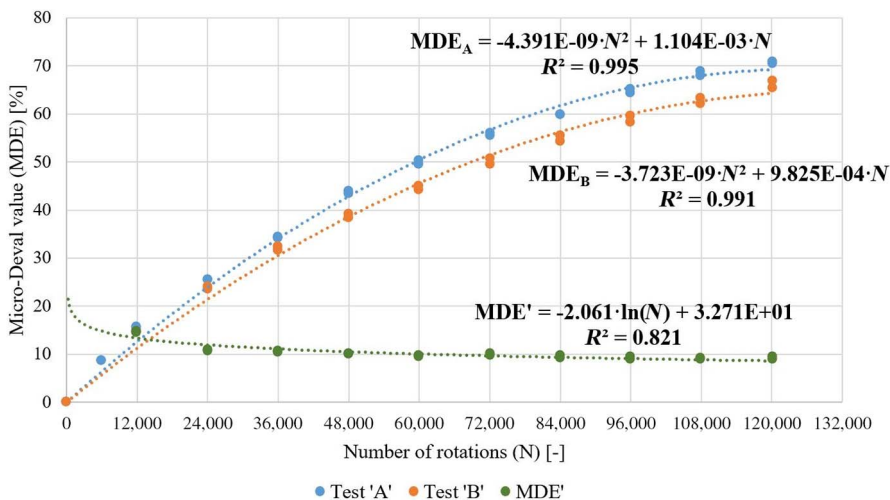


Fig. 6 Long-term Micro-Deval test results of the andesite from Nógrádkövesd

number of rotations, the decrease of the  $MDE'$  values was unambiguous and the quadratic model would show an increasing tendency after the minimum of the function. Applying logarithmic models provides better fit (Figs 5 and 6).



Table 3  
The  $R^2$  values of the different models

Mathematical models	Recsk			Nógrádkövesd		
	$MDE_A$	$MDE_B$	$MDE'$	$MDE_A$	$MDE_B$	$MDE'$
Linear ( $P = 1$ )	0.859	0.771	0.553	0.883	0.867	0.587
$P = 2$	0.967	0.963	0.807	0.995	0.991	0.803
$P = 3$	0.988	0.990	0.931	0.999	0.998	0.894
$P = 4$	0.990	0.997	0.978	0.999	0.999	0.952
$P = 5$	0.992	0.998	0.987	0.999	0.999	0.963
$P = 6$	0.996	0.999	0.993	1.000	0.999	0.970
Logarithmic	–	–	0.809	–	–	0.821

$MDE_A$ : test result of test 'A';  $MDE_B$ : test result of test 'B';  $MDE'$ : modified Micro-Deval value;  $P$ : the degree of the polynomial

Different mathematical models were used to find suitable curves which fit well to the measured data points. Linear and polynomial (the degree of the applied polynomials was increased to 6) curves were also analyzed. In the case of the modified Micro-Deval coefficient, the fitting of logarithmic curves was also tested. The Pearson's coefficients of linear, polynomial, and logarithmic correlations were calculated (Table 3). Although the polynomial models with higher degree provided the best  $R^2$  values for the  $MDE_A$  and  $MDE_B$ , it is suggested to use the easier quadratic models since these also provided adequate fitting to the data points to describe the behavior of the aggregates under continuous abrasive impact. Another issue in this question is that the curves of the higher polynomials show both increasing and decreasing trends in the studied range of the number of rotations, which makes these ambiguous.

## Conclusions

The relevant guidelines and regulations of road construction or railway construction required the use of materials with relevant Micro-Deval coefficients (tested at 12,000 rotations). This study shows that this short-term test cannot describe the long-term behavior of the aggregates in the course of continuous abrasive impact. Thus, long-term durability tests are needed. This is especially important since aggregates used in road or railway construction are subjected to continuous abrasive impact. The Micro-Deval test results showed that the andesite from Recsk has a higher resistance against abrasive impacts ( $M_{DE} = 4.9$ ) than the andesite from Nógrádkövesd

( $M_{DE} = 15.6$ ), but these mere values of 12,000 rotations are far better than the ones obtained after 120,000 rotations. New parameters were introduced to describe the long-term properties of the aggregates. The long-term Micro-Deval coefficient (MDE) is calculated as the ratio of the abraded and the original mass after the increased number of rotations. The modified or relative Micro-Deval coefficient ( $MDE'$ ) is determined as the degree of abrasion according to the measured masses at two sequential stages of the increasing number of rotations.

According to the long-term test results, the data points followed a decreasing trend. Quadratic models were suitable to describe the abrasion of the studied andesites. The newly introduced relative Micro-Deval coefficient could be described by logarithmic models.

The long-term properties could be analyzed by two test methods if the aggregate samples are washed, dried, and measured after every 12,000 rotations (test 'B') or just at the end of the test process (test 'A'). There were no significant differences between the results of these two test methods; the tendencies of the fitted curves were very similar. Only one pair of aggregate samples was needed for test 'B'; thus, a smaller amount of material is needed for this test, i.e., it is more economic.

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