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Testing of Natural Stone - Slip Resistance Using a Pendulum

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Abstract: This paper presents an examination of natural stone to slip resistance. The test is carried out according to the BAS EN 14231:2009 standard. This standard specifies a test method for determining the slip resistance value of the surface of the exposed face on natural stone elements intended to be used for flooring in buildings. The aim of the paper is to present the equipment, auxiliary means, samples and the test procedure. Tests are carried out on stone samples with different finishes. The test surfaces are: cut, polished and flamed. After the tests, the authors analyze and evaluate the obtained results. The results of this scientific research were presented for the first time as part of the 4th international symposium Herzegovina Land of Stone.

Key words: dimension stone test, slip resistance, SRV, EN 14231

Ispitivanje prirodnog kamena - Otpornost na klizanje pomoću klatna

Sažetak: Ovaj rad prezentira ispitivanje otpornosti kamena na klizanje. Ispitivanje se provodi prema normi BAS EN 14231:2009, koja utvrđuje metodu za određivanje vrijednosti otpornosti na klizanje, površine izloženog lica elemenata od prirodnog kamena, namijenjenih za oblaganje podova u građevinarstvu. Cilj rada je prikazati opremu, pomoćna sredstva, uzorke i provedbu ispitivanja. Ispitivanja se provode na uzorcima kamena s različitim završnim obradama. Ispitne površine su: rezana, polirana i površina dobivena paljenjem. Nakon provedenih ispitivanja autori analiziraju i vrednuju dobivene rezultate. U sklopu 4. međunarodnog simpozija Hercegovina zemlja kamena prvi put su predstavljeni rezultati ovog stručno-znanstvenog istraživanja.

Ključne riječi: ispitivanje AG kamena, otpornost na klizanje, SRV, EN 14231

1. INTRODUCTION

From the aspect of durability requirements and safety and aesthetic requirements, natural stone slip resistance is one of the main parameters that should be taken into account when designing floor surfaces. The European standard EN 14231 was developed for the purposes of classifying natural stone products according to slip resistance. This standard belongs to the group of methods dealing with natural stone testing. The full name of the standard is "Natural stone test methods - Determination of the slip resistance by means of the pendulum tester". The current edition issued by the European Committee for Standardization (CEN) is from 2003. The Croatian Standards Institute (HZN) accepted and published this standard in 2004 under the code HRN EN 14231:2004, while the Institute for Standardization of Bosnia and Herzegovina (ISBiH) accepted and published this standard in 2009 under the code BAS EN 14231:2009. The Bosnian-Herzegovinian code of the standard will be used hereafter. By definition, this European standard describes a test method to determine the slip resistance value of the surface of an exposed natural stone element intended for flooring. Also, exposed element surfaces that have a roughness greater than 1.0 mm, measured according to BAS EN 13373:2020, are considered as not slippery, without performing the test. This method can be used on laboratory samples as well as on floors in service. This paper will present the procedure for testing slip resistance and the results of testing natural stone "Gabro" with three different finishes of the test surfaces (cut, polished and flamed).

2. TERMS AND DEFINITIONS

The standard describes the basic terms and definitions used during the test and preparation of the test report.
Slip resistance is the property of a floor surface to maintain the adhesion of pedestrian footwear. Note, loss of adhesion leads to loss of control by the pedestrian with consequent increase in the risk of falling.
In this case, friction is the resistance to relative motion between the slider and the test surface (footwear sole and walking surface). The friction force is a force acting tangentially in the contact area.
Slip Resistance Value (SRV) is the value obtained using a pendulum tester. The device (pendulum) is equipped with a rubber slider. The resistance of the slider against the test surface is measured. The resulting value is called slip resistance (SRV) and is measured in dry (SRV, d) and wet (SRV, w) conditions.

3. TESTING EQUIPMENT

The slip resistance testing device is equipped with a pendulum with a slider at the free end. There are two measurement scales on the device. Measurement scale C is used when testing samples with test dimensions of 136 x 80 mm or greater. A wide slider with width 76 mm, length 25.4 mm and thickness 6.4 mm is used in these tests. The total weight of the slider with the base is 32±5 grams. The measurement scale C has a range from 0 to 150 with a division of 5 measurement units.

Measurement scale F is used when testing samples of smaller dimensions, using a narrow slider with width 38 mm, length 25.4 mm and thickness 6.4 mm. The total mass of the narrow slider with the base is 20±5 grams. This measurement scale has a range from 0.0 to 1.0 with a division of 0.05.

The slider is made of rubber in the shape of a rectangular cuboid. The edge that is in contact with the test sample is 1-3 mm wide. The material for preparation of the slider (rubber) must have elasticity in the range from 66 to 73%, at a temperature of 20 °C and according to the standard ISO 4662:2017. The hardness of the material (rubber) at a temperature of 20°C must be in the range from 53 to 65 IRHD (International Rubber Hardness Degrees) in accordance with the standard ISO 48-2:2018.

The device is equipped with a pointer that moves together with the pendulum, when the pendulum is released.

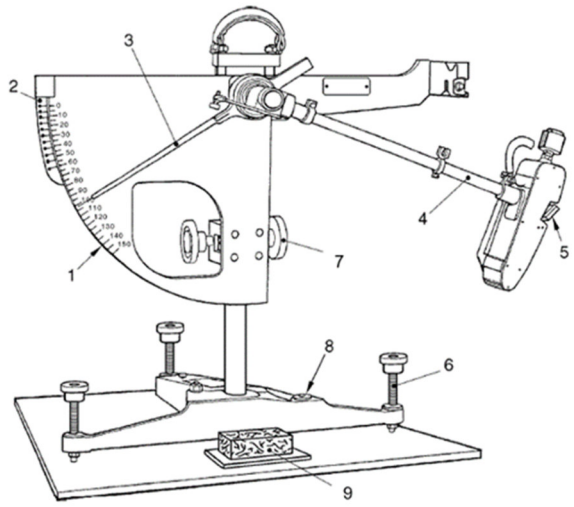
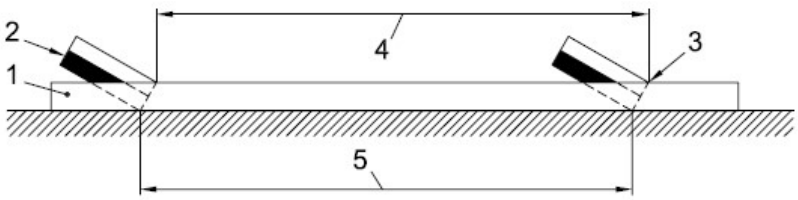


Figure 1. Slip resistance testing device

The device is calibrated by setting everything in the initial position, but without the sample. The pendulum with the slider is released and the pointer must stop at the position with reading 0. The device needs to be calibrated for both dry and wet procedure separately.

4. DESCRIPTION OF THE TEST PROCEDURE

To carry out this test, it is necessary to prepare a minimum of six test samples for testing in the laboratory, or six test surfaces when testing the finished floor. Test samples or test surfaces must be representative of a certain type of stone. The dimensions of the test samples, or the area, are 136 x 86 mm, and the test length ("swept length") is 126 mm. A wide slider is used and it is read on the C scale. In the case when samples of prescribed dimensions are not available, testing is performed on test samples or surfaces with dimensions of 86 x 42 mm and the test length is 76 mm. A narrow slider is used and the reading is carried out on the F scale. The test length ("swept length") is the length between the contact point of the slider and the sample in the pendulum position when the slider approaches the sample and the contact point of the slider and the sample in the pendulum position when the slider leaves the sample. Schematic view in Figure 2.

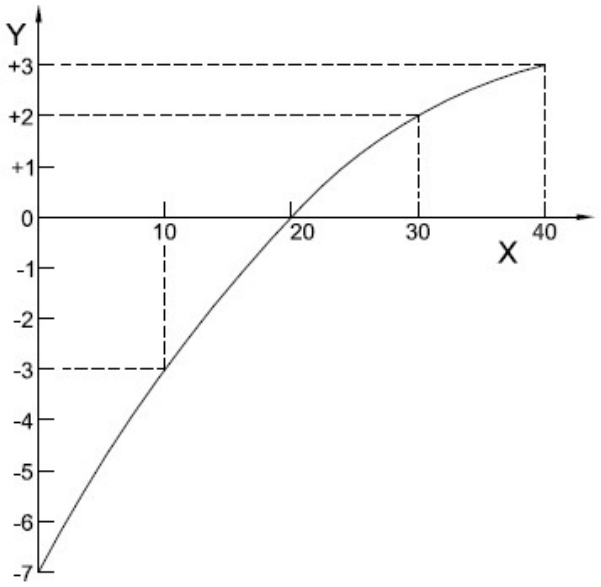


1 Mjerilo *2 Klizač* *3 Referentni rub* *4 Izmjerena ispitna duljina* *5 Stvarna ispitna duljina*

Figure 2. Setting the test length ("swept length")

Testing in laboratory conditions is carried out at a test room temperature of 20±5°C. The device and samples are conditioned to the test room temperature for a minimum of two hours. When testing finished floors, the test surface should be cleaned with a brush and washed with water. The test is carried out when the floor temperature is in the range from 5 to 40°C. Before starting, it is necessary to set the device vertically on the test sample or test surface. The sample must be placed so that the longer dimension is in the direction of the pendulum, taking care that the slider movement direction is parallel to the longer axis of the test sample. Set the test length and fix the sample. Set the corresponding slider and read the obtained value from the appropriate scale. Before starting the test, the pointer and the pendulum are set in the same position. The pendulum is released and the pointer stops at the test value. The pendulum needs to be caught by hand and calmed so that it does not hit the sample on its way back. The obtained value is recorded in the appropriate form. It is necessary to perform five consecutive tests in the same direction and the obtained values should not differ by more than three units (e.g. SRV readings 56, 58, 57, 55 and 57 on the C scale. With the F scale, the values must not differ by more than 0.03). On the same test sample or surface, it is necessary also to carry out the test in the opposite direction and record five test values that do not differ by more than three units. For laboratory samples, it is necessary to turn the sample 180°, and when testing finished floors, the test device is rotated. Before starting the testing of samples in the opposite direction, check the calibration of the device.

The test is carried out in dry and wet conditions. In the dry state, the sample and slider are dried and conditioned to the test temperature. In the wet state, the samples should be saturated with water at a temperature of 20±5°C for a minimum of two hours. Before each release of the pendulum, thoroughly dampen the slider and the test surface with deionized water at a temperature of 20±5°C. For the wet procedure too, it is necessary to record five consecutive values that do not differ by more than three units in each direction.



X - Test temperature °C;
Y - Factor to be added for correction to 20 °

Figure 3. Correction for test temperature

For one test sample or test surface, the expression of the results is performed by calculating the mean value for five readings in one direction and the mean value for five readings in the other direction. After that, the mean value of these two numbers is calculated. The same procedure is repeated for all six test samples. The final value of slip resistance is obtained as the mean value of the six test samples. So, to determine the slip resistance of a stone in one of the conditions (dry or wet), it is necessary to test a minimum of six test samples. For each test sample, record five values in one direction and five values in the opposite direction. All together, it is necessary to record a minimum of 60 values from which the slip resistance value (SRV) is calculated.

When testing finished floors, it is necessary to correct the obtained values for the test temperature since the elasticity of the slider depends on the test temperature. Figure 3 shows a graph from which corrections with respect to the test temperature can be read.

5. TEST RESULTS

In order to develop this paper with the subject of presenting the natural stone test for slip resistance using a pendulum, the testing of dimension stone from Jablanica was carried out. The petrographic name of the stone is gabbro and it belongs to surface igneous rocks. The commercial name is granite or Jablanica granite. Sample preparation, treatment and testing were carried out according to the standard BAS EN 14231:2009 – Natural stone test methods – Determination of the slip resistance by means of the pendulum tester. A total of 18 test samples with three different finishes were prepared. The samples are 5 cm thick. The samples were assigned a laboratory group designation 23/376. Types of finishes are: cut, polished and flamed. For clear marking, test samples are marked with codes that are a combination of letters and numbers. The letter designations according to the type of processing are: cut (mark C), polished (mark P) and flamed (mark F). Numbers from 1 to 6 were used for the numerical part of the code. In this way, we obtained test samples with the codes presented in Table 1.

Table 1. View of test sample codes

Finishing "cut"	Finishing "polished"	Finishing "flamed"
23/376-C1	23/376-P1	23/376-F1
23/376-C2	23/376-P2	23/376-F2
23/376-C3	23/376-P3	23/376-F3
23/376-C4	23/376-P4	23/376-F4
23/376-C5	23/376-P5	23/376-F5
23/376-C6	23/376-P6	23/376-F6

The dimensions of the test samples are 150 x 100 mm. A wide slider (76 mm) was used and the readings were taken on the C scale. The test was conducted on test samples in dry and wet conditions. The test results according to the types of finishing of the test surface are presented below. Results of mean values for both directions are shown (five results for each direction). Table 2 shows the results of slip resistance for samples with a cut surface.

Table 2. Slip resistance results for samples with cut surface

Test results - dry condition			Test results - wet condition	
Test sample code	Mean value of SRV (two directions)		Test sample code	Mean value of SRV (two directions)
23/376-C1	72		23/376-C1	54
23/376-C2	67		23/376-C2	54
23/376-C3	67		23/376-C3	54
23/376-C4	67		23/376-C4	54
23/376-C5	65		23/376-C5	55
23/376-C6	59		23/376-C6	54
SRV "dry"	*66*		*SRV "wet"*	*54*

Furthermore, Table 3 shows the slip resistance results for the samples with a polished surface.

Table 3. Slip resistance results for samples with polished surface

Test results - dry condition			Test results - wet condition	
Test sample code	Mean value of SRV (two directions)		Test sample code	Mean value of SRV (two directions)
23/376-P1	59		23/376-P1	12
23/376-P2	50		23/376-P2	13

Table 3. Continuation

23/376-P3	50		23/376-P3	12
23/376-P4	46		23/376-P4	12
23/376-P5	53		23/376-P5	12
23/376-P6	53		23/376-P6	12
SRV "dry"	51		SRV "wet"	12

Furthermore, Table 4 shows the results of slip resistance for samples with a burnt surface.

Table 4. Slip resistance results for samples with flamed surface

Test results - dry condition			Test results - wet condition	
Test sample code	Mean value of SRV (two directions)		Test sample code	Mean value of SRV (two directions)
23/376-F1	67		23/376-F1	49
23/376-F2	63		23/376-F2	45
23/376-F3	67		23/376-F3	49
23/376-F4	61		23/376-F4	53
23/376-F5	64		23/376-F5	49
23/376-F6	64		23/376-F6	47
SRV "dry"	64		SRV "wet"	48

The obtained results can be compared with the data from Table 5, which shows the slip probabilities in relation to the obtained slip resistance, SRV.

Table 5. Slip probabilities obtained from pendulum testing

Slip probability	SRV
High probability of slipping	0 - 24
Medium probability of slipping	25 - 35
Low probability of slipping	> 36

Furthermore, the test results can be used to calculate the kinematic coefficient of friction of the tested surface according to the expression given in UK Slip Resistance, 2005:

$$\mu = \frac{3xSRV}{330-SRV} \quad (1)$$

Table 6 shows the slip probabilities in relation to the calculated kinematic coefficient of friction.

Table 6. Slip probabilities based on the kinematic coefficient of friction

Description of probability	Kinematic coefficient of friction, μ
High probability of slipping	less than 0.30
Medium probability of slipping	0.30 - 0.45
Low probability of slipping	greater than 0.45

The calculated values of the kinematic coefficient of friction based on the obtained SRV values for the tested types of surfaces in both conditions are shown in Table 7.

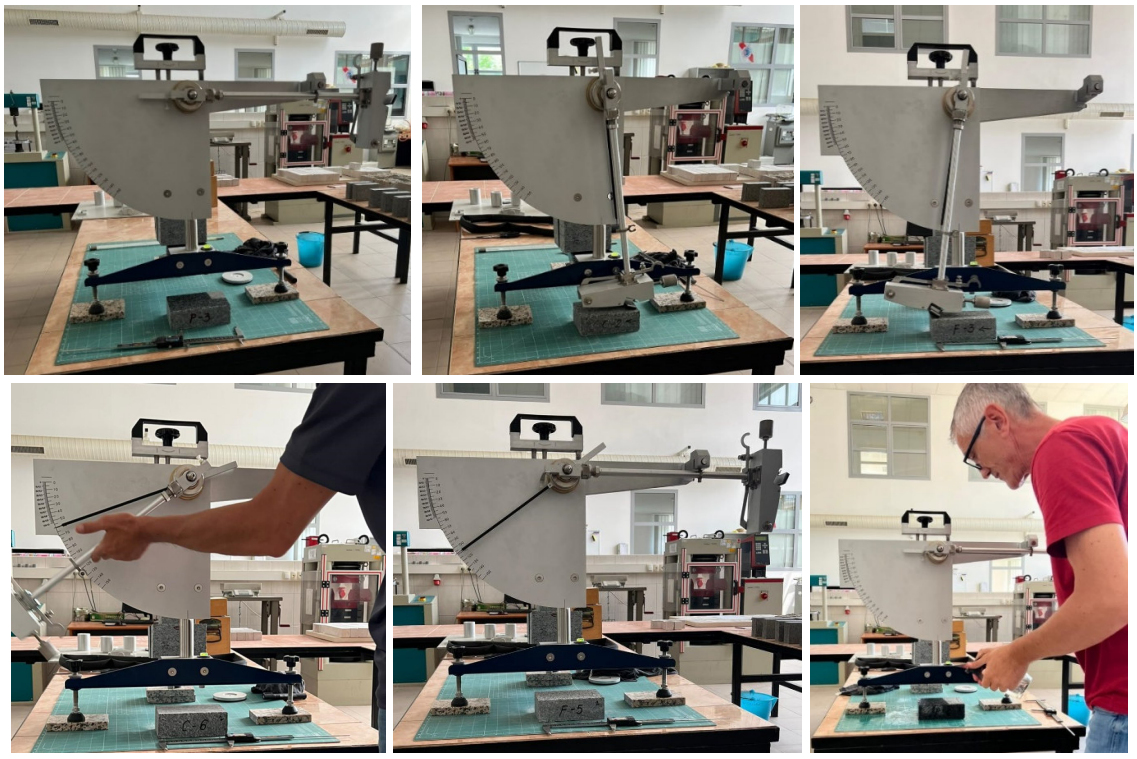
Table 7. Values of the kinematic coefficient of friction (Lether, 2005)

Type of finish	Kinematic coefficient of friction μ (dry condition)	Kinematic coefficient of friction μ (wet condition)
Cut (C)	0.75	0.59
Flamed (F)	0.72	0.51
Polished (P)	0.55	0.11

It must be emphasized here that the values of the kinematic coefficient of friction $\mu > 0.8$ are not recommended, because the excessive resistance of the surface causes sticking (stumbling).

6. PHOTOGRAPHIC DOCUMENTATION

The following photos, Figure 4 (a, b, c, d, e and f) show the different stages of testing natural stone "Gabro". The testing was performed in the Central Laboratory of the company "IGH" d.o.o. Mostar.



Figures 4a-4f - Different stages of testing natural stone "Gabro"

7. ADDITIONAL TESTS

Additional tests were performed on the test samples in order to check the basic physical properties of the natural stone, such as bulk density (apparent density), water absorption and open porosity. The tests were carried out according to the following standards:

BAS EN 13755:2009 - Natural stone test methods - Determination of water absorption at atmospheric pressure;
BAS EN 1936:2009 - Natural stone test methods - Determination of real density and apparent density, and of total and open porosity;

Water absorption - The test results are shown in Table 8. The samples are divided according to the type of processing: cut (C), polished (P) and flamed (F).

Table 8. Results of the water absorption test

Test sample code	m_d (g)	m_s (g)	Absorption, A_b (%)
23/376-C1	2338.4	2341.1	0.12
23/376-C2	2320.7	2323.5	0.12
23/376-C3	2388.2	2390.8	0.11
23/376-C4	2384.9	2387.5	0.11

Table 8. Continuation

23/376-C5	2144.5	2146.7	0.10
23/376-C6	2353.3	2356.2	0.12
		Mean value, cut processing C	0.1
23/376-P1	2165.3	2167.9	0.12
23/376-P2	2164.1	2166.7	0.12
23/376-P3	2153.8	2156.4	0.12
23/376-P4	2160.0	2162.6	0.12
23/376-P5	2149.1	2151.6	0.12
23/376-P6	2161.4	2163.9	0.12
		Mean value, polished processing P	0.1
23/376-F1	2159.6	2161.9	0.11
23/376-F2	2151.5	2154.1	0.12
23/376-F3	2139.8	2142.3	0.12
23/376-F4	2133.7	2136.9	0.15
23/376-F5	2122.9	2125.4	0.12
23/376-F6	2166.7	2169.2	0.12
		Mean value, flamed processing F	0.1

** Measured values: md - mass of dry sample, ms - mass of saturated surface-dry sample*

According to the specified standard, the absorption value is rounded to the nearest 0.1%.

Apparent density and open porosity - test results are shown in Table 9. The samples are divided according to the type of processing: cut (C), polished (P) and flamed (F).

Table 9. Results of bulk density and open porosity tests

Test sample code	Sample mass			Apparent density ρ_b (kg/m^3)	Open porosity p_0 (%)
	m_d (g)	m_h (g)	m_s (g)		
23/376-C1	2338.4	1551.3	2341.1	2951.87	0.3
23/376-C2	2320.7	1541.9	2323.5	2960.26	0.4
23/376-C3	2388.2	1593.0	2390.8	2984.50	0.3
23/376-C4	2384.9	1594.2	2387.5	2997.28	0.3
23/376-C5	2144.5	1409.8	2146.7	2900.25	0.3
23/376-C6	2353.3	1566.2	2356.2	2969.92	0.4
			Mean value cut C	2960	0.3

Table 9. Continuation

23/376-P1	2165.3	1429.7	2167.9	2924.42	0.4
23/376-P2	2164.1	1428.4	2166.7	2922.40	0.4
23/376-P3	2153.8	1420.7	2156.4	2918.77	0.4
23/376-P4	2160.0	1425.5	2162.6	2921.61	0.4
23/376-P5	2149.1	1417.7	2151.6	2919.54	0.3
23/376-P6	2161.4	1425.8	2163.9	2919.54	0.3
Mean value polished P				2920	0.3
23/376-F1	2159.6	1421.1	2161.9	2906.48	0.3
23/376-F2	2151.5	1415.0	2154.1	2902.24	0.4
23/376-F3	2139.8	1407.8	2142.3	2904.53	0.3
23/376-F4	2133.7	1401.5	2136.9	2892.71	0.4
23/376-F5	2122.9	1396.1	2125.4	2902.14	0.3
23/376-F6	2166.7	1425.1	2169.2	2903.10	0.3
Mean value flamed F				2900	0.3

According to the specified standard, the obtained density value is rounded to the nearest 10 kg/m3 and the porosity value to 0.1%. Measured values: md - mass of dry sample, mh - mass of sample under water, ms - mass of saturated surface-dry sample.

8. CONCLUSION

This test was conducted for the purpose of presenting the BAS EN 14231:2009 test method, or the necessary equipment and test procedure in order to draw attention to this important property of natural stone. This paper presents the testing of slip resistance of the dimension stone, Jablanica granite. This natural stone is used for covering outdoor surfaces (squares, streets, promenades,...), for interior decoration of floor surfaces and staircases (public institutions, residential buildings, ...) and for the construction of cultural and historical monuments and monuments in general. Considering its wide application in covering floor surfaces, one of the main properties that should be known is slip resistance. Samples with three different finishes on exposed surfaces were tested. The test results obtained can be defined as expected. The highest slip resistance in both conditions was measured on samples obtained by cutting (sawing), while the lowest slip resistance in both conditions was measured on samples with polished surface.

From all of the above, it can be concluded that it would be good to put into practice that stone samples for covering floor surfaces are first tested in the laboratory in order to select the most suitable stone in the project development phase, taking into account slip resistance. According to previous tests, this test method, using a pendulum tester, has proven to be reliable and accurate and is introduced in many countries as a standard test method for determining the probability of slippage on floor surfaces.

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