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Research paper

The comparison of the compressive strength of rock in view of requirements according to selected civil engineering standards

Joanna Hydzik-Wiśniewska[1], Łukasz Bednarek[2]

Abstract: This study is aimed at analysing the requirements for compressive strength values of rocks used in the universally understood construction industry as stone materials. The compressive strength value obtained in laboratory tests may prove significantly different from the actual compressive strength of a given rock, depending on its application. According to PN-EN 1342:2013, lower expected value must be declared for paving block stone, normalised value for wall components, as per PN-EN 1996-1-1:2023 and PN-EN 771-6:2015, while with respect to stone for hydrotechnical works – structural integrity acc. to PN-EN 13383-1:2003. Despite testing samples in the same manner, e.g. acc. to PN-EN 1926:2007, all these parameters differ with the declared value and, in many cases, significantly differ from the most frequently used average compressive strength value. The analysis involved the results of compressive strength tests performed as per PN-EN 1926:2007, for samples of sandstone, granite, and limestone. The tests were performed for the aforementioned rocks in the air-dry condition, after saturation, and after the frost resistance test. On average, for all rock types, the lower expected value vs. average value was lower: in the air-dry condition by 25%, after saturation by 29%, and after frost resistance test by 37%. Furthermore, in most analysed cases, lower expected value did not exceed minimum compressive strength value. Normalised value in the air-dry condition was by approximately 15% lower than the average value, while after saturation totalled from 10% to 25%, depending on rock type.

Keywords: compressive strength, stone materials, standard requirements, lower expected value, normalised value, resistance to breakage

[1]PhD., Eng., AGH University of Krakow, Faculty of Civil Engineering and Resource Management, al. A. Mickiewicza 30, 30-059 Krakow, Poland, e-mail: hydzik@agh.edu.pl, ORCID: 0000-0002-3273-9876
[2]PhD., Eng., AGH University of Krakow, Faculty of Civil Engineering and Resource Management, al. A. Mickiewicza 30, 30-059 Krakow, Poland, e-mail: bednarek@agh.edu.pl, ORCID: 0000-0002-8239-5864

1. Introduction

Compressive strength is one of the most important mechanical properties of rocks used in the universally understood engineering. The parameter is necessary for assessment of rock properties, starting from the diagnosis of geotechnical foundation soils through selection of stone materials for road surfaces, wall components, or stone for hydrotechnical works. Compressive strength (R) is the ratio of the highest critical compressive destructive force (Newton) to the cross-section of the sample (square meter). The compressive strength value forms the basis for many classifications used, among others, for geotechnical assessment of rocks and rock massifs (Table 1) [1–7].

Table 1. Rock compressive strength classification acc. to ISRM [3] and PN-EN ISO 14689:2018 [6]

ISRM 1979		**PN-EN ISO 14689:2018**	
Qualification	***R* [MPa]**	**Qualification**	***R* [MPa]**
		Extremely low	< 1
Very low	< 6	Very low	1–5
Low	10–20	Low	5–25
Moderate	20–60	Moderate	25–50
High	60–200	High	50–100
Very high	>200	Very high	100–250
		Extremely high	>250

For rocks used as building material, however, classification can be found in the withdrawn standard PN-B-01080:1984 [8]. Table 2 presents classification broken into air-dry condition, saturation with water, and after frost resistance test. Table 3, in turn, presents ranges of compressive strength values depending on rock type [9].

Table 2. Rock compressive strength classification acc. to PN-B-01080:1984 [8]

Qualification	$R_{\text{air-dry condition}}$ **[MPa]**	$R_{\text{saturation condition}}$ **[MPa]**	$R_{\text{condition after frost resistance}}$ **[MPa]**
Very low	< 15	< 12	< 10
Low	15–60	12–50	10–45
Moderate	61–120	51–100	46–80
High	121–200	101–190	81–180
Very high	>200	>190	>180

Standard classification is yet different depending on compressive strength of rock samples armourstone acc. to PN-EN 13383-1:23003 [10] (Table 4). Compressive strength tests are performed on samples saturated with water to constant weight.

Table 3. Rock compressive strength classification acc. to Kamieński & Skalmowski [9]

Qualification	$R_{\text{air-dry condition}}$ **[MPa]**	**Type of rock**
Very high	>280	Basalts, diabases, quartzites, some sandstones
High	180–280	Fine-grained granites, diorites, porphyries, basalts, compact limestones, sandstones
Moderate	80–180	Limestones, sandstones, medium and fine-grained granites, gneisses
Low	40–80	Porous limestones, sandstones
Very low	< 40	Tuffs, chalk, very porous sandstones

Table 4. Categories of resistance to breakage requirements [10]

Mean compressive strength of 9 specimens, after striking out the lowest value from 10 specimens [MPa]	**Compressive strength of no more than 2 specimens out of 10 [MPa]**	**Category *CS***
≥ 80	< 60	CS_{80}
≥ 60	< 40	CS_{60}
Other value declared by the producer		CS_{Declared}
No requirement		CS_{NR}

Compressive strength is significantly affected by the rock type. Many authors points to the correlation between mechanical properties and mineral composition, mineral hardness, texture, and structure. It was determined that sandstones and igneous rocks become stronger with the increased content of quartz, whereas in the case of carbonate rocks the increase of quartz results in loss of their compressive strength [5, 11–13]. In assessment of compressive strength, many authors pointed to its correlation with rock texture and structure. Structural-textural properties have been presented in the form of respective coefficients developed pursuant to data from macroscopic and microscopic observations involving such parameters as: grain shape, grain size and grain orientation, porosity, cracking, etc. [4, 14–16].

In the meaning of building material, during their use, rocks are exposed to climatic factors, namely precipitation, sunlight exposure, and temperature. Long impact of such factors on building elements made of stone may lead to their deterioration. In the broadly available literature, authors principally point to decreased compressive strength value. Rock saturation with water may cause over 50% decrease in compressive strength vs. samples tested in the air-dry condition. In the case clayey sandstones, saturation with water mainly causes dissolution and dispersion of clayey minerals [17]. The effects of saturation are more visible in sedimentary rocks rather than in igneous and metamorphic rocks, and depend on rock porosity and sorption capacity [18–24].

Another destructive factor reducing compressive strength is the periodic change of temperature, in winter, causing freeze-thaw effect. Similarly as in the case of saturation with water, the rocks most at risk of significant compressive strength decrease as a result of frost resistance test are sedimentary rocks, namely sandstones, limestones, and dolomites, particularly with high open porosity. Igneous and metamorphic rocks, however, are the most resistant [24–28].

Another factor affecting compressive strength is the shape and size of samples, as well as the deformation velocity. Depending on the assessment criterion and test method, samples used are cylinder- or cuboid-shaped with cross-section ranging from 50 mm to 100 mm, and slenderness from 1 (PN-EN 1926:2007 [29]) to even 3 (ISRM [30]). It is a very important factor for correct interpretation of compressive strength test results because if other sample dimensions and shapes are used, different results are obtained. Usually, the larger the samples than recommended in the standards, the lower compressive strength values are obtained, and vice versa, the smaller the samples, the higher the results. This is caused by higher probability of mechanical discontinuities and defects in larger samples [31–34]. Similarly as in the case of slenderness, the tests pointed to as much as 30% decrease in compressive strength for samples with slenderness 2 [33, 35].

The compressive strength value obtained in laboratory tests may prove significantly different from the actual compressive strength of a given rock. Therefore, it is very important to follow the standardised procedures, both when performing the test, and interpreting the results. This study is aimed at analysing test methods and requirements, and at comparing the compressive strength results depending on the application. The database of compressive strength tests results conducted at Accredited Laboratory for Testing Properties of Rocks and Stone Products at the Faculty of Civil Engineering and Resource Management of the AGH University of Science and Technology in Krakow were analysed. The necessary parameters of compressive strength, namely average value, lower expected value and normalized value, as required civil engineering were calculated and compared.

2. Requirements and test methods

Eurocode 6 (PN-EN 1996-1-1:2023 [36]) states that materials for wall components may include natural stone conforming with PN-EN 771-6:2015 [37]. For wall structure design calculations, normalised average compressive strength of wall components (f_b) is used. Normalised average compressive strength can be adopted as manufacturer-declared value or according to PN-EN 772-1:2011 [38] by calculating it depending on ripening conditions and sample dimensions. Compressive strength test method envisages performing tests for at least 10 samples drawn from a delivered batch. If testing of entire components is difficult to perform, samples may include cut out cubes with side length of 100 (±5) mm, 70 (±5) mm, or 50 (±5) mm, or cylinders with the height equal to their diameter and amounting to 100 (±5) mm, 70 (±5) mm, or 50 (±5) mm. Test result should state the average and normalised compressive strength value.

Eurocode 7 (PN-EN 1997-2:2009 [39]) requires provision of compressive strength value for rock component classification and for assessment of rock massif properties. Samples are prepared based on cores drawn from the rock mass. As regards test method, Eurocode 7 recommends two test methods contained in ISRM [30] and ASTM D 2938:1991 [40] with modifications included in the standard. ISRM method states that samples for testing should be cuboid or cylinder-shaped with the diameter not lower than 54 mm. The test is to be involve at least 5 samples. The final result should be the arithmetic mean of the obtained results.

Requirements for stone materials to be used as paving blocks acc. to PN-EN 1342:2013-05:2013 [41] recommend compressive strength testing as per PN-EN 1926:2007 [29] and declaring the result as lower expected value. The standard requires that the test must involve at least 10 cubic samples with side dimensions of 70 (±5) mm or 50 (±5) mm, or cylinder samples with diameter and height equal to 70 (±5) mm or 50 (±5) mm.

With respect to armourstone, PN-EN 13383-1:2003 [10] defines compressive strength as structural integrity (resistance to breakage). The test must be performed in line with the requirements of PN-EN 1926:2007 [29] provided that each sample must be drawn from a different piece of stone. In order to determine the category of armourstone, the final result is to be the average compressive strength from 9 (nine) samples after rejecting the lowest of the 10 (ten) tested samples. Furthermore, lowest values from not more than 2 (two) out of 10 (ten) tested samples must be classified.

3. Declared compressive strength value

Depending on the application of the stone material in building facilities, compressive strength values must be declared in line with the applicable standard (PN-EN 13383-1:2003; PN-EN 1342:2013-05, PN-EN 1996-1-1:2023). The most frequently declared value is the average value calculated as arithmetic mean ($\overline{x}$), standard deviation (s) and coefficient of variation (v). With the assumption of normal distribution, the parameters are determined based on the following equations:

$$\overline{x} = \frac{1}{n}\sum x_i \tag{3.1}$$

$$s = \pm\sqrt{\frac{\sum (x_i - \overline{x})^2}{n-1}} \tag{3.2}$$

$$v = \frac{s}{\overline{x}} \tag{3.3}$$

where: n – number of tested samples, x_i – compressive strength value of i-th sample.

To calculate normalised average compressive strength for wall components in line with PN-EN 772-1:2011 [38], compressive strength value is first of all calculated into equivalent compressive strength appropriate to ripening in the air-dry condition by applying the following multipliers:

- 0.8 for samples dried in a drier to constant weight,
- 1.2 for samples saturated with water.

Next, the obtained compressive strength value is multiplied by the shape coefficient thus calculating compressive strength value to sample size of 100 mm. For samples with the size of 50 mm, the coefficient totals 0.85. Moreover, the standard categorises wall components. Category I covers components with declared compressive strength with the probability that the occurrence of lower compressive strength is not greater than 5%. For wall components of Category II, however, there are no requirements as to the probability of occurrence of values lower than declared.

In the case of calculation of lower expected value (E) as per PN-EN 1926:2007 [29], normal logarithmic distribution was adopted. The lower expected value of compressive strength (E) corresponds to 5% quantile of normal logarithmic distribution with 75% confidence.

$$\overline{x}_{\ln} = \frac{1}{n}\sum \ln_{xi} \tag{3.4}$$

$$s_{\ln} = \pm\sqrt{\frac{\sum(\ln_{xi} - \overline{x}_{\ln})^2}{n-1}} \tag{3.5}$$

$$E = e^{\overline{x}_{\ln} - k_s \bullet s_{\ln}} \tag{3.6}$$

where: $\overline{x}_{\ln}$ – average value, $s_{\ln}$ – logarithmic standard deviation, E – lower expected value, k_s – quantile estimation coefficient for 10 samples totals 2.10 [29].

4. Own study

With the aim at assessing the results of compressive strength tests, a comparison was made of average, minimum, maximum, normalised, and lower expected values. This analysis used the database of compressive strength tests performed at the Accredited Laboratory for Testing Properties of Rocks and Stone Products at the Faculty of Civil Engineering and Resource Management of the AGH University of Science and Technology in Krakow in the period 2007–2023 [42]. A selection of result groups involved compressive strength tests as per PN-EN 1926:2007 [29]. All the tests were performed on 10 (ten) cubic samples with side length of approximately 50 mm. All tests were performed to assess usefulness of such rocks for construction purposes, namely for production of paving blocks, wall components, or stone for hydrotechnical works. Tests were performed in three conditions, namely the air-dry condition, after saturation with water, and after 56 freeze-thaw cycles (frost resistance test as per PN-EN 12371:2010 [43]). Samples of all sandstones came from quarries in southern and southeastern Poland. Samples of granites came from quarries in Lower Silesia (Poland) and from Ukraine, Sweden and China. Samples of limestones came from Poland, Portugal, Germany, France and the Balkan region. Due to confidentiality of the test, no exact sampling location or client names were provided. Compressive strength test results were grouped by rock types and testing conditions.

Table 5 presents the listing of average compressive strength values (R) with standard deviation (s) and coefficient of variation (v) broken by rock types and condition of samples during the test (air-dry condition, after saturation with water, and after 56 freeze-thaw cycles).

Table 5. Listing of average compressive strength values in three testing conditions

No.	Name	Air-dry condition			Saturated condition			Condition after 56 freeze-thaw cycles		
		R [MPa]	*s* [MPa]	*v* [–]	*R* [MPa]	*s* [MPa]	*v* [–]	*R* [MPa]	*s* [MPa]	*v* [–]
1	Granite 1	144	19	0.13	147	7	0.05	–	–	–
2	Granite 2	205	14	0.07	–	–	–	–	–	–
3	Granite 3	210	14	0.07	132	21	0.16	186	37	0.20
4	Granite 4	223	9	0.04	182	26	0.14	188	13	0.07
5	Granite 5	242	54	0.22	276	8.92	0.03	257	20	0.08
6	Granite 6	192	21	0.11	170	26	0.15	97	20	0.21
7	Granite 7	–	–	–	179	29	0.16	–	–	–
8	Sandstone 1	107	12	0.12	64	12	0.19	70	4	0.06
9	Sandstone 2	139	46	0.33	–	–	–	–	–	–
10	Sandstone 3	123	20	0.16	98	15	0.16	100	16	0.16
11	Sandstone 4	129	20	0.16	100	7	0.07	–	–	–
12	Sandstone 5	101	13	0.12	75	6	0.08	63	11	0.18
13	Sandstone 6	130	7	0.05	97	15	0.16	88	18	0.20
14	Sandstone 7	112	4	0.04	81	7	0.08	68	28	0.42
15	Sandstone 8	121	4	0.03	87	14	0.16	85	6	0.07
16	Sandstone 9	159	9	0.06	–	–	–	–	–	–
17	Sandstone 10	–	–	–	129	14	0.11	–	–	–
18	Sandstone 11	–	–	–	89	30	0.34	–	–	–
19	Sandstone 12	–	–	–	94	15	0.16	–	–	–
20	Limestone 1	76	12	0.16	58	17	0.29	53	15	0.28
21	Limestone 2	148	8	0.06	128	22	0.18	93	26	0.29
22	Limestone 3	139	41	0.30	117	11	0.10	130	41	0.31
23	Limestone 4	191	47	0.25	151	29	0.19	151	28	0.19
24	Limestone 5	190	27	0.14	158	26	0.16	131	42	0.32
25	Limestone 6	164	30	0.18	137	27	0.19	141	21	0.15
26	Limestone 7	173	20	0.11	174	7	0.04	180	28	0.16
27	Limestone 8	142	14	0.10	116	13	0.14	130	30	0.23
28	Limestone 9	171	15	0.09	151	32	0.21	142	23	0.16
29	Limestone 10	144	30	0.21	132	21	0.16	123	21	0.17
30	Limestone 11	142	21	0.15	–	–	–	–	–	–
31	Limestone 12	–	–	–	116	16	0.14	–	–	–

Depending on the classification, the analysed stone materials can be included among rocks with high compressive strength (sandstones and limestones), and even with very high compressive strength (some granites – max. 276 MPa). Based on the standard deviation and coefficient of variation, however, as presented in Table 5, one may state that some sample sets revealed very high variation of parameters, even over 30%. The lowest variation was recorded for granites (min. 7%), while the highest – for limestones (max. 32%).

Figures 1–3 present graphic diagrams of interdependencies among the compressive strength average, minimum, maximum, normalised, and lower expected value. For samples saturated with water, compressive strength values have also been presented for armourstone. The diagrams have been presented depending on rock type and testing condition.

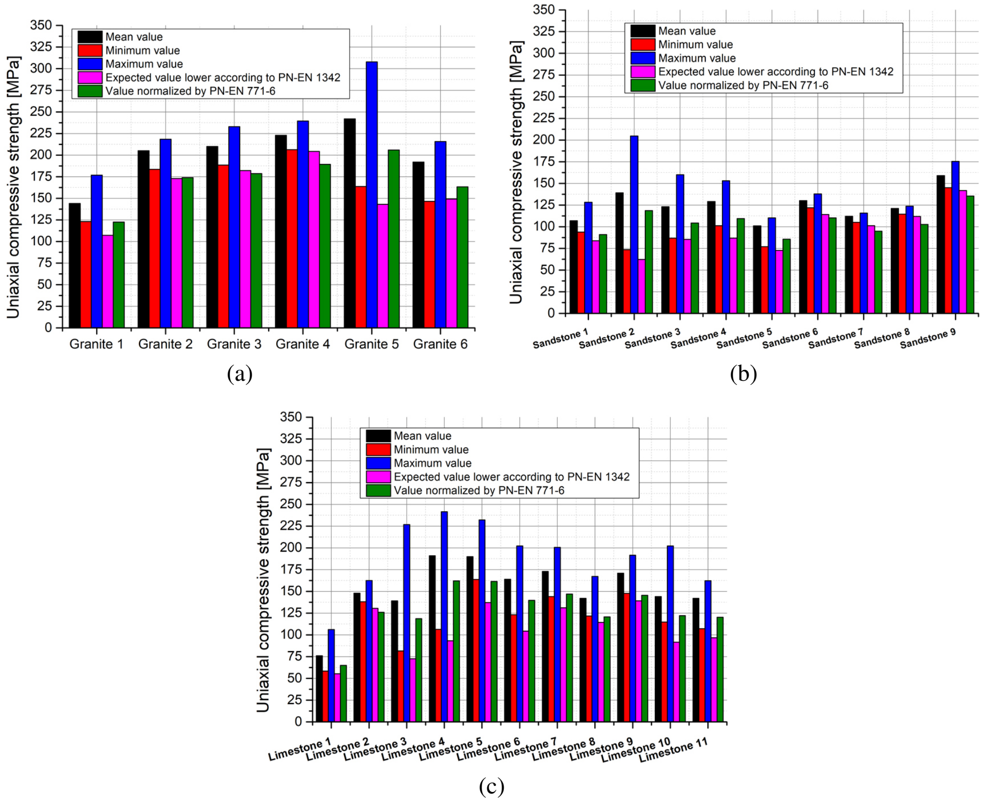

Fig. 1. Compressive strength values in air-dry condition for: (a) granites, (b) sandstones, (c) limestones

The greatest difference between the maximum and minimum compressive strength value vs. average value occur for limestone samples, medium – for sandstone samples, and the lowest – for granite samples. As regards the testing condition, however, the greatest amplitude of results was observed for limestone samples after the frost resistance test.

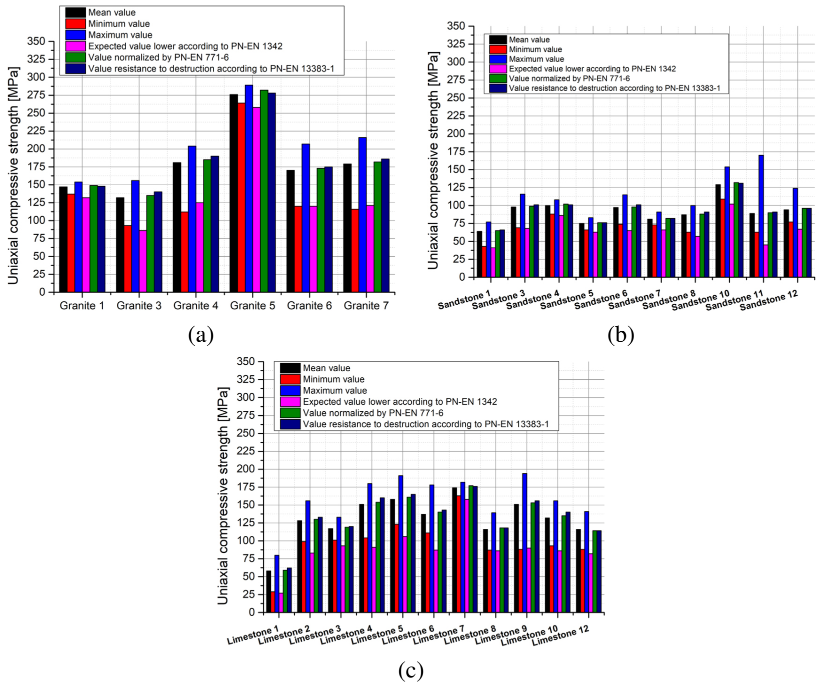

Fig. 2. Compressive strength values after saturation with water for: (a) granites, (b) sandstones, (c) limestones

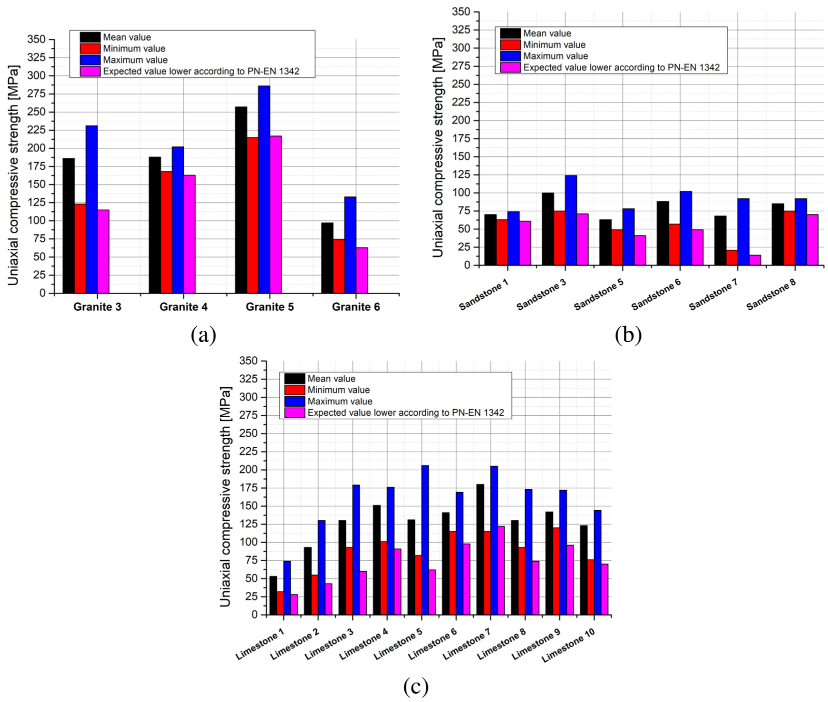

Fig. 3. Compressive strength values after frost resistance test for: (a) granites, (b) sandstones, (c) limestone

4.1. Lower expected value

Lower expected value of compressive strength, regardless of the condition of the samples, was almost always lower than minimum value. The exception is made for granites numbers: 6 for air-dry condition, 4 and 7 after saturation with water, as well as granite 5 and limestone 7 after the frost resistance test. Table 6 presents changes to the lower expected value versus average and minimum compressive strength.

Table 6. Changes to the lower expected value versus average and minimum compressive strength

Type of rock	**Air-dry condition**		**Saturated condition**		**Condition after 56 freeze-thaw cycles**	
	$E/R_{śr}$	E/R_{min}	$E/R_{śr}$	E/R_{min}	$E/R_{śr}$	E/R_{min}
Granite	0.79	0.94	0.76	1.00	0.74	0.94
Sandstone	0.77	0.93	0.72	0.91	0.64	0.87
Limestone	0.70	0.89	0.67	0.91	0.57	0.84

The highest decrease vs. average value was observed for limestone samples, on average totalling: for the air-dry condition – 30%, after saturation with water – 33%, while after 56 freeze-thaw cycles – even 43%. The lowest decrease in values was recorded for granites: 21%, 24%, and 26%, respectively.

There is a strict linear correlation between the reduction in the lower expected value (E) vs. average compressive strength value ($R_{śr}$) and the coefficient of variation. Diagram (Fig. 4) presents such correlations for all the samples in the three testing conditions. The higher the coefficient of variation, the lower is the lower expected value from the average value.

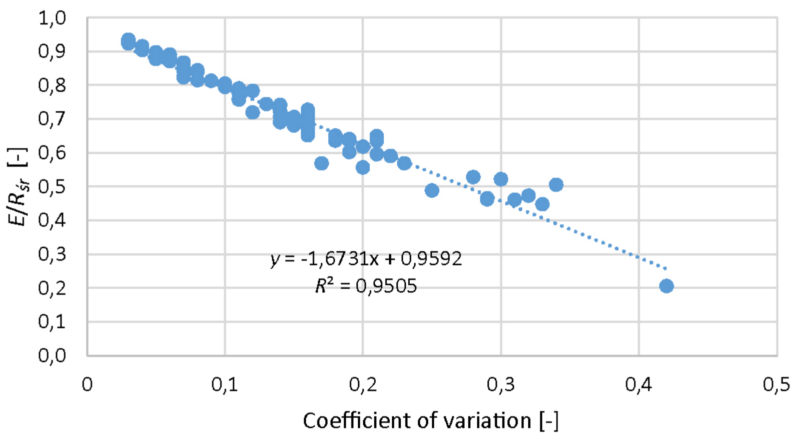

Fig. 4. Correlation between the change in the lower expected value vs. the average compressive strength value and the coefficient of variation

Irrespective of the condition of samples tested for compressive strength, with the coefficient of variation of 0.1, lower expected value can be lower by 20% vs. the average value. In turn, with the coefficient of variation of 0.3, the value can be lower by even 50% than the average value.

4.2. Normalised value and structural integrity

For the condition after saturation with water (Fig. 2), normalised values of compressive strength (as per PN-EN 771-6:2015 [37]) and structural integrity (acc. to PN-EN 13383-1:2003 [10]) are very similar, and their value is up to several percent higher than the average compressive strength value. Normalised values, however, calculated for air-dry condition, are by approximately % lower than the average value. When analysing normalised values calculated pursuant to compressive strength values in the air-dry condition and after saturation with water, significant differences can be observed. Table 7 presents the aforementioned average values for particular rocks.

Table 7. Normalised values of compressive strength and structural integrity for particular rock types

Type of rock	$R_{\text{air-dry condition}}$ **[MPa]**	$f_{\text{bair-dry condition}}$ **[MPa]**	$f_{\text{bsaturated condition}}$ **[MPa]**	**Structural integrity [MPa]**
Granite	203	172	184	186
Sandstone	125	106	93	94
Limestone	153	130	133	135

For granites, most frequently, normalised value calculated from compressive strength when saturated with water is higher than the value for the air-dry condition. For sandstones, normalised value calculated for saturation with water is usually by several percent lower than the value calculated for the air-dry condition. For limestones, however, the analysed values are similar to one another. Also, normalised values calculated for samples saturated with water are also identical as the ones calculated after rejecting the lowest of compressive strength values from 10 results (structural integrity for armourstone).

5. Conclusions

Depending on the application of the stone material, different parameters related to compressive strength are required. According to PN-EN 1342:2013 [41], lower expected value is to be declared for paving block stone, normalised value for wall components, as per PN-EN 1996-1-1:2023 [36] and PN-EN 771-6:2015 [37], while with respect to armourstone – structural integrity acc. to PN-EN 13383-1:2003 [10]. All these parameters differ in values despite the fact that the samples are tested in the standardized procedure. Therefore, pursuant to the conducted analysis, one may state as follows:

– For the purpose of using a given stone material type, one must calculate the value required by the respective standard, not simply relying on the average compressive strength value.
– The lower expected value of compressive strength for the 10 samples required by the standard is usually by several percent lower than the minimum value of compressive strength test results. It can be, however, lower than the average value by even several dozen percent.
– There is a strict linear correlation between the coefficient of variation and the ratio of the lower expected value to average compressive strength value. For the coefficient of variation of 0.1, lower expected value is lower than the average compressive strength by approximately 20%. Whereas for the coefficient of variation of 0.3, the reduction of lower expected value in relation to the average compressive strength exceeds even 50%.
– Normalised values for the stone for brickwork indicate differences for parameters calculated for samples in the air-dry condition and after saturation with water. The differences can reach even 20%, depending on the rock type.

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Wytrzymałość na ściskanie skał w świetle wymagań norm dla budownictwa

Słowa kluczowe: materiały kamienne, oczekiwana wartość niższa, odporność na zniszczenie, wartość znormalizowana, wymagania normowe, wytrzymałość na ściskanie

Streszczenie:

Wytrzymałość na ściskanie jest jedną z najważniejszych właściwszości mechanicznych skałwykorzystywanych w szeroko pojętej inżynierii. Parametr ten jest niezbędny przy ocenie właściwości skał, począwszy od rozpoznania geotechnicznego podłoża gruntowego aż do doboru materiałów kamiennych na nawierzchnie drogowe, elementy murowe czy też kamień do robót hydrotechnicznych. Wytrzymałość na ściskanie jest to iloraz największej krytycznej siły ściskającej, niszczącej próbkę do powierzchni jej przekroju poprzecznego. Wartość wytrzymałości na ściskanie skały zależy przede wszystkim od składu mineralnego i fazowego, ale też od oddziaływania środowiska i klimatu. Bardzo istotnym czynnikiem wpływającym na wartość wytrzymałości jest też sposób przeprowadzenia badania oraz interpretacji jego wyniku. Uzyskana w badaniach laboratoryjnych wartość wytrzymałości na ściskanie może okazać się znacząco różna od rzeczywistej wytrzymałości danej skały w zależności od zastosowania. Wytrzymałość naściskanie dla kamienia na kostkę brukową wg PN-EN 1342:2013 powinna być deklarowana jako wartość oczekiwana niższa , dla elementów murowych wg PN-EN 1996-1-1:2023 oraz PN-EN 771-6:2015 jako wartość znormalizowana, natomiast dla kamienia do robót hydrotechnicznych wg PN-EN 13383-1:2003 będzie to tzw. odporność na zniszczenie. Wszystkie te parametry, pomimo, że próbki badane są w ten sam sposób, zwykle wg normy PN-EN 1926:2007, różnią się wartością deklarowaną i w wielu przypadkach znacznie odbiegają od najczęściej stosowanej wartości średniej wytrzymałości na ściskanie. Analizie poddano wyniki badań wytrzymałości na ściskanie, przeprowadzonej zgodnie z normą PN-EN 1926:2007, dla próbek piaskowców, granitów i wapieni. Badania wykonano dla ww. skał w stanie powietrzno-suchym, po nasyceniu i po badaniu mrozoodporności. Średnio dla wszystkich rodzajów skał, wartość oczekiwana niższa w stosunku do wartości średniej wytrzymałości na ściskanie, była niższa: w stanie powietrzno-suchym o 25%, w stanie po nasyceniu o 29%, a po badaniu mrozoodporności o 37%. Ponadto wartość oczekiwana niższa w większości analizowanych przypadków nie przekroczyła wartości minimalnej wytrzymałości na ściskanie. Wartość znormalizowana obliczona z wartości średniej wytrzymałości na ściskanie w stanie powietrzno-suchym była o około 15% niższa od średniej. Natomiast wartość znormalizowana obliczona dla próbek badanych w stanie po nasyceniu była niższa od 10% do 25% w zależności od rodzaju skały i była prawie identyczne jak odporność na zniszczenie dla kamienia do robót hydrotechnicznych. Przeprowadzono analiza wymaganych przez normy przedmiotowe wartości wytrzymałości na ściskanie materiałów kamiennych dla celów budowlanych wskazuje jak ważne jest obliczenie normowego parametru. Wykazano, że wartości normowych parametrów w znaczący sposób różnią sią od najczęściej stosowanych wartości średnich. Ponadto materiały kamienne często charakteryzują się wysoką zmiennością właściwości, nawet w obrębie jednego pola eksploatacyjnego, co skutkuje szczególnie obniżeniem wartości oczekiwanej niższej.

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