

# New Methodology for Rocks' Geomechanical Characterization with Schmidt Sclerometer



Victor Cavaleiro , Leonardo Marchiori , Maria Vitoria Morais , Gabriel Marchi , and Marcela Cocchiarale

**Abstract** Hardness is a parameter that gives information about the behavior of rocks when subjected to certain deformations. Various non-destructive tests are available for hardness quantification, the use of the Schmidt Sclerometer is the most used due its expedition, among existing sclerometers, the Schmidt rebound hammer, type N-34, with an impact energy equal to 2,207 N.m (0.225 Kgm) was selected for experimental tests. Schmidt's hardness index (R) obtained were related to other physical parameters of the rock, namely uniaxial compressive strength (UCS), elasticity modulus (E), specific gravity and granularity. For comparison purpose, several literature's methodologies are present focused on improving procedures and developing correlations for different rock types. In this sense, to assess the methodology that best suits granitic rocks' characterization, several laboratorial and "in situ" tests from the literature were performed. Additionally, the paper proposes a new methodology based on the analysis of the results and a good relation between R and UCS parameters, concluding reliability on the methodology for values of non-porphyroid granitic rocks, predominantly biotitic and from medium to fine granularity, in a precise and consistent way.

**Keywords** Schmidt sclerometer · Rock's hardness · Rock's characterization · Methodology

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## 1 Introduction

Hardness has proved to be an important parameter in rock massif's characterization for most applications [1]. This work aims to propose a new methodology based on hardness ratio of Schmidt (R) intending to reduce inaccuracies and making correlations with uniaxial compressive strength (UCS).

The Schmidt hardness of a given material is obtained by measuring the rebound of a mass of steel, which happens when the hammer is struck against a surface. The piston that is incorporated in the Sclerometer, which is attached to a load spring, is automatically released from its chamber. Thus, a part of the piston's energy is dissipated by absorption and transformed, the remaining energy is the one which returns the penetration impact resistance of a given structural surface [2]. In this way, the lower the energy released, the greater the resistance of the rocky surface, and, in turn, time, the greater the piston bounce. The Schmidt hardness is represented by the value of R. This value can be related to the uniaxial compressive strength ( $\sigma_c$ ) of the constituent rock of the surface tested or with its elasticity modulus ( $E_t$ ), according to the value of its specific weight [2, 3]. However, the evaluation of rock hardness through the Schmidt hardness index is influenced by several factors, such as the type of Schmidt sclerometer used, the procedure adopted for the test, and the specifications of the sample [4]. This fact has led to the publication of several works where different methodologies are presented focused on improving procedures for collecting data, and development of new correlations for different rock types. In this sense, to assess the most appropriate methodology to obtain hardness of granite rocks for ornamental purposes, several tests were carried out according to methodologies presented in the literature.

## 2 Materials and Methods

Three types of Portuguese's fine-to-medium-grained non-porphyroid granites with different degrees of alteration were considered: the fine-grained "Golden Yellow" granites from Figueira (FIG), the "Blue-Grey" granites from Ruvina (RUV), and the "Medium Grain" from Rochoso (ROC) granite. These granites are from Guarda region, chosen based on more than a hundred tests carried out by the working group, making a representative number for the region. "In situ" tests followed methodologies from Table 3, and laboratorial R used the new methodology proposed by this work, also, UCS were obtained with hydraulic press Seidner D-1740 Reidlingen.

For laboratorial R tests, 10 representative samples of each type of granite were collected from the same sites selected for the in-situ tests for results' validation, by the proposed methodology. The samples were prepared in specimens with dimensions of 150 × 150 mm. A square with dimensions of 120 × 120 mm was drawn in the central part of the specimen with a mesh of 20 × 20 mm, as shown in Fig. 1, and seven impacts were randomly distributed in this mesh, with the specimens confined in the



**Fig. 1** Laboratorial specimens

hydraulic press. From the readings obtained, the smallest value and the maximum value are eliminated, and the final admissible value of  $R$  is the average of the five readings with a standard deviation ( $\sigma_R$ ) value never greater than three (3). The result is a dimensionless number that is considered as the hardness index of the tested material that varies in a linear scale from 10 to 100.

It is important to emphasize that the calibrated Schmidt Sclerometer must always be placed perpendicular to the tested surface, avoiding variations in the readings, values acquired in directions other than the horizontal are subject to gravitational action and should be normalized using to the correction curves provided by the manufacturer. Petrographically, these granites are non-porphyroids of two micas, predominantly biotitic, make part of the great granitic batholith of Beira region. These are monzonitic granites, with great uniformity in terms of chemical and textural composition, exposed in Table 1.

Table 2 summarizes essential physical parameters for the analyzed rocks, RUV and ROC materials being very similar to each other, and FIG differing, having lower specific gravity, and higher water absorption and open porosity. The “Golden Yellow” granite from FIG is a homogeneously textured and fine-grained rock, the average

**Table 1** Chemical composition

Granite	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O
FIG	71.03	0.23	14.55	2.35	–	0.46	0.63	3.33	5.46
RUV	72.52	0.43	14.76	1.82	0.03	0.032	1.09	3.51	4.82
ROC	73.10	0.15	14.41	1.53	0.04	0.28	0.59	2.99	5.27

**Table 2** Physical characteristics

Granite	Specific gravity (-)	Water absorption (%)	Open porosity (%)
FIG	2.55	1.74	4.41
RUV	2.60	0.68	1.78
ROC	2.61	0.55	1.44

value of open porosity (4.40%) confirms its greater degree of alteration compared to the other granites. And Table 3 summarizes literature's methodologies.

According to Aydin [4] the Type N hammer is less sensitive to uneven surfaces and should preferably be used in applications in field. From Table 3, it is seen that the number of readings performed in each method varies substantially. If on the one hand Deere and Miller [6] and Ege et al. [7] suggest the execution of 24 and 25 readings, Hucka [5] and Poole and Farmer [13] observed that the R values obtained by repeated readings (ten and five impacts respectively) at individual points are more consistent than the values of one individual impact, and, Shorey et al. [14] defends the realization of a single impact because seems to be more reliable for estimating uniaxial compression.

**Table 3** Schmidt sclerometer methodologies

Authors	Methodologies for R determination
[5]	Performance of 10 tests, considering as R the highest value
[6]	Execution of at least 24 tests, considering R as the average value
[7]	Execution of 25 tests, where R is the average of the 13 readings that record higher values
[8]	Run 25 tests, where R is the average of the values
[9]	Execution of 15 tests in locations not more than 25 mm and takes the value of R as the average of the 10 highest results, since that the maximum deviation does not exceed 2.5
[10]	Carry out 10 tests, on a surface of at least 100 cm <sup>2</sup> and obtaining R as the average of all readings, after eliminating the tests whose results deviate $\pm 5$ from the mean
[11]	Carry out 20 tests, in places with a distance equal to or greater than the diameter of the Schmidt sclerometer, R is determined by averaging 50% of the trials recorded with higher values
[11]	R is obtained by calculating the average of 5 trials that recorded higher values raised for a total of 10
[12]	Performance of 8 tests, with R being the average value
[13]	R is the maximum value assigned during the performance of 5 tests
[14]	Advocates obtaining R from the execution of a single test
[15]	R is obtained by averaging the results recorded in 5 trials

### 3 Results and Discussion

A linear relation was developed between R and UCS parameters in Eq. (1) following Table 4 author's experimental tests results.

$$\sigma_c = 20.91 + 0.33 * R \quad (1)$$

Figure 2 correlates the average of other methodologies applied in situ following Table 3 methodologies; and laboratorial values of R, using author's methodology, for 10 tests performed for FIG, RUV and ROC granites. And Fig. 3 shows laboratorial R values with UCS.

When analyzing the results, it appears that the granite FIG has R lower than the other granites, this one also presenting a higher standard deviation, these values may be related to the greater degree of alteration presented by these granites due to its open porosity of 4.1%, this physical property is linked to the existence of networks of interconnected cracks and pores. Open porosity affects the strength and mechanical characteristics, and it is inversely proportional to the strength mechanics, specific density, and porosity, resulting in void areas, increasing weakness.

Comparing the values of R obtained by the different methods, it seems that there is a slight inconsistency in results, this fact is to be expected considering the specificities of each method and in particular the number of readings considered. It is verified,

**Table 4** Schmidt sclerometer results

Methodologies for R determination	FIG		RUV		ROC	
	R	$\sigma_R$	R	$\sigma_R$	R	$\sigma_R$
[5]	44.0	–	54.0	–	65.0	–
[6]	33.3	6.3	47.5	4.5	65.5	3.7
[7]	40.1	6.1	50.6	3.8	62.2	2.9
[8]	35.2	6.5	46.8	4.3	59.4	2.9
[9]	38.7	6.3	50.5	4.8	62.2	3.4
[10]	31.3	6.5	45.5	4.8	57.8	2.1
[11]	38.4	5.9	52.6	4.4	63.4	3.2
[11]	39.2	5.6	50.8	4.7	62.4	2.6
[12]	32.5	5.2	47.4	3.5	59.6	3.7
[13]	32.7	3.9	50.3	5.4	63.3	3.3
[13]	38.0	3.5	51.0	2.7	58.2	2.6
[14]	29.0	–	46.0	–	60.0	–
[15]	31.6	4.9	46.8	5.4	61.8	2.8
Author's	35.6	2.9	49.2	2.8	61.2	2.6
UCS,med (MPa)	52.9		96.4		1339	
$\sigma_c$ (MPa)	7.5		2.5		1.0	

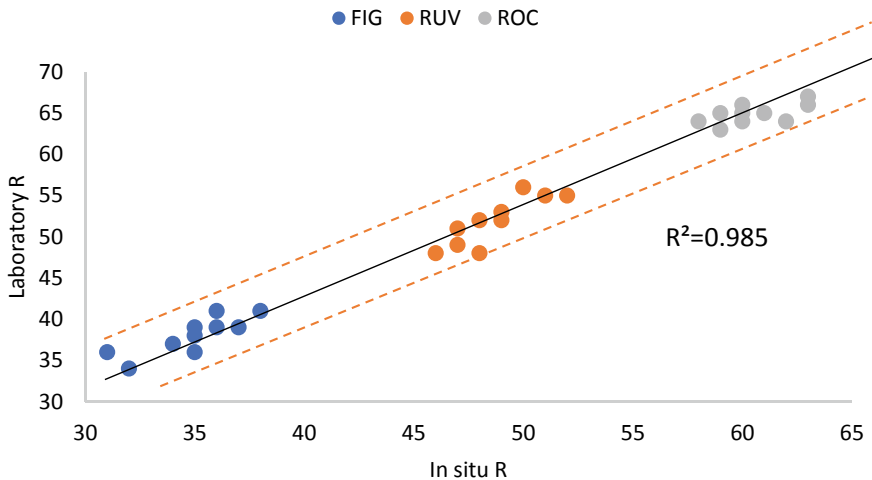


Fig. 2 In situ and laboratorial R values correlation

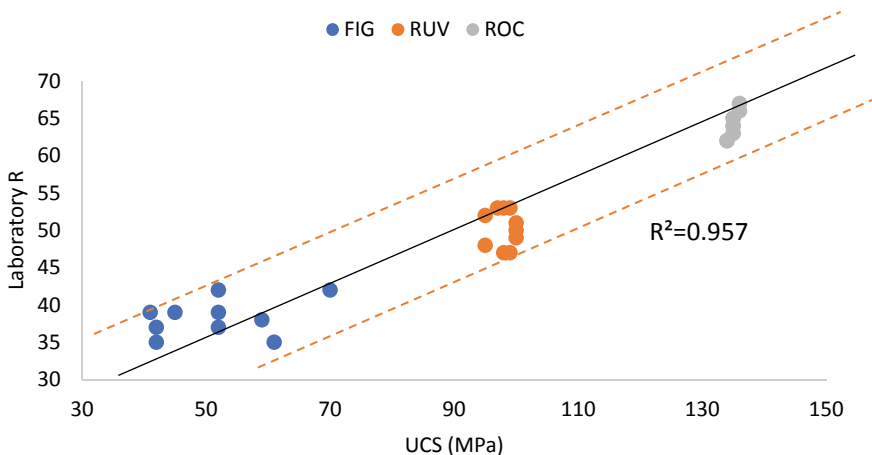


Fig. 3 UCS and laboratorial R correlation

however, that the value of R obtained by method proposed here is very close to the average of the values of R obtained by all the methods rehearsed, and that in general it has a smaller standard deviation.

To minimize reading errors caused by microfractures or other discontinuities near the points of impact on the rock mass, and to test the validity of the values obtained in situ by the proposed methodology, 10 tests were performed with the Schmidt Sclerometer according to the proposed methodology in 10 different specimens for each type of granite. Subsequently and since the Schmidt hammer is a non-destructive method, the same methods were used to the same samples to determine the values of

uniaxial compression, and thus, establish a direct relationship with Schmidt hardness values. All results were treated statistically, to understand if this method can be considered valid for the determination of hardness in granites, in such a way that it is a value representative of the resistance in question.

From the analysis of the graph in Fig. 3, for a confidence interval of 95%, it appears that the coefficient of determination between the variables tested is  $R^2 = 0.957$ , so it is evident that there is a strong relationship, indicating a good degree of precision in the use of this equation to determine the compression value uniaxial from the Schmidt hardness value. Comparing the values of R obtained in situ and in the laboratory, for the method proposed here, it appears that the values obtained in the laboratory are higher. This situation was to be expected since in situ tests, for most cases, the average of the R values decreases and the degree of dispersion between the R value increases [15]. As for the uniaxial compression values, it appears that granites with a higher degree of alteration have a lower  $\sigma_c$  value, this fact had also been described by [16]. These were related to the R values obtained in the laboratory.

## 4 Conclusions

1. The proposed methodology is presented:
2. A smooth, flat, and clean surface with an area of 15 cm<sup>2</sup> of the rock is selected and prepared. It is verified that this area is free from cracks or any discontinuity in the rock mass, to a depth of about 6 cm. In cases where this is not the case, another area is chosen to be not influenced by these conditions.
3. Seven (7) impacts are carried out with a calibrated Schmidt type N-34 rebound hammer, with an impact energy equal to 2,207 N.m, randomly distributed on the surface of the selected area.
4. From these 7 readings, the smallest value and the maximum value are eliminated, with the final R value being the average of the remaining five readings, with a standard deviation value never greater than three.

The result is a dimensionless number that is considered as the hardness index of the tested material that varies in a linear scale from 10 to 100. Schmidt hardness values obtained in situ are closer to the average of the values obtained comparing to other methodologies; R values from Table 1 obtained in situ and in the laboratory showed good correlation ( $R^2 = 0.985$ ), for a confidence interval of 95%, and R values, in general, had a smaller dispersion in relation to the mean, with a standard deviation of less than 3; Schmidt hardness index, in addition to providing information about the surface hardness of the rock, provides a good correlation with the UCS ( $R^2 = 0.957$ ).

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