Weathering influence on physical properties of the Guarda granite, Portugal

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WEATHERING INFLUENCE ON PHYSICAL PROPERTIES OF THE GUARDA GRANITE, PORTUGAL

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ABSTRACT

The research developed aimed to quantify and understand the evolution of the physical properties of the Guarda granite, Portugal, related with weathering. Samples were collected in selected outcrops representative of the different weathering grades, and when necessary were prepared in the laboratory to be tested with nondestructive techniques. The grades of weathering were defined considering the macro and microscopic observations of the samples combined with the properties measured. It was found that porosity and water absorption tend to increase with increasing weathering, while a reduction in ultrasound velocity occurs. Moreover, it was found that the density of the rock showed no major changes during the weathering sequence, not allowing an easy differentiation of the weathering grades. This is due to the type of weathering imposed on these granites that are essentially of physical nature, without significant variations in the density of the rock. The analysis of the type of porosity was very important in understanding the geometric characteristics of the pore space. Being the granite a material of low porosity, small variations of the property lead to large variations in the behavior of the material. As the increase of porosity in granites indicates major changes, it can be used for a first assessment of rock characteristics. Good correlations were obtained between ultrasound velocity and other parameters like: dry density, porosity, water absorption by capillarity and permeability to oxygen. It was concluded that the texture and the average grain size are important factors to consider in the water absorption by capillary. The relations obtained allow a fast characterization of this granite along its weathering profile.

Keywords: Granite, weathering, physical properties, Portugal

INTRODUCTION

Civil engineering works are mainly developed on the surface of the ground or at shallow depths, where rock masses are most weathered. It is therefore important to characterize the influence of weathering on the properties of rock materials to better understand the behavior of the rock material and the rock mass.

This paper deals with the assessment of the physical properties modifications of the in the Guarda granite, in Portugal. The granite outcrops with varying grades of weathering, since sound granite to the completely decomposed granite.

GEOLOGICAL SETTING

The Guarda granite is a monzonitic granite, two-mica with large predominance of biotite [1]. The rock is is leucomesocratic with large crystals of feldspar and usually coarse grained. Essential elements are quartz, oligoclase, microcline, albite, muscovite and biotite. Accessory minerals include apatite, zircon and magnetite. The most abundant secondary minerals are kaolinite, sericite and chlorite. The percentages of these minerals vary considerably depending on the degree of weathering presented by the rock [2]. The granite texture is very coarse-grained to coarse porphyry (average matrix grain size of 7 mm) and the feldspar mega crystals with average size between 45 and 70 mm.

WORK METHODOLOGY

Several borehole campaigns were carried out to obtain representative samples of different weathering grades. As the granite is coarse-grained porphyry granite, samplers with 80 and 100 mm diameter were used, seeking obtaining cylindrical specimens with a height/diameter equal to or greater than 2, according to the ISRM [3] and IAEG [4] recommendations. With regard to testing the more weathered rock materials, prismatic specimens were also used, obtained by cutting blocks with a diamond saw, keeping the height/width ratio of 2. The physical characterization tests were performed on samples where the mechanical characterization tests would subsequently be executed but that will not be addressed in the present work, as only the physical tests results will be reported and discussed. The classification of the weathering grades was done based on the physic-chemical, mineralogical (macroscopic) and on the visual observation of the specimen [2, 5, 6].

The measurement of the unit weight, porosity, saturation water content and density followed the procedure No. 3 of the ISRM [3]. The free porosity after 48 hours of submersion (n_{48}) was determined using the procedure described by Begonha [7]. This freely accessible to water porosity is a parameter widely used in the case of masonry construction of monuments and buildings in general. It is directly related to the free movement of fluid at atmospheric pressure inside the stone, being important in the weathering of these rocky materials, as it can easily transport fluid with aggressive characteristics to the interior of the rock. Based on the free porosity the Hirschwald coefficient (S_{48}) was determined given by the ratio between n_{48} and the porosity, to quantify the percentage of void volume that is freely filled by water. Table 1 shows the values obtained for the Guarda granite with different grades of weathering.

Since the ultrasound velocity is an important physical parameter to characterize the rock material [8, 9] its determination over the weathering sequence, either in dry samples or after saturation in vacuum was always made for compression waves. In some cases shear waves were also determined. The purpose was to estimate the fissuration of the rock material based on its fissuration index (FI) and to determine the quality index (QI) which together with the porosity (n) allows to quantify the type of porosity (pore or fissure) of a rock [10]. It should be noted that the determination of these velocities in the most weathered rock samples presented some difficulty due to the rough surfaces with many voids, which hampered the contact between the sample and the transducers. In the most affected materials all the voids in the contact surface between the rock and the transducers were properly filed. As can be seen in Table 2 the increase in the grade of weathering correspond to a decrease of the ultrasound velocity of either dry or saturated samples. The ratio between the velocity of longitudinal waves in the dry and saturated samples is quite constant (Fig. 1) ranging between 0.79 and 0.86. This ratio is considered as an index of the fissuration intensity [11], and as it is always greater than 0.6 thereby indicating low average contribution of micro fissures for the total porosity of the rock.

Table 1 - Physical properties of the Guarda granite.

Weathering Grade		n (%)	n_{48} (%)	W_{max} (%)	S_{48} (%)	γ_{dry} (kN/m^3)	γ_{sat} (kN/m^3)	γ (kN/m^3)	G
W1	Average	0.80	0.37	0.30	51.09	25.71	25.79	25.92	2.64
	Range	0.52-1.03	0.12-0.72	0.20-0.40		25.2-25.9	25.3-26.0	25.4-26.1	2.59-2.66
	N	10	4	10		10	10	10	10
W2	Average	1.91	1.03	0.74	43.33	25.68	25.86	26.18	2.67
	Range	0.96-4.26	0.41-3.36	0.36-1.67		24.9-25.9	25.3-26.0	26.0-26.3	2.65-2.68
	N	10	10	10		10	10	10	10
W3	Average	5.67	4.90	2.27	85.69	24.5	25.07	25.97	2.65
	Range	4.14-6.99	3.37-6.85	1.63-2.83		23.6-24.9	24.3-25.4	25.2-26.2	2.57-2.67
	N	22	15	22		22	22	22	22
W4	Average	10.03	8.59	4.29	88.24	23.01	23.99	25.58	2.61
	Range	7.34-14.02	5.70-9.90	2.99-6.17		22.3-24.2	23.5-24.9	25.1-26.2	2.56-2.67
	N	13	7	13		13	13	13	13

N - number of tested specimens; n - porosity; n_{48} - free porosity; W_{max}.- maximum absorption of water content; γ_d - dry unit weight; γ_{sat} - saturated unit weight; γ - real unit weight; G - density.

Table 2 - Average ultrasound velocity in the Guarda granite.

Weathering Grade	V_L (m/s) Dry	V_L (m/s) Saturated	V_S (m/s) Dry
W1	3193 (7)	4062 (7)	2642 (1)
W2	2632 (10)	3564 (10)	1288 (1)
W3	1408 (16)	1736 (15)	479 (1)
W4	980 (11)	1107 (7)	---

V_L – Longitudinal waves; V_S – Shear waves; (7) – Number of tested samples; --- – No data.

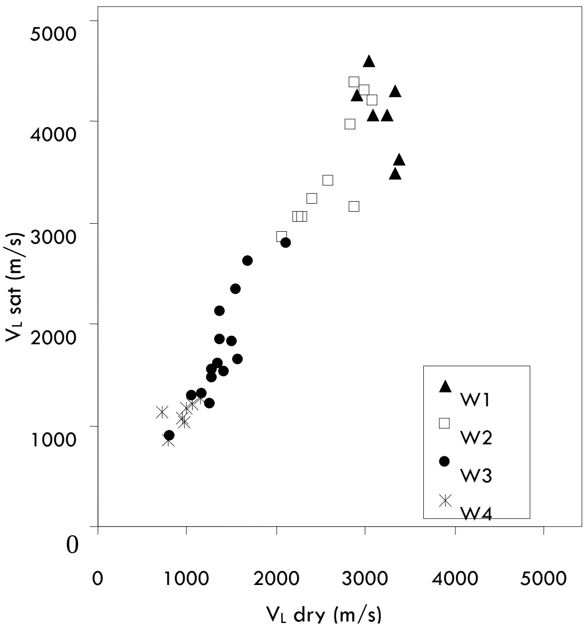

Fig. 1 - Ultrasound velocities for longitudinal waves in dry versus saturated samples with weathering.

The fissuration was determined in an indirect way through the quality index (QI) and the fissuration index (FI) [10]. It was intended to evaluate the contribution of the pore porosity and of the fissure porosity in total porosity along the alteration sequence of the Guarda granite, using the following equations.

$$QI = \frac{V_{Ldry}}{V_{Lc}} \times 100 \qquad (1)$$

$$FI = \sqrt{\frac{(V_{Lc} - V_{Lsat})^2 + (V_{Lc} - V_{Ldry})^2}{(V_{Lc} - 1500)^2 + (V_{Lc} - 340)^2}} \times 100 \qquad (2)$$

where:
V_{Lc} - theoretical velocity of longitudinal waves (m/s);
V_{Ldry} - velocity of longitudinal waves in dry samples (m/s);
V_{Lsat} - velocity of longitudinal waves in saturated samples (m/s);
1500 and 340 - velocity of longitudinal waves in water and in air (m/s).

To obtain the theoretical velocity of longitudinal waves it was used the work of Aleksandrov et al. [12] that allows to compute the velocities in ideal rocks free of voids. For the granite those authors computed a velocity of 6000 m/s for the longitudinal waves and 3600 m/s for the shear waves. Based on these figures the quality index (QI) and the fissuration index (FI) were computed using equations (1) and (2), and the results are summarized in Table 3. It was also calculated the IQ_w (quality index in saturated specimens) replacing in equation (1) V_{Ldry} by V_{Lsat}.

Table 3. Values QI, QI_W and FI along the weathering sequence.

Weathering grade	**Nº of tested samples**	**n (%)**	**QI (%)**	**QIw (%)**	**FI (%)**
W1	10	0.8	53.2	67.7	47.5
W2	10	1.91	43.9	59.4	57.7
W3	22	5.67	23.3	28.9	86.8
W4	13	10.03	16.2	18.4	97.2

n - porosity; QI - Quality index; QI_w - Quality index in saturated specimens; FI - Fissuration Index.

These values were then introduced in the abacus developed by Tourenq et al. [10] for the determination and quantification of the pore porosity (np) and of the fissure porosity (nf), considering the graphic decomposition based on the porosity and on the quality index (QI) as illustrated in Fig. 2.

As can be concluded from Fig. 2 and Fig. 3, as porosity increases there is an increased contribution of the pores (np) for total porosity, while the fissure porosity (nf) remains substantially constant between 1 and 1.5%. Moreover, in fresh rock (W1) the porosity corresponds exclusively to fissure porosity. If we analyze the values of the quality indexes QI and QIw, presented in Table 3, we find that the difference between them is higher in the less weathered rock samples (W1 and W2) reaching a difference around 15%. In the more weathered samples (W3 and W4), the percentage of fissure porosity relative to the pore porosity drastically decreases, making the difference between QIw and QI very small, around 2 to 5%. By analyzing a number of Portuguese granites, Quinta Ferreira [13] also stated that in low-porosity granite rocks, the initial contribution of the fissures is important, but as weathering increases greatly increases the contribution of the pores to total porosity.

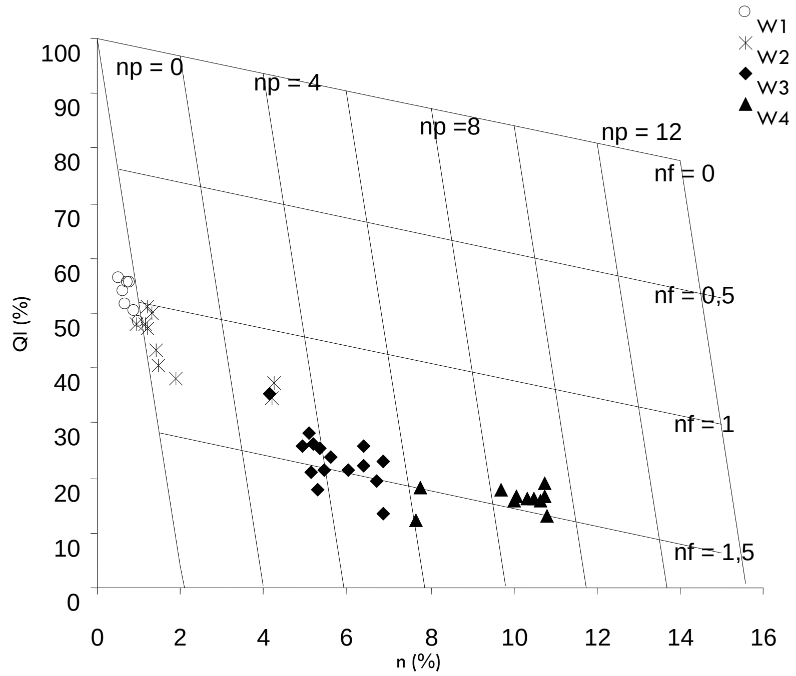

Fig. 2 - Abacus for determining the pore porosity (np) and the fissure porosity (nf) for samples with different weathering grade.

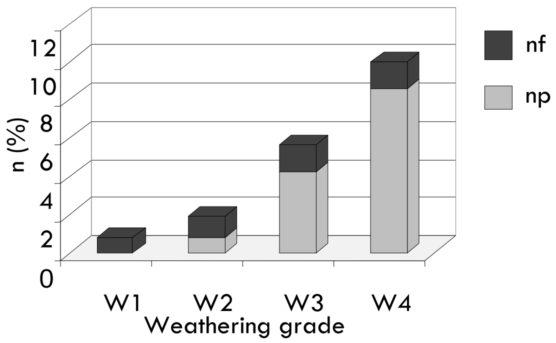

Fig. 3. Relationship between the pore porosity (np) and fissure porosity (nf) related with weathering. n - porosity.

The measurement of the permeability of a rock implies the existence of an interconnected network of voids enabling the circulation of a fluid. In the present study the permeability was determined according to the procedure described in Castro Gomes et al. [14], and it was used oxygen as percolating fluid. The samples used in the permeability tests were cored with a diamond drill to obtain samples with the dimensions of the test cells. It was also determined the capillary absorption of water, following the NP EN 1925:2000 test procedure (Natural stone test methods. Determination of water absorption coefficient by capillarity), having determined parameter C1 (in grams per square meter by square root of time in seconds). For each sample four cubes with 5 cm edge were used. The values obtained are presented in Table 4.

Table 4 – Results of oxygen permeability tests and of capillary water absorption.

Weathering grade	**Nº of tested samples**	**n (%)**	**K x 10^{-15} (m^2)**	**C_1 ($g/m^2.s^{0.5}$)**
W1	3	0.77	0.026	1.67
W2	3	1.33	0.085	2.80
W3	3	5.64	12.31	24.16
W4	2	9.24	---	26.88

n - average porosity; K - oxygen permeability; C_1 - water absorption by capillary; --- - No data.

The data from Table 4 shows that there is a positive relationship between porosity, water absorption by capillarity and permeability to oxygen. Indeed, samples with larger pores have larger values of C_1 and K.

DISCUSSION OF RESULTS

With regard to the physical properties of the Guarda granite, it was tried to evaluate whether there was any reliable relationships between the parameters measured, so that another parameter could be inferred with reasonable confidence without the need to do more tests. The correlation coefficients obtained for the parameters analysed and considered statistically significant ($r \geq |0.80|$) are presented in Table 5.

Table 5 - Correlation coefficients between the physical indexes.

	V_{Ldry} (m/s)	**V_{Lsat} (m/s)**	**n_{48} (%)**	**n (%)**	**γ_d (kN/m^3)**
G	+ 0.62	+ 0.59	- 0.67	-0.57	+ 0.75
γ_d (kN/m^3)	+ 0.90	+ 0.89	- 0.98	- 0.97	
n (%)	- 0.97	- 0.92	+ 0.98		- 0.97
C_1 (g/m^2 x $s^{0.5}$)	- 0.83	- 0.86	+ 0.89	+ 0.96	- 0.86
K (m^2)	- 0.94	- 0.90	+ 0.88	+ 0.88	- 0.82

n - porosity; n_{48} - free porosity at 48 hours; V_{Lsat} - velocity of longitudinal waves in saturated samples; V_{Ldry} - velocity longitudinal waves in dried samples; G - density; γ_{dry} – dry unit weight; K - oxygen permeability; C_1 - water absorption by capillary action.

Generally good correlations were obtained (table 6), confirming the results obtained by other authors. The correlations between density and all other physical parameters and indices are weak, with correlation coefficients less than |0.80| possibly due to the fact that in these granites, the weathering is essentially of physical origin without promoting the decomposition of the minerals, and without a decrease in the density of the rock (see Table 1).

As the weathering of physical origin is predominant in relation to chemical weathering, the porosity plays an important role in the control of other rock properties and indexes. The correlations obtained between C_1 and the porosity (n) and between the oxygen permeability (K) and porosity are both positive. The correlation between the velocity of ultrasound in dry and saturated samples and C_1 is negative. For a few correlations the low number of samples tested does not validate the correlations unequivocally. Indeed, in some cases it was not possible to carry out the tests in the whole weathering range of the rock. However several authors have observed better correlations of the same type between these parameters for a larger number of data. Begonha [7] reported good correlations for Porto Granite, between C1 and porosity, and between the ultrasound velocity and C_1.

Table 6 - Relations between the physical indexes of Guarda granite.

Obtained relationships	r	N	Comments
$\gamma_d = 2.166 \ln(V_{Ldry}) + 8.53$	+ 0.90	43	All weathering grades
$\gamma_d = 1.740 \ln(V_{Lsat}) + 11.39$	+ 0.89	39	All weathering grades
$\gamma_d = -0.345\, n_{48} + 26.07$	- 0.98	35	All weathering grades
$\gamma_d = -0.301\, n + 26.13$	- 0.97	55	All weathering grades
$n = 26.53\, e^{-0.0011\, VLdry}$	- 0.97	43	All weathering grades
$n = 19.15\, e^{-0.0007\, VLsat}$	- 0.92	39	All weathering grades
$n = 1.023\, n_{48} + 0.751$	+ 0.99	35	All weathering grades
$C_1 = 84.91\, e^{-0.0012\ VLdry}$	- 0.96	7	Small number of samples
$C_1 = 90.77\, e^{-0.001\ VLsat}$	- 0.95	6	Small number of samples
$C_1 = 2.18\, n^{1.21}$	+ 0.98	8	Small number of samples
$\text{Log } K = 6E + 22(V_{Ldry})^{-6.98}$	- 0.93	8	Small number of samples
$\text{Log } K = 3E + 48e^{-4.43}\, \gamma_d$	- 0.94	8	Small number of samples
$K = 0.042\, n^{2.86}$	+0.88	8	Weathering grades W1, W2 and W3

N - number of tested samples; r - correlation coefficient.

The values of ratio V_{Ldry}/V_{Lsat} and the differences between QIw and QI in the different weathering grades allow to conclude that the fissure porosity is initially dominant representing over 65% of the voids volume, lowering its proportion in the higher grades of weathering with less than 27% of the voids in the most weathered specimens (W3 and W4 grades).

FINAL REMARKS

The results obtained illustrate that the weathering of the Guarda granite led to an increased in porosity, affecting most of its physical properties. The ultrasound velocity from sound rock (W1) to very weathered rock (W4) decreased about 60%, and as this parameter is easy to determine and non-destructive, without requiring great preparation of samples, it may be used as a good indicator of the weathering of granitic rocks.

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