Determination of tensile strength of rocks by CTC (compression-tensile load converter test)

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ABSTRACT: In order to obtain the direct tensile strength of the rocks by means of a device that is inexpensive and easy to use in a rock mechanics laboratory, a compression load converter was designed and manufactured in the PUC-Rio laboratory. This apparatus was named as a compression-tensile load converter (CTC), and was developed by Klanphumusri (2010). The equipment design allows the user to switch between tensile stress and compression applications on the same specimen during placement in the conventional compression machine. The apparatus was designed to test dog bone or halter rock samples with end diameter ranging from 75 to 100 mm. Seven specimens of syenogranites from Cachoeiro de Itapemirim, ES - Brazil were tested for equipment validation and the results were compared to those obtained in fifteen Brazilian tests. The direct tensile strength using the CTC showed consistent results, with lower strength than those obtained by the indirect method.

Keywords: Direct tensile test; Tensile strength of rocks; Load converter, Geomechanical Properties.

1 INTRODUCTION

Obtaining the tensile strength of rocks in a precise and representative way has always attracted the interest of the scientific community. However, its determination has been compromised, as the direct tensile test, frequently performed in materials such as concrete, has seldom been used in rocks, due to the difficulty in preparing samples and the sensitivity of this type of tests related to eventual problems in their execution. As a result, indirect methods have been widely used as faster and more affordable alternatives to determine the tensile strength of rocks.

However, despite being practiced all over the world, the scientific community does not ignore the deficiencies involving indirect tests, especially the most widespread among them, the Brazilian test. The present study, based on the results by Baêsso (2021), explores a particular technique for the determination of the tensile strength of rocks using a direct test. This test is carried out using a compression-tensile load converter (CTC) similar to the one created by Klanphumeesri (2010). The equipment was reproduced, after modifications, with the aim of determining, through an experimental campaign, the direct tensile strength of syenogranites. In parallel, a numerical analysis was developed in order to define possible geometries for the test specimens.

2 THE STUDY AREA CHARACTERISTICS

The quarry from which rock samples were collected is located in the vicinity of Cachoeiro do Itapemirim, Espírito Santo State, in Southeastern Brazil. To the west of this region there is a domain of high topography corresponding to an area of predominance of granitoid and gneissic rocks with the occurrence of sound rock pontoons that evolved through processes of differential erosion and concentric displacement. The Santa Angélica Intrusive Suite, the unit in which rock samples were collected, is located in this west area.

The rock samples, defined as syenogranites by Jaques et al. (2020), were obtained from the quarry with degrees of weathering W1 and W1/W2. Some micro cracks are present, which is to be expected for samples from quarries, where uncontrolled blasting is common, in addition to the physical weathering attack, which occurs naturally.

3 DIRECT TENSILE STRENGTH TESTS USING A LOAD CONVERTER

A number of experimental schemes are available for the determination of the tensile strength of rocks using direct methods (Luong, 1988) including the conventional direct test carried out in cylindrical samples (ASTM D2936-08). It is known however that these tests are difficult to carry on due to experimental problems, such as sample alignment amongst others. The necessity of an apparatus that was durable, low-cost, and easy to use in a conventional rock mechanics laboratory, led Klanphumeesri (2010) to develop a load converter to be used in commercially existing compression loading machines, commonly available on most rock mechanics laboratories. The device was named compression to tension load converter (CTC).

The apparatus can be used to measure elastic rock parameters under uniaxial tension and compression of the same specimen. The test apparatus transforms compression loads on tensile loads by applying tensile loads to opposite ends of the rock specimen and thereby submitting the specimen midsection to direct uniaxial tensile stress.

The characteristics of the developed equipment satisfy the suggestions established in ISRM (1978) to characterize direct tensile strength. The equipment consists of two sets of end plates and backing plates made of stainless steel. These plates (270 × 110 × 27 mm) are connected by means of two steel columns 25 mm in diameter and 280 mm of length. Figure 1 shows the device prepared for tensile loading.

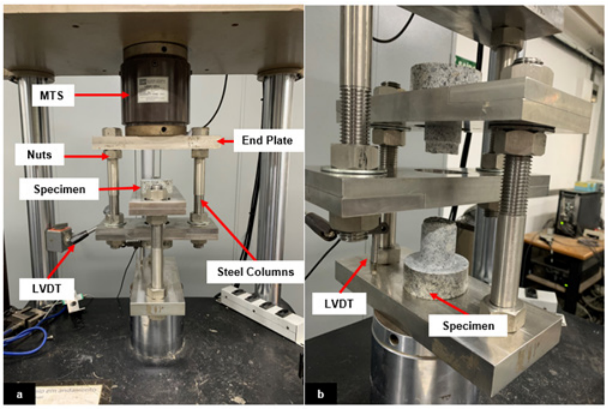

Figure 1. a) CTC equipment showing the specimen positioned in a MTS 810 compression machine. b) CTC equipment showing the specimen after failure.

4 NUMERICAL ANALYSIS OF THE STRESS DISTRIBUTION IN SPECIMENS

A finite element analysis using software Abaqus (Abaqus, 2014) was carried out in order to evaluate possible geometries for specimens. Two geometries were considered in the study, one in the form of a dog bone and another in the form of a halter as shown in Figure 2 and Figure 3. Klanphumeesri (2010) used a dog bone geometry in his tests, but the halter shape specimen is considered here for being easier to be manufactured using conventional sample preparation equipment (lathes for example), normally encountered in university and commercial rock mechanics laboratories. The numerical study focused on the determination of tensile stresses in the central part of the specimens and an optimization of the proposed geometry for the halter shape specimens. The experimental work only used halter shaped specimens.

The CTC apparatus / sample dimensions used in the present study had similar dimensions when compared to the one used by Klanphumeesri (2010). However, the latter used sample diameters of 100mm, while the present work attempted to use smaller, with 75mm diameter. The reason for this was the obvious difficulty in producing larger diameter samples.

The numerical analyses were carried out considering axisymmetric conditions, assuming that the rock is isotropic and presents a linear elastic behavior. Modulus of elasticity (E) and Poisson's coefficient (ν) of 55.3 GPa and 0.3, respectively, were assumed. Figure 4 to Figure 7 show the distribution of tensile and shear stresses in the specimen.

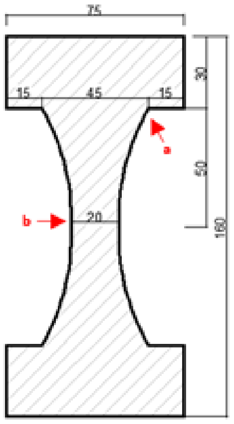

Figure 2. Dimensions (in mm) of dog bone geometry.

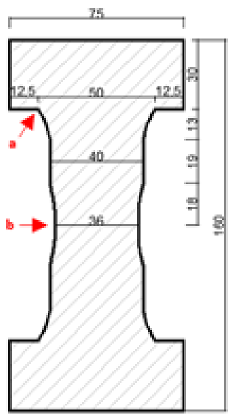

Figure 3. Dimensions (in mm) of the halter geometry.

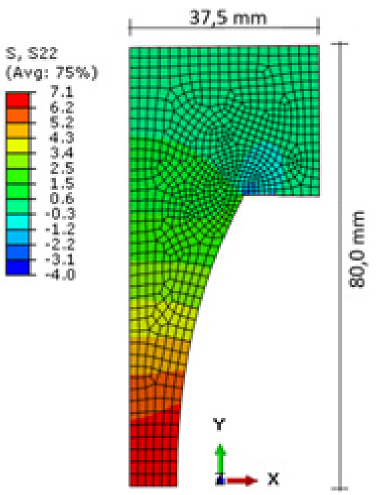

Figure 4. Tensile stress distribution (MPa) for the dog bone geometry.

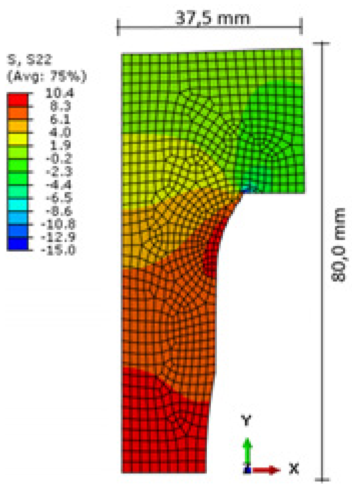

Figure 5. Tensile Stress Distribution (MPa) for the halter shaped geometry.

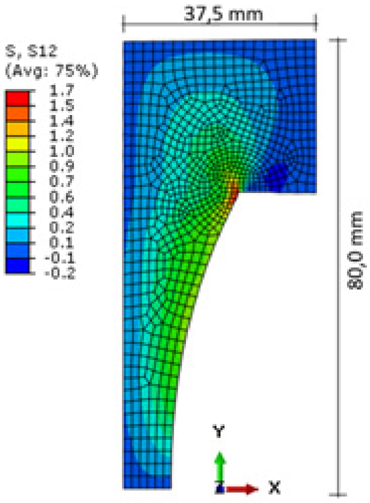

Figure 6. Shear stress distribution (MPa) – Dog bone geometry.

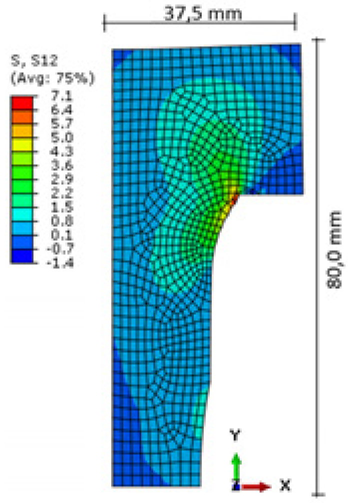

Figure 7. Shear stress distribution (MPa) – Halter geometry.

The results show that both specimens present uniform distribution of tensile stresses in their central portion. There is a greater uniformity in the distribution of tensile stresses in the two analyzed geometries (halter and dog bone), with a diameter of 75 mm, when compared to the tensile stresses in the dog bone model with a diameter of 100 mm as shown by Klanphumeesri (2010). It is possible to observe that there are very small shear stresses in the central part of the sample and a concentration with higher values at its ends (Part a in Figure 2 and Figure 3).

5 RESULTS AND DISCUSSION

5.1 Physical Index and Uniaxial Compression Resistance

The values of uniaxial compressive strength (σ_c/UCS), deformability modulus (E) and Poisson's coefficients were obtained in tests using ISRM standards (2007) using cylindrical specimens with diameter NX (54mm). The results, as well as their statistics (for different samples) are reported in Table 1 based on 3 (three) specimens of W1/W2 and 5 (five) of W1.

Table 1. Uniaxial compression test results for the syenogranite.

Material		**ρ_d (g/cm³)[1]**	**n (%)[2]**	**γ_d (kN/m³)[3]**	**UCS (MPa)**	**E (MPa)**	**Poisson Coefficient**
W1/W2	Average	2,62	1,54	25,68	109,1	48,7	0,4
	CV (%)	0,7	25,73	0,7	15,1	11,8	4,2
W1	Average	2,61	0,9	25,59	147,6	60,6	0,4
	CV (%)	0,98	15,38	0,98	2,9	1,8	25,4
[1]Dry Specific Mass; [2]Porosity; [3]Dry Specific Weight							

5.2 Brazilian Test

The tensile strength values (σ_t) obtained in Brazilian tests using ISRM standards (1978) and CTC tests, its statistics and indication of the degree of weathering are shown in Table 2. Fifteen specimens were tested for Brazilian tests, five from W1/W2 and ten from W1 weathering degrees and nine specimens were tested, 4 (four) from W1/W2 and 5 (five) from W1. For CTC, on average, each specimen required 6 (six) hours on the lathe to prepare the geometry in the shape of a halter.

Table 2. Tensile strength of syenogranite.

Indirect tensile strength				Direct tensile strength	
Resistance	**Statistic**	**W1/W2**	**W1**	**W1/W2**	**W1**
σ_t (MPa)	Max	11,6	15,1	6,38	8,56
	Min	5,9	7,9	5,78	8,31
	Average	8,8	9,9	6,08	8,44
	CV (%)	22,9	21,6	7,05	1,92
σ_t/σ_c (%)	Average	8	6,7	5,6	5,72

Using data obtained from Brazilian tests, the σ_t/σ_c ratio for syenogranite varied approximately 8% for W1/W2 and 6.7% for W1, in agreement with average values found in the literature (works mentioned in Table 3). Although there is an empirical expectation in literature that the tensile strength corresponds, on average, to approximately 10.0% of uniaxial compressive strength. The values of σt correspond to approximately 8.77MPa and 9.87MPa for W1/W2 and W1, respectively, which reflect the effects of the degree of weathering in the tensile strength of rocks (Jaques et. al, 2020).

The strength provided by the load converter is lower than that obtained by the indirect method (Brazilian tests), corroborating the fact that indirect tests, despite being easier to perform, generally produce conservative values of tensile strength.

Table 3. Tensile strength values of granites obtained by several researchers.

Authors	Method	σ_t (MPa)
Erarslan e Williams (2012)	Direct Tensile Brazilian test	5,65 13,51
Perras e Diederichs (2013)	Direct Tensile Brazilian test	6,30 10,30
Khanlari et al. (2016)	Brazilian test	15,29
Xu e Sun (2018)	Brazilian test	8,12
Jacques (2019)	Brazilian test	9,74

Figure 8 shows a plot of tensile stresses and displacements measured with a LVDT positioned at the end plate of the compression machine. Despite the fact that these results do not reflect the true stress-displacement behavior of the specimen at the failure zone, basic information on stiffness both pre and post-peak can be obtained. The specimens are named by the letter B followed by the block number and by the letters CP followed by the specimen number.

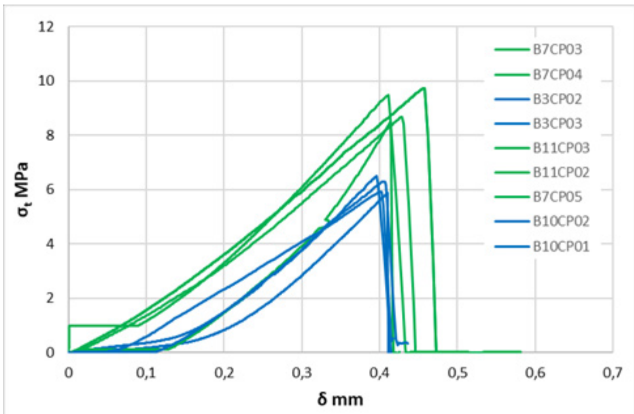

Figure 8. Tensile stress vs. displacement obtained from test results using CTC. The displayed displacements were measured outside the failure zone. In green test specimens W1 and in blue W1/W2.

Figure 9 and Figure 10 show obtained failure planes in the CTC tests, located in the middle portion of the specimens with halter type geometry, corroborating what was predicted in the numerical study shown in item 4. Care should be taken during assembling sample into the CTC apparatus, as the adjustment of the specimen must be made in a way that the sample remains precisely centralized in the load converter and to ensure the parallelism of the equipment when coupled to the universal testing machine.

Figure 9. Dimensions (in mm) of dog bone geometry.

Figure 10. Dimensions (in mm) of the halter geometry.

6 CONCLUSION

The present work presents results of a testing program involving the determination of the direct tensile strength of rocks by using the compression-tensile load converter (CTC). The tested rock was a syenogranite, with samples displaying two different levels of weathering.

The results showed a good performance of the proposed load converter and the tested samples failed due to pure tensile stresses at the center of the specimens. For all rock samples, the direct tensile strength determined with the proposed equipment were clearly lower than the indirect tensile strength, obtained with Brazilian type tests. Furthermore, the obtained results were in line with data found in the literature for granites. The obtained results suggest, as well, that the CTC test configuration can be used as a low-cost and reliable alternative, in the determination of the direct tensile strength in rocks.

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