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Application of a Traction Tests Device in Rock Material Specimens

M. I. Álvarez-Fernández, L. Álvarez-Gómez & J. C. Peñas-Espinosa
DinRock Research Group, Universidad de Oviedo, Mieres, Asturias 33600, Spain.
inma@dinrock-uniovi.com
0000-0002-5681-6530

V. Martínez Ibáñez
Polytechnic University of Valencia, Valencia, Spain

Abstract

This work addresses the application of a device designed by the DinRock Research Group from the University of Oviedo (Spain) for performing tensile tests on rock material specimens, with the aim of evaluating its usefulness and versatility under different loading conditions (Nicieza et al., 2020) (Guerrero-Miguel et al., 2021). The research focuses on evaluating the mechanical behaviour of rocks subjected to static and dynamic tensile stresses, in addition to the application of various thermal treatments. Tubular specimens of granite were used as the study materials.

In the static tests, a manual press was used along with strain gauges to register deformations, allowing for the determination of tensile strength and the elastic modulus of the samples.

Dynamic tests were carried out by the controlled drop of calibrated weights from different heights to analyse the material's response to impact loads, reaching velocities between 1 and 50 m/s.

Additionally, complementary tests were performed under different temperature conditions, in both static and dynamic regimes. External heaters were used to maintain a constant temperature throughout the tests. The specimens were tested at temperatures of 200, 300, and 400 ºC, in order to study the influence of thermal treatments on the tensile strength of these materials.

The results obtained demonstrate that the proposed device is an effective tool for characterizing the tensile behaviour of rock materials, providing consistent and reproducible measurements. Furthermore, its adaptability to different loading modes and temperature ranges broadens its potential application in experimental studies and in the analysis of the structural integrity of rocks exposed to extreme conditions.

Keywords

Tensile device, Dynamic, static, Thermal treatment, Rock materials.

1 Introduction

Tensile strength testing in rock-type materials has historically presented challenges in the characterization of their mechanical properties. The Brazilian test is commonly used to determine the tensile strength of brittle materials because it avoids some of the limitations of direct tensile testing, such as premature specimen failure during gripping and the formation of microcracks that may affect the measured strength. In addition, cylindrical specimens are easy to prepare and do not require special fixation systems. Nevertheless, the test provides valid tensile strength values only when fracture initiates at the specimen centre and propagates along the vertical diameter; otherwise, a detailed

analysis of the fracture location and the associated stress state is necessary to correctly estimate the tensile strength.

For this reason, the DinRock research group at the University of Oviedo, has designed a wedge-based device that enables the application of tensile stresses to hollow cylindrical rock specimens through the application of a vertical load to the device (Nicieza et al., 2020;Guerrero-Miguel et al., 2021).Upon vertical compression of the wedge system, the device walls undergo horizontal displacement, thereby inducing tensile stresses across the specimen wall thickness perpendicular to the direction of device motion. A four-component tensile device was developed, consisting of two wedges and two steel walls or semi cylinders as shown in Fig. 1, each featuring inclined internal surfaces that guide the wedges motion during compression of the system. The two wedges have a cylindrical base with a diameter of 52 mm and a height of 8.5 mm. The trapezoidal part of the wedge has 32 mm for the greater base, 12 mm for the smaller base and an angle of 18 º between the z axis and its non-parallel sides. More details appear in Guerrero-Miguel et al. (2021).

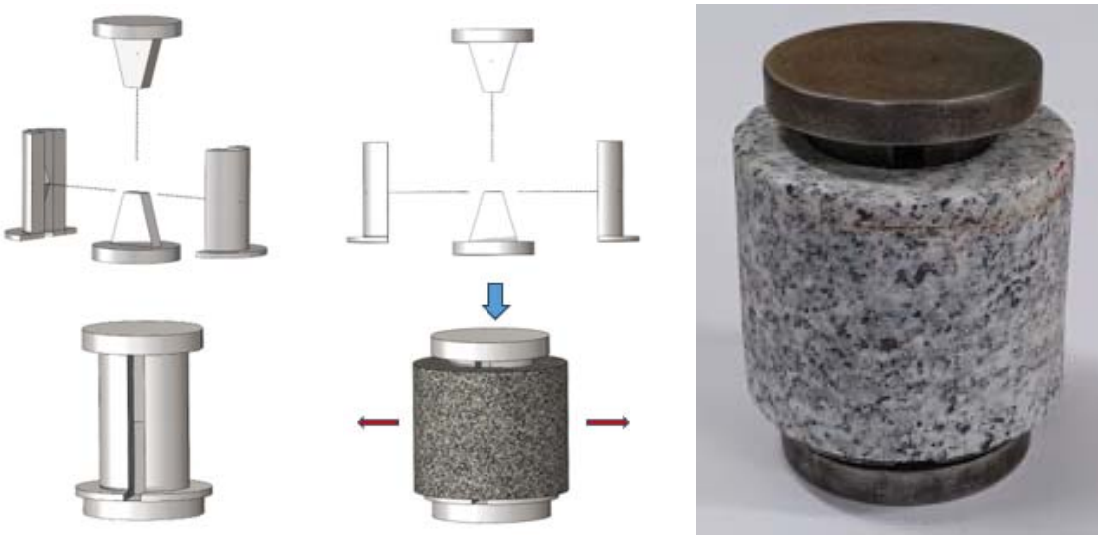


Fig. 1 Traction device parts and assembly example with the test specimen and direction of the loads.

In this case, the aim is to assess the device's versatility by extending its applicability to extreme loading conditions, such as dynamic fracture or the combination of tensile loads and temperature. These conditions are particularly relevant in mining and tunnelling applications (ground subjected to blasting loads) and, in particular, in projects related to the activation or enhancement of geothermal reservoirs.

Although the influence of temperature on the mechanical properties of rock is a field undergoing continuous development, with very recent work such as that by Tomás et al. (2025) or Liu et al. (2023)standing out, the equipment required to carry out tests whilst maintaining the sample temperature is both limited and expensive.

In this regard, the device developed by the DinRock Group provides a simple way of determining the tensile strength of rock at the target temperature.

2 Experimental Procedure

First of all, it was necessary to prepare the samples to test. One natural rock was used, granite, in particular de variety named *Granito Gris Quintana* (from Badajoz, Spain). Their mechanical properties, tested in the Rock Mechanics lab of the Polytechnic University of Valencia, are showed in Table 1.

Table 1. Mechanical properties of rocks tested.

Rock Type	Density [kg/m^3]	Ultrasonic speed [m/s]	UCS [MPa]	Young´s Modulus [GPa]	Poisson´s Coefficient	Indirect Tensile Strength [MPa]
Granite	2,70±0.01	5490±73	162.0±8.0	68.7±8.4	0.29±0.07	9.54±2.21

Starting from 200x200mm blocks, hollow cylindrical test tubes with an outer diameter of 65mm, an inner diameter of 35mm and a variable height between 50 and 60mm were made.

After preparation, the test specimens are divided into two types depending on whether they are limestone or granite. The test specimens used in each test are referenced in the following sections, with one group for static tests, another for dynamic tests, and a third for static tests with thermal treatment.

All test specimens share similar dimensions regardless of their material composition. The length ranges between 50 and 60 mm, the outer diameter between 64.5 and 65.0 mm, and the inner diameter between 35.0 and 35.5 mm. The weight of the specimens falls between 300 and 350 grams.

Each specimen is identified by a name that also conveys additional test information. In the static and dynamic test groups, a letter at the end of each specimen's identification indicates whether the force applied by the wedges is direct or perpendicular to the strain gauges used in those tests. In the thermal treatment group, since strain gauges are not employed, the identifier instead reflects the temperature to which each specimen was subjected. Strain gauges are placed as shown at the next figure

The experimental campaign is divided into three different types of tests:

- Conventional Wedge Tests (CWT): A vertical load is applied to the wedge using a universal press. These results are the “white samples” for the rest of the tests.
- Dynamic Drop Wedge Tests (DDWT): A known weight (24.6 kN) is dropped onto the wedge from a known height (100 or 150 mm) to test the behaviour of the material and the system under dynamic loads. The employed device and sample disposition are showed in Fig.2.In this case, strain gauges were placed in the external surface of the samples.

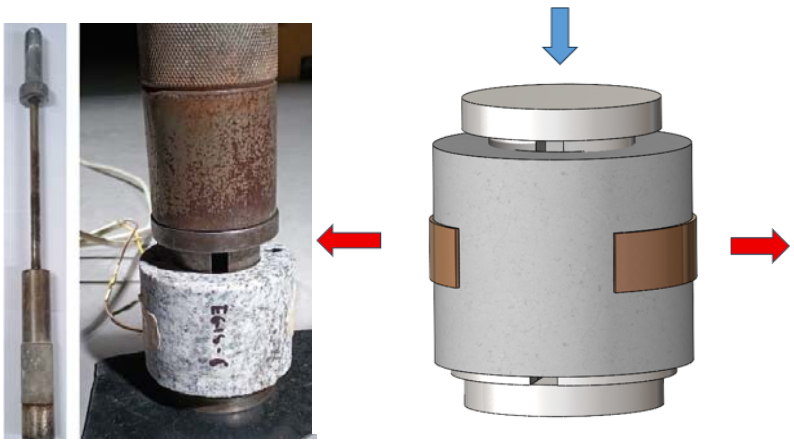


Fig. 2 Disposition for a DDWT and scheme for the strain gauges placement.

- Wedge tests with Temperature (WTT): Using a ceramic ring heater (Fig. 3), the sample rises a target temperature and, simultaneously the mechanical load is applied onto the wedge.Temperatures of 200, 300, and 400°C (±5°C) were selected. A Comet datalogger was used to monitoring the temperature.

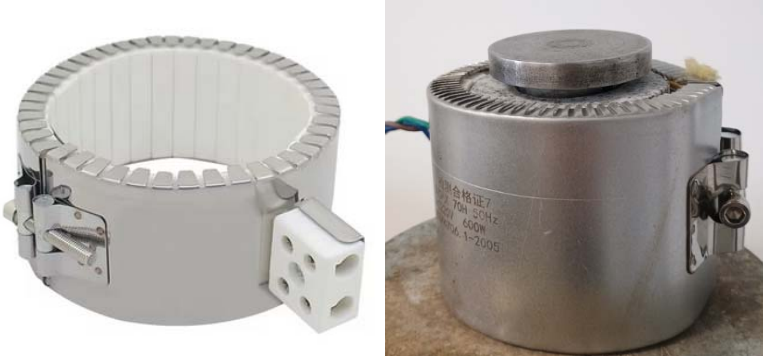


Fig. 3 Heating ring used in test with temperature.

3 Results and discussion

After conducting the various experimental tests, the researchers sought to determine the tensile strength under different temperature conditions and the energy that the materials were capable to absorb during dynamic testing.

The tensile strengths of the specimens were determined using Eq. 1, from (Guerrero-Miguel et al., 2021):

$$\sigma_t = \frac{P_v(-\alpha^4 + 5\alpha^2 + 2)}{1.3RL\alpha(\alpha^2 - 1)^2} \quad (1)$$

Where: σ_t Tensile strength (MPa)
P_v Vertical load applied (N)
α Dimensionless coefficient between the internal radius and the external radius
R External radius of the sample (mm)
L Length of the sample (mm)

3.1 Conventional Wedge Tests (CWT)

Four granite samples (named as CWT1-G, CWT2-G, CWT3-G and CWT4-G) were tested. Results are summarized in Table 2, with a mean value of 8.62 MPa (slowly lower than those obtained with Brazilian tests) and a standard deviation of 1.25 MPa. These values are similar to those found in previous studies (Wang & Hu, 2017), which reported a tensile strength for granite of approximately 8.5 MPa.

Table 2. Summary of tensile strengths obtained through CWT for granite specimens.

Sample	Tensile Strength [MPa]	Mean [MPa]	Standard Deviation [MPa]
CWT1-G	10.15	8.62	1.25
CWT2-G	8.57		
CWT3-G	8.91		
CWT4-G	7.11		

3.2 Dynamic Drop Wedge Tests (DDWT)

In this series of tests, nine samples were tested. Two heights, 100 or 150 mm, were selected to drop the known weight in order to establish the number of impacts needed to break the sample and the energy and velocity of each impact. The observed failure mode was consistent across specimens, corresponding to the expected diametral tensile fracture, in which the rock tubes split into two fragments along the loading axis (see Fig. 4).

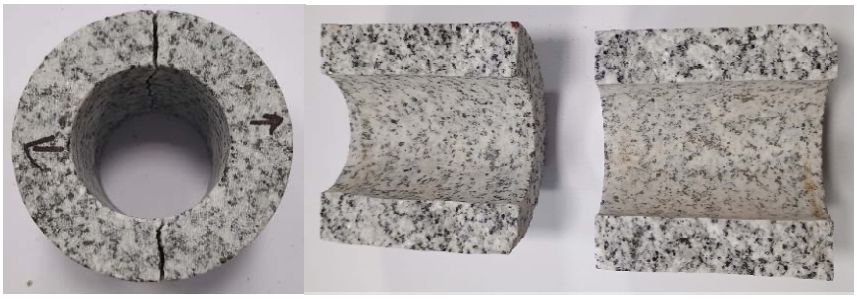


Fig. 4 Fragments obtained during DDWT tests.

The fact that multiple impacts were generally required before fracture occurred suggests that damage accumulates progressively through microcracking until the tensile strength of the material is exceeded. This idea is supported by the strain monitoring during tests. As can be seen in Fig. 5, after each impact, a permanent strain progressive higher, is induced.

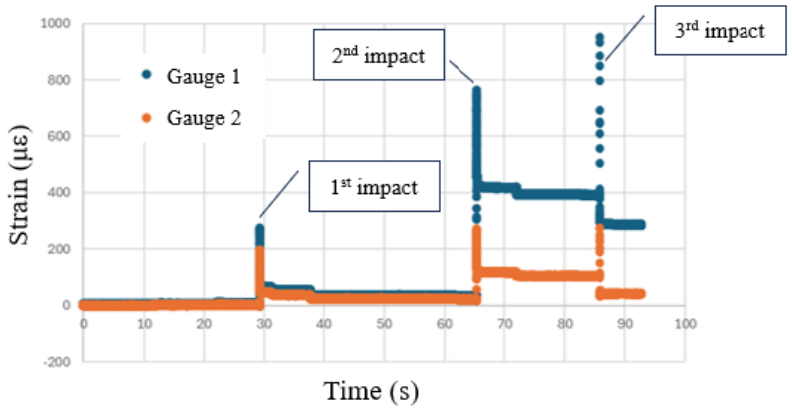


Fig. 5 Strain evolution during a test with three impacts before breakage.

Table 3 summarizes test results. In this case, the term cumulated energy, represents all the energy used to fracture the sample, i.e. the energy of each impact multiplicated for the number of impacts to breakage. As can be seen, in all cases, the number of fragments obtained was two, and the new surfaces generated by fracture was between 1674 and 2497 mm^2. Although, as is usual, there is a variability due the nature of the material, six samples show identical results for cumulated energy (7.39 J). The mean value for all samples is 6.43 J, with a standard deviation of 1.48 J. So, the energy to create new fractures is 0,0032 J/mm^2.

Table 3. Summary of the results from dynamic drop tests.

Sample	Number of Impacts	Height [mm]	Number of Fragments	Impact Speed [m/s]	Cumulated Energy [J]
DDWT1-G	1	150	2	1.72	3.69
DDWT 2-G	2	100	2	1.41	4.93
DDWT 3-G	3	100	2	1.41	7.39
DDWT 4-G	3	100	2	1.41	7.39
DDWT 5-G	3	100	2	1.41	7.39
DDWT 6-G	2	150	2	1.72	7.39
DDWT 7-G	2	150	2	1.72	7.39
DDWT 8-G	3	100	2	1.41	7.39
DDWT 9-G	2	100	2	1.41	4.93

3.3 Wedge tests with Temperature (WTT)

Once the target temperature has been reached using the ceramic heaters, the sample is submitted to a mechanical tensile load through the wedge, maintaining the temperature during the test. Six samples were tested at temperatures of 200, 300 and 400 ºC. Results are provided in Table 4. As can be seen, the two results obtained at 200 °C differ significantly. As with any other experimental test, a larger number of repetitions (typically between three and five) would be required to draw reliable conclusions. In any case, this isolated discrepancy does not undermine the validity of the testing device under heating conditions.

Table 4. Results for wedge tests with temperature.

Sample	Target Temperature (º)	Tensile Strength [MPa]
WTT -1-G	400	11.30
WTT -2-G	400	11.58
WTT -3-G	300	15.29
WTT -4-G	300	12.39
WTT -5-G	200	8.20
WTT-6-G	200	18.01

Fig. 6 shows the representative values alongside the tests carried out at room temperature. It can be seen that there is a slight increase in strength around 300°C, which decreases slightly at 400°C. Although further testing is required to verify this trend, the tensile testing apparatus has been shown to be suitable for use under these conditions.

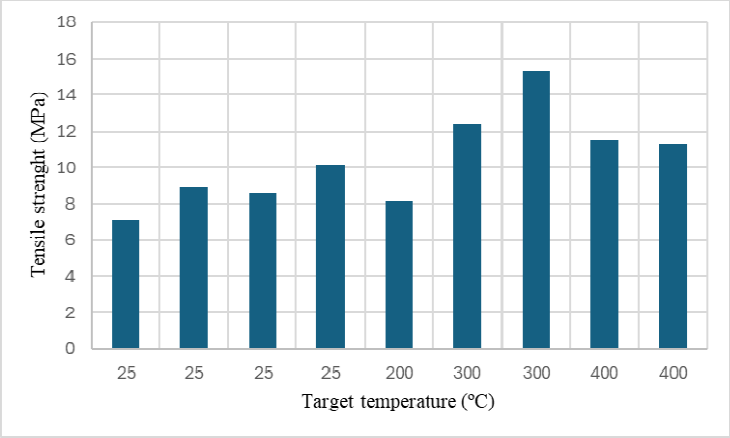


Fig. 6 Tensile strength evolution with the temperature.

4 Conclusions

The wedge-based tensile device developed by the DinRock Research Group has proven to be a viable and adaptable tool for characterizing the tensile behavior of rock materials under static, dynamic, and heated conditions. Across all test types, the device consistently induced tensile failure in hollow cylindrical granite specimens, with fracture patterns largely aligned with theoretical expectations. Cases of anomalous fracture geometry were identified in all test series but were consistently attributed to device misalignment rather than material behavior, underscoring the importance of careful specimen placement in future campaigns. Dynamic tests further confirmed the device's effectiveness under impact loading conditions. Overall, the results support the continued development of this testing approach for applications in the study of rock behavior under extreme conditions.

The tensile device can be easily implemented in a rock mechanics laboratory, requiring only a load cell, a displacement sensor, and, if needed, strain gauges. In addition, it enables the determination of the uniaxial tensile strength without the need to clamp the specimen to the testing machine jaws.

Acknowledgments

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