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On Direct Tensile Strength Measuring of Anisotropic Rocks

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Abstract

The tensile strength of the anisotropic rock-like material specimens is meastred directly in the laboratory using a new device converting the compressive loading to that of the tensile before the rock breakage. The specially prepared concrete slabs of dimensions 19 cm * 15 cm * 15 cm with a central hole of 7.5 cm in diameter are tested experimentaly. The specimens are located in the compressive-to-tensile load converting device, and tested under a compressive loading rate of 0.02 MPa/s by the universal testing machine. The cubic slab samples are made in three different configurations to have the directions of 0°, 45°, and -45° with respect to the applied loading direction. In order to compare the direct tensile strength of the concrete samples with that of the indirect measuring tests, some Brazilian tests are also carried out on the concrete disc specimens prepared in the laboratory. By comparing the direct and indirect testing results of the concrete tensile strength, it can be concluded that the direct tensile strength values are somewhat lower than those of the indirect ones. The tensile strength values for the three different configurations of the concrete specimens are nearly the same.

1. Introduction

The design and the safe operation of many geo-engineering structures mainly rely on the tensile strength of brittle materials such as rocks and concretes, which are weak under the tensile loading conditions. The tensile strength determination and its measuring is generally accomplished through some sophisticated laboratory test setups including the direct and indirect experiments. Due to some difficulties associated with the direct tests, the indirect tensile strength tests (such as the point load and Brazilian tests) are standardized and used for many years. Although these tests are simple, applicable, and independent from the specimen size and boundary conditions, their analysis is somewhat complicated so that the results obtained may be less reliable, especially for the delicate engineering structures. Due to the easy preparation of rock specimens and setup simplicity, the Brazilian tensile strength tests are widely used for the design of rock structures [1-7]. Some indirect tensile strength measuring tests have been carried out on the specimens in the form of rings, cylinders or cubes [8-27]. The double punch tests and the flexural tests on beams (three-point and four-point bending tests) have also been extensively used in the laboratory in order to experimentally determine the tensile strength of rocks and concretes [28, 29]. However, the indirect tensile strength results such as those of the Brazilian tests are somewhat overestimated (usually more than 26% in most cases), and may cause some problems in the modern applications of geo-mechanics [8]. Therefore, the direct tensile strength measurements have found some new places in the modern geo-mechanic's applications since they are able to accurately measure the tensile strength of concretes and rocks [9-24]. The direct tensile strength of concretes can be determined by performing some special direct pull tests on the dumb-bell shaped rock-like specimens, which are specifically

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designed and prepared in a rock mechanics laboratory [25-27]. Swaddiwudhipong *et al*. [30] have carried out some direct tension tests in order to measure the concretes' tensile strength. They used different types of cements to prepare the concrete specimens, and measured their tensile strength based on their strain capacity. The direct uniaxial tensile stress tests on some specifically prepared specimens give the most precise and reliable tensile strengths for the brittle materials. Compared with the indirect tensile testing approaches, these methods require careful measuring apparatus, and may need an elaborate and significant amount of specifically prepared specimens. The rotation of failure surfaces, the asymmetric deformation in the failed and damaged zones, the eccentricity of the applied load, and the non-symmetry of specimens all may be considered as the drawbacks of the indirect tensile strength tests [14]. These drawbacks may cause the moments to be produced within the specimens or around the damaged zones, and therefore, affect (increase) the indirect tensile strength of the brittle materials such as rocks and concretes. Some challenges have been accomplished by the researchers in order to overcome such difficulties and improve the tensile strength methods. They have tried to remove the stress concentration points, where the unexpected failing of the material may occur, e.g. by using cubical, cylindrical or disc type specimens of rock-like materials or concretes [14]. As far as the direct tensile strength measuring methods are concerned, some direct tensile measuring tests have been performed on the cylindrical concrete specimens by Kim and Taha [13]. They performed the direct tensile testing on the concrete specimens by stablishing a uniform stress distribution within the failure plane of the failed specimens in the laboratory. During the testing, they could asses and confirm that the unit weight distribution of the specimens may affect the cracking zone (failure plane) in the direct tensile testing methods. Zail *et al*. [31] have compared the indirect tensile and uniaxial compressive strengths of a highly strong concrete, stating that the existing indirect tensile strength tests have some limitations mainly related to the basic assumptions such as the linear elastics behavior of the rocks and rock-like materials during the analysis. The uniform tensile stress condition that is assumed during the test and also on the splitting failure surface cannot be achieved, which may cause an increase in the value of the strength since the failure surface may deviate, and the eccentricity in the applied loading may occur [32]. Therefore, the indirect tensile testing results may give a rough value of the rock and concrete strength, and cause some problems in the design of the engineering structures. The other mechanical properties of the rocks and concretes such as their rapture modulus can also be measured by measuring the indirect tensile strengths with 3- and/or 4-point bending tests, in which the real values of the modulus are overestimated due to the above-mentioned drawbacks in estimating the indirect tensile strength of rock materials [8]. However, it can be concluded that a more precise and reliable direct tensile testing approach for measuring the tensile strengths of rocks and concretes may be developed in order to overcome the limitations and drawbacks of the indirect tensile testing methods. In the present research work, we suggest a direct tensile testing method based on the concept of transferring the applied compressive load to that of the direct tensile during the testing. The proposed direct tensile testing machine uses a sophisticated compression-to-tensile loading convertor (CTLC) containing the specimen to be tested. This specimen should be specifically prepared from the rock or concrete samples. In the present work, the preparation and uses of these specimens in the CTLC device during the direct tensile testing performance are explained.

2. Compressive-to-tensile load convertor (CTLC) apparatus

The CTLC device has been specially designed to use some specifically prepared concrete specimens for measuring the direct tensile strength of concretes using the conventional laboratory testing machines. The direct tensile strengths of rocks can also be measured by preparing the specimens with a central hole at their centers so that the applied compressive load to the specimen can be transferred to that of tensile as required by the CTLC device placed in the universal testing machine. The main parts of a CTLC device are illustrated in Figures. 1a to 1d. The "U" shape part (Part I) of the device consists of the two parts, "L" and "1", all built from stainless steel (Figure 1a). Figure 1b shows the second part (Part II) of the device with a "Π" shape. Part III of the device consists of two stainless sub-segments of semi-cylindrical shape, where each segment has the dimensions of 75 mm × 10 mm × 60 mm (Figure 1c). Finally, Figure 1d shows Part VI of the device, which consists of two steel blades with 20 mm ×10 mm × 190 mm in dimensions. The complete setup of a CTLC device is illustrated in Figs. 6a to 6f, respectively. These figures show the useful procedure for performing the direct tensile strength measurement process for the concrete and rock samples in the laboratory. Six distinguished stages can be visualized in this setup procedure, as follow: i) as shown in Figure 2a, Part III of the CTLC device is inserted in the central hole of the specimen; ii) as illustrated in Figure 2b, the "L" shape segment of Part I is placed on the left side of the specimen; iii) one of the blades (Part 4) is inserted to the upper part of the central hole that is in contact with Part III, while at the same time, its lower surface should be in contact with the "L" shape segment of Part I (Figure 2c); iv) again, as shown in Figure 2c, Part II is placed on the right hand side of the specimen; v) as shown in Figure 2d, the second blade of Part IV is located in the lower surface of the specimen's central hole, and is in contact with the cylindrical steel. At the same time, the upper part of the second blade will be in contact with the "I" shape segment of Part II; and at the end, vi) as shown in Figure 2e, the "I" shape segment of Part II is screwed into the "L" shape segment of Part I. This setup is managed in such a manner that the upper section of the specimen is in contact with the lower cylindrical steel, while at the same time, the lower section is in contact with the upper cylindrical steel, and then the setup is completed. This completed setup is placed in the conventional uniaxial compression loading frame in the laboratory. By this procedure, during the loading process, the upper part of the specimen compresses its lower part while moving down, and at the same time, the lower part of the specimen compresses downward (Figure 2f) so that a direct tensile loading is applied to the specimen.

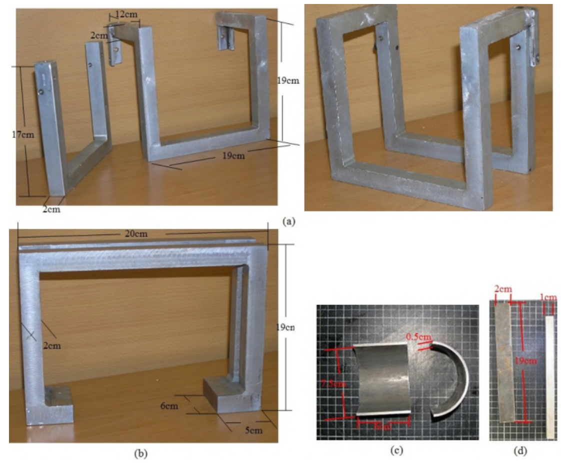


Figure 1. Different parts of CTLC device.

2.1 Rock Specimen's preparation for CTLC device

The direct tensile strength of the concrete with a specific gravity of 3.1 g/cm^3 is measured in the laboratory using some specially prepared UHPC specimens for the CTLC device. These specimens have the dimensions of 15 cm × 19 cm × 6 cm, and a hole of 7.5 cm in diameter and 6 cm in height is situated at the center of each specimen. In this work, the ratio of the central hole diameter to that of the sample's width was taken as 0.5.

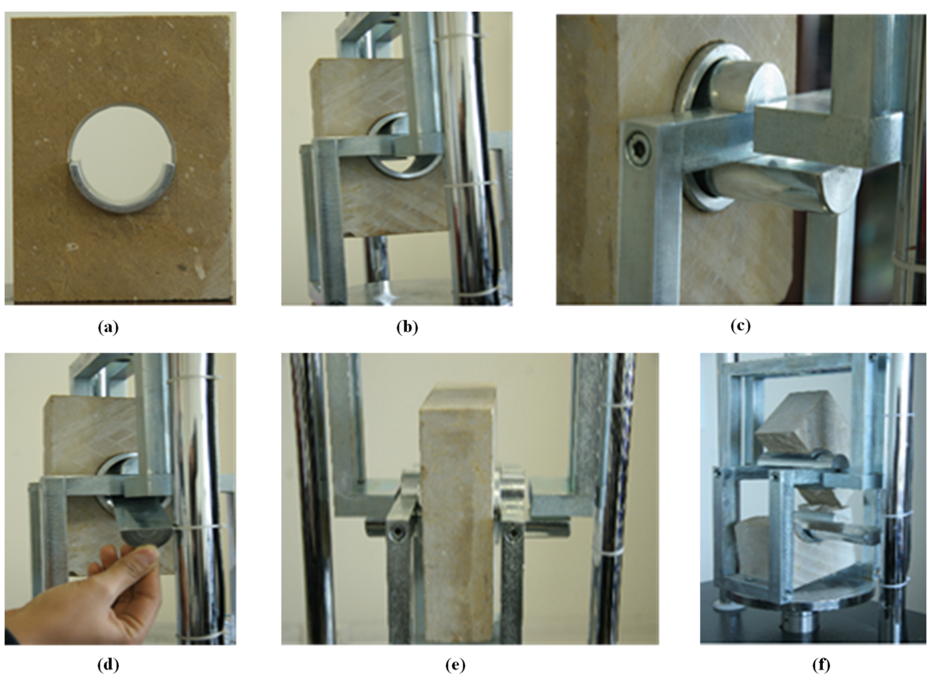


Figure 2. Setup procedure of CTLC device.

2.2 Direct tensile strength test by CTLC

In this work, a Universal Tensile Testing device (UTTM) is developed, as shown in Figure 3. The CTLC device together with the specimens already prepared in the laboratory can be used to complete the required arrangement for measuring the direct tensile strength of the concrete in UTTM (Figure 3). In this experimental approach, UTTM has a conventional uniaxial compression frame, which can provide the required uniaxial compression for the CTLC device already contained in a specimen. The loading frame of UTTM is specially designed for applying a uniaxial compressive load to the end plates of the CTLC device via a 5-tons gearbox load cell, which can electronically record the applied load increments during the tensile testing process. During the testing operation, a constant loading rate of 0.02 MPa/s is applied in order to minimize its effects on the final testing results of the direct tensile strength of the specimen. This loading rate is suggested for the tensile strength measurement using a rock splitting approach [33]. UTTM is powered by a single-phase electricity applying through a rigid frame of 5 tons loading capacity, and can be effectively used for measuring the direct and indirect tensile strengths, the uniaxial compressive, and the fracture toughnesses of concretes, rocks, ceramics, mortars, and asphalts.

In the present research work, UTTM with the CTLC device was used in order to measure the direct tensile strength of the UHPC specimens. Three pre-holed rectangular concrete specimens were prepared and placed in the CTLC device for testing with UTTM in a rock mechanics laboratory. The samples had three different configurations related to the loading axis: 0°, 45°, -45° (Figs. 4a-c). Figures 8a to 8c show the failure and crack propagation process in three failed specimens. These figures show that when the specimens are subjected to tensile loading, the horizontal line cracks start from the boundary of the center holes and extend through the specimens' width. This is the direct tensile failure causing the splitting tensile failure to be produced by the semi-cylindrical steels or rings around the periphery of the central hole in the specimens.

In this research work, the performance of the CTLC device for measuring the direct tensile strength of the anisotropic concrete slabs was assessed by performing six laboratory tests in the universal testing machine. It was observed that nearly all the tested specimens were cracked from the interior hole wall along a horizontal line at right angle to that of the applied compressive loading direction. Therefore, the direct tensile failure was induced in the horizontal direction due to the vertical direct tensile force exerted to the specimen via the two sleeves of the CTLC device during the testing (Figure 5).

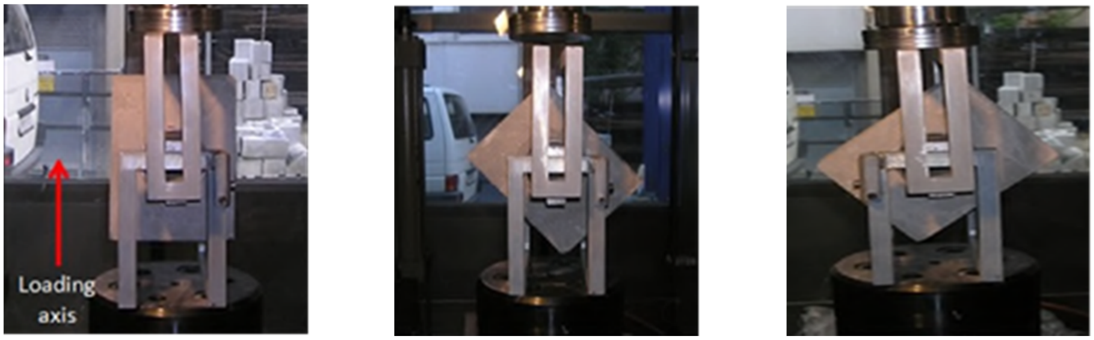
2.3 Laboratory measurement of direct tensile strengths of UHPC specimens

In the direct tensile strength measuring approach explained in this work, distribution of the induced tensile stress at the UHPC specimen is more than that of the far field tensile stress. Therefore, this tensile stress cannot be directly considered as the real tensile strength of the concrete specimen. However, the following simple formula is suggested to be used for the calculation of the direct tensile strength (σ_t) of the specimens:

$$\sigma_t = \frac{F}{(d1 + d2) \times t} \quad (1)$$

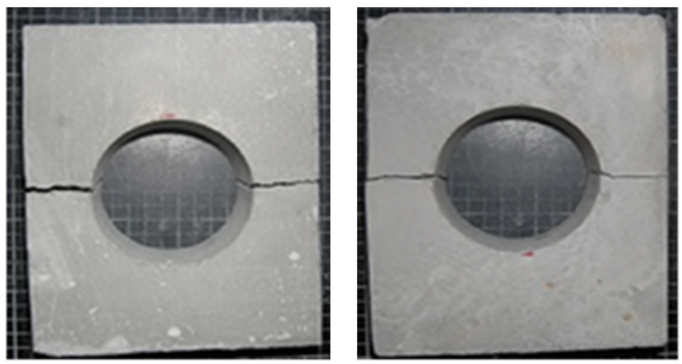
where σ_t is the tensile strength of the material in kg/cm^2, ***F*** is the applied force in kg, ***t*** is the thickness of the specimen (in cm), and ***d1*** and ***d2*** (expressed in cm) are the specimen's width on either sides of the central hole (Figure 6). The values of the experimental results are given in Table 1.

Figure 3. Universal tensile testing machine.

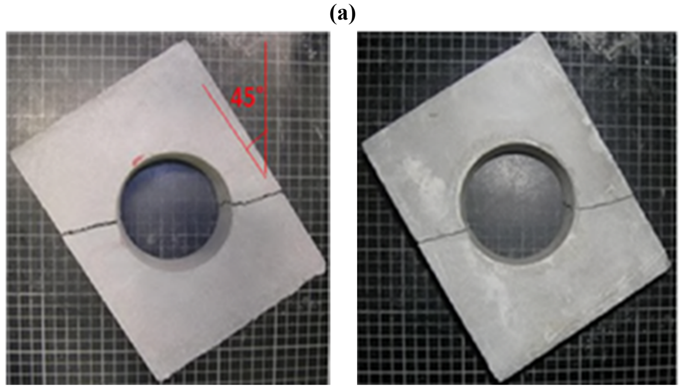


(a) (b) (c)

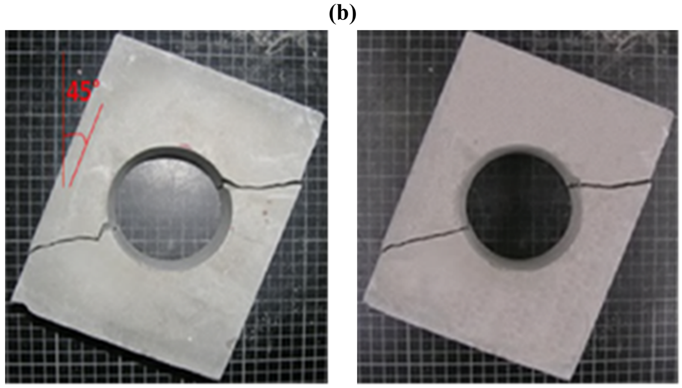
Figure 4. Three loading configuration for the testing specimens: (a) located parallel to the loading axis, (b) turned 45° in a clockwise direction with respect to the loading axis, (c) turned 45° in counter-clockwise direction with respect to that of the load axis.



(a)



(b)



(c)

Figure 5. Direct tensile failure pattern in specimens.

Table 1. Direct tensile strengths of concrete specimens.

Sample No.	Tensile strength (MPa) when vertical sides of sample are parallel to the loading axis	Tensile strength (MPa) when vertical sides of sample are turned 45° in the clockwise direction related to that of the loading axis	Tensile strength (MPa) when vertical sides of sample are turned 45° in the counter-clockwise direction related to that of the loading axis
1	3.1	3.16	3.19
2	3.08	3.2	3.21
Average	3.09	3.18	3.2

However, three splitting tension tests were carried out on the disc type concrte specimens in order to compare the results obtained with those of the indirect tension tests. Fig 7 shows the tensile failure of the disc specimens in the splitting test.

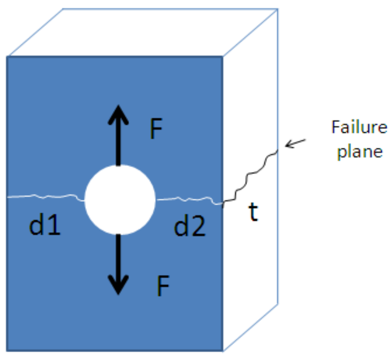


Figure 6. Parameters used for calculation of rock's direct tensile strength.

Figure 7. Failure pattern in experimental Brazilian tensile test.

3. Comparing direct and indirect tensile strengths of concrete specimens

In order to consider the effect of anisotropy on the tensile strength of the concrete, three diferent loading directions were selected to measure the direct tensile strength of the specimens. The results obtained are shown in Table 2. However, the effect of anisotropy is relatively low due to the bonding homogeneity of the rock-like materials in the concrete mixture. The strength values for both the direct and indirect measurement methods are also presented in Table 2 for comparison. As it was expected, the Brazilian tensile strength results were about 30% higher than those measured by the direct tensile strength testing method. It is expected that the indirect tensile strength results to be higher than the direct ones because in this case, the tensile stress is induced in the specimen due to the direct applied compressive load, and then the tensile stress is induced indirectly and distributed in the middle part of the test sample.

Table 2. Results of direct tensile strength in two different methods.

Sample No.	Indirect tensile strength (MPa)	Splitting tensile strength (MPa)
1	3.18	4.2
2	3.09	4.1
3	3.2	4.07
Average	3.16	4.12

4. Conclusions

The anisotropic tensile strength of the rock-like materials was measured by considering three specimen configurations located in the CTLT device, where the direction of loading was changed through the turning of the concrete slab samples in the clockwise and counter-clockwise directions at an angle of 45°, respectively. The diference between the direct and indirect tensile strengths was also determined by performing some indirect tensile testing on the Brazilian discs provided from the same concrete mixture. It was observed that the effect of anisotropy was low due to the homogeneity of the bonding in the concrete specimens. On the other hand, the indirect tensile strength values obtained by the Brazilian test were about 30% higher than those measured directly using the CTLC device. It is mainly due to the indirect induced tensile stress concentration at the middle of the Brazilian disc specimens used in the indirect tensile testing method. A central hole of 75 mm in diameter was present at the mid-section of the CTLC concrete specimens. The effect of its size on the tensile strength could also be determined. Based on the experiments performed, the optimum hole diameter was taken as 75 mm. It can be concluded that as the hole size increases (up to some extent), the tensile stress concentration on either sides of the hole increases.

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اندازه گیری مقاومت کششی سنگهای آنیزوتروپ

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چکیده:

در این مقاله، مقاومت کششی مستقیم آنیزوتروپ نمونه های شبه سنگی با استفاده از دستگاه مبدل بار فشاری به کششی اندازه گیری شد. بلوک های بتونی با ابعاد ۱۵ cm × ۱۵ cm × ۱۹ cm حاوی یک حفره مرکزی به قطر ۷/۵ cm آماده شد. نمونه بتونی در دستگاه مبدل بار قرار گرفت و این مجموعه در دستگاه تک محوره جایگذاری شد. نمونه ها با زوایای ۰، ۴۵ درجه و ۴۵- درجه نسبت به محور قایم تحت بار قرار گرفتند. نرخ بارگذاری ۰/۰۲ مگاپاسکال بر ثانیه است. به منظور مقایسه نتایج کشش مستقیم با روش غیر مستقیم، سه نمونه برزیلی از جنس بتن آماده شد. با مقایسه نتایج دو آزمایش، مشاهده شد که مقادیر حاصل از تست کشش مستقیم کمتر از مقادیر تست برزیلی است. مقادیر مقاومت کششی سه آرایش مختلف بتن تقریبا یکسان است.

کلمات کلیدی: بتن، مقاومت کشش مستقیم، مبدل بار فشاری به کششی.