Vol. 15, No. 45, Winter 2026, pages 63-74

Journal of Analytical and Numerical Methods in Mining Engineering

Journal home page: http://anm.yazd.ac.ir/

Research article

Investigating the effects of loading rate and mixing design on concrete's direct tensile strength using the CTLC test

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(Received*: January 2025,* Accepted*: May 2025)*

DOI: 10.22034/ANM.2025.22631.1657

Keywords

Concrete
Direct tensile test
Brazilian tensile test
Mixing design
Loading rate

Abstract

The tensile strength of concrete is measured using direct tensile tests on rectangular concrete samples with dimensions of 19 cm in length, 16 cm in width, and 6 cm in thickness, with a central hole of 9 cm in diameter. The concrete specimens were prepared in the laboratory by mixing cement, fine sand, gravel, and water in appropriate proportions. Calibration of the new direct tensile strength test apparatus was carried out to determine the tensile strength of different brittle materials (gypsum and concrete) under various loading rates and different mixing design types. The direct tensile strength tests were accomplished by a compressive-to-tensile load converter (CTLC) fitted with the specimens and placed in the universal testing machine in the laboratory. For the indirect Brazilian tensile strength tests, loading rates of 5, 10, and 15 kg/s were considered. For the direct tensile strength tests, loading rates of 2, 2.5, and 3 mm/min were used. The results of this paper show that the direct tensile strengths measured by the CTLC apparatus are approximately 25% lower than those measured by the Brazilian tests. The average tensile strengths of the geo-material samples increase as both the loading rate and the ratio of fine sand to gravel increase.

1. INTRODUCTION

Concrete is one of the most important materials in today's society and is widely used in many construction projects consist including foundations, dams, and tunnel stability [1-6]. The tensile strength of concrete is one of the most basic and key features that has a significant impact on the stability of structures, tunnels, and bridges. Furthermore, due to its brittle nature, concrete performs very poorly against applied stresses, so it is not expected to withstand direct stress. Therefore, when the tensile forces exceed the tensile strength of concrete, cracks are created in concrete, which eventually cause fracture [7-13]. Therefore, measuring the tensile strength of concrete as a heterogeneous material is a challenging issue. The existing methods for measuring tensile strength are grouped according to indirect and direct tensile strength. In the indirect tensile test, various methods such as the Brazilian and bending tensile tests have been presented to measure the tensile strength [14-18]. The Brazilian tensile test is performed on cylindrical specimens, and the flexural test on beam-like specimens; although these methods are widely accepted, they do not provide the true tensile strength of concrete [19-25]. In direct tensile testing, the load application mechanism must be carefully designed to reduce load eccentricity and stress concentration at the end of the specimen. It is challenging to place the specimen and apply the load in the direct tension apparatus. Direct tensile testing is usually performed uniaxially. However, setting up a direct tensile test is time-consuming, and the results can depend on the applied boundary conditions [26-29]. Many experimental and theoretical studies have been conducted to determine the tensile strength [30], including the tensile strength of concrete using a uniaxial tensile test on rectangular samples [31]. Sarfarazi et al. have presented a new approach to determine the direct tensile strength of concrete based on the uniaxial method using a dumbbell sample [32]. Liao et al. conducted a direct tensile test using cylindrical specimens with a diameter of 101.6 mm and a height of 203.2 mm, similar to that used in the uniaxial tensile test [33]. Sarfarazi et al. have used the compressive to tensile load transformer apparatus as a modern approach to determining the direct tensile strength of concrete [34]. Fakhimi and Laboz have proposed the development of a new method for testing the tensile strength of concrete using a Strut and tie method [7]. Haeri et al. studied the direct tensile strength measurement of granite by the universal tensile testing machine [35]. Fu et al. improved the tensile strength of reinforced concrete by evaluating the impact of different fiber additives through numerical and experimental analysis [36].

Wang et al. developed the dynamic tensile strength prediction model and tensile behavior of concrete considering pores based on the impact splitting tensile test [37]. They have measured the tensile strength of concrete by using special samples, considering the compressive to tensile load converter apparatus. According to the previous research and the results expressed by the researchers, it can be claimed that additional studies are still needed to develop the apparatus to determine the tensile strength of concrete, as well as various investigations to evaluate the quality of concrete. Although there are many tensile strength devices, most of them are either limited in availability or expensive. Therefore, it is necessary to develop a new device that can measure the tensile strength of concrete.

According to the limitations stated in this field, a new method has been used to test the tensile strength of concrete using a new direct tensile test apparatus based on a compressive-to-tensile load converter. Also, the calibration of the new direct tensile test apparatus was performed by considering the effect of different loading rates and different mixing designs on two types of materials, concrete and gypsum, with two methods, the Brazilian test and direct tensile test. This newly developed apparatus is equipped with a data logger and records information such as time, load, and displacement to the computer through the cable with a serial port monitor Software. Then, using the newly developed apparatus, the effect of loading rate and different mixing designs on concrete was investigated. It is essential to mention that one of the important goals of this study is to analyze the effect of loading rate and different mixing designs by using this new apparatus. Also, comparing the results of this apparatus with the Brazilian test shows a 26% difference in tensile strength.

2. DETERMINATION OF TENSILE STRENGTH

While this study focuses on the direct tensile behavior of concrete under varying loading rates and mix designs, the broader implications of tensile strength in geomechanical systems are evident across diverse applications. Tensile resistance plays a critical role not only in wellbore stability analysis within petroleum engineering—where directional drilling and safe mud weight windows are governed by subsurface stress conditions—but also in the structural integrity of underground caverns for hydropower facilities. Moreover, the interaction between tensile capacity and dynamic fluid loads becomes particularly relevant in large-scale infrastructure such as double-arched dams, where water-structure coupling under impact conditions demands robust numerical modeling. These parallels underscore the interdisciplinary relevance of tensile strength across both surface and subsurface engineering domains [38-40]. Generally, determining tensile strength is measured by two indirect and direct methods using separate apparatus. In the following section, a brief description of the mentioned methods will be given.

2.1. Indirect Tensile Strength Measurement

Brazilian tests and bending tests are widely used as indirect approaches to measure tensile strength [1, 11]. In this section, the Brazilian test is used to determine the tensile strength of concrete. Also, the impact of loading speed and different mixing designs on the tensile strength of concrete has been considered using the Brazilian method, which will be discussed further.

2.1.1. Indirect Brazilian tensile strength test (IBTS)

In the Brazilian test to measure the tensile strength of concrete, standard cylindrical specimens with a ratio of length to diameter (0.5) are prepared and placed horizontally under the testing apparatus. As a result, applying a plane or radial force on a cylindrical specimen causes a vertical crack along the diameter of the specimen.

Then, the tensile strength of Brazil is calculated from Eq. (1).

$$\sigma_t = \frac{2p}{\pi Dt} \quad (1)$$

Where p is the vertical force, t is the thickness of the Brazilian specimen, and D is the diameter of the Brazilian specimen.

In this topic, a concrete sample prepared with a central hole has been used to perform a direct tensile test, whose central hole has a height of 6 cm and a diameter of 9 cm as a Brazilian sample under vertical loading with a load of 0.03. mm/s, considering the standard conditions applied. 6 Brazilian concrete samples were tested as standard Brazilian samples after 28 days under the loading of the testing apparatus to measure the tensile strength.

Figure 1 shows a Brazilian sample subjected to a testing apparatus to determine the tensile strength, which caused a crack along the diameter of the sample as a result of the application of a vertical force. The tensile strength of concrete in the Brazilian test was calculated using Eq. (1), the results of which are shown in Table 1.

Fig. 1. Concrete sample under Brazilian test

Table 1. Test results of concrete samples using the Brazilian tensile method

Mix design	Components	Values %	Test Method	Tensile strength (MP)
Proper mixing design with Portland cement for 28 days	water	10	Brazilian	0.89
	cement	15	Brazilian	0.93
	sand	43	Brazilian	0.82
			Brazilian	0.97
			Brazilian	0.87
	gravel	32	Brazilian	0.83
			average	0.88

Also, in Table 2, samples of Brazilian gypsum with a length to diameter ratio of 0.5 were prepared under standard conditions after 48 hours under the load of the testing machine to measure tensile strength, the results of which are reported.

Table 2. Test results of gypsum samples using the Brazilian tension method

No	Test Method	Time(hour)	Tensile strength (MP)
1	Brazilian	48	0.70
2	Brazilian	48	0.82
3	Brazilian	48	0.82
	average		0.78

Measuring tensile strength directly in the laboratory is not an easy task. The uniaxial tensile test is performed to determine the direct tensile strength of brittle materials such as concrete and rock using different methods and special samples [8, 24]. The uniaxial tensile strength of concrete is significantly affected by the way the test is performed. The shape of the sample, the concentration of local stress, and the way of sample setting are important factors that affect the obtained results [8, 25].

Therefore, in this section, the direct tensile strength of concrete was measured using a new apparatus based on a compressive-to-tensile load converter. In this developed apparatus, easy loading and direct tensile strength measurement results are close to reality. We will talk more about this apparatus in the following.

2.2. New Direct Tensile Testing Using CTLC

A new direct tensile test apparatus based on a compressive to tensile load converter (CTLC) is used to determine the direct tensile strength of concrete, considering specific samples with dimensions of 19 cm in length, 16 cm in width, 6 cm in thickness, and a central hole diameter of 9 cm. This testing apparatus is equipped with strain gauges that are installed on the specially prepared samples. The load converter apparatus comprises different hard steel components. Component 1 comprises two sections that are installed at the top and bottom of the apparatus, as shown in Figure 2a. Component 2 comprises two steel circles with diameters of 65 mm and a thickness of 10 mm, as shown in Figure 2b. Component 3 comprises two cylindrical rods, with 200 mm and

120 mm in length, 38 mm in width, and 15 mm in thickness, as shown in Figure 2c.

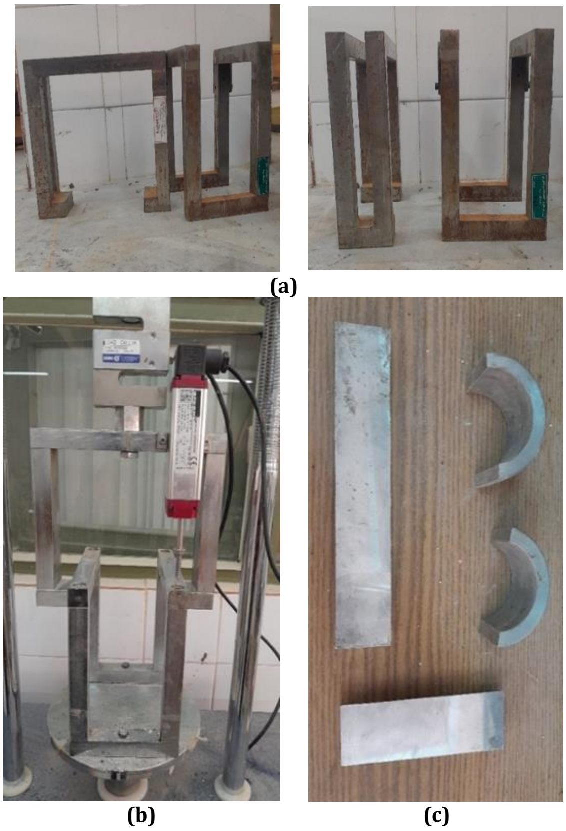

Fig. 2. Components of the compressive to tensile load converter (CTLC): (a) Jaws for direct traction, (b) Cylindrical rods and loading steel circles, and (c) CTLC apparatus assembly

The steps for setting up the CTLC apparatus are as follows:

- The concrete sample is placed along the top of the lower jaw of the apparatus, and the upper jaw is placed on the left and right sides of the sample.
- Two steel circles are inserted into the central hole of a rectangular sample, and a cylindrical rod is placed on the steel circle above the lower jaw of the apparatus, which holds the upper part of the sample. The second cylindrical rod is placed on the lower steel circle of the sample, on which the upper jaw of the apparatus is placed.

This apparatus is developed in such a way that the upper part of the concrete sample is in contact with the lower jaw of the apparatus, and the lower part of the concrete sample is in contact with the upper jaw of the apparatus. The lower jaw of the apparatus is movable and drives a cylindrical rod upwards, which compresses the upper part of the sample. So that the upper jaw of the apparatus is fixed, and the lower part holds the sample. As a result of applying force in the opposite direction, the lower part of the sample is also under pressure. It can be seen that the concrete samples are fractured under tension along the horizontal axis. The setup process of the compressive to tensile load converter is shown in Figure 3.

Fig. 3. The process of setting up the new apparatus based on the compressive to tensile load converter

The direct tensile strength is calculated using the compressive to tensile load converter from Eq. (2).

$$\sigma_\tau \frac{f}{(d_1 + d_2)\ x\ t} \qquad (2)$$

Where σ_τ is the tensile strength, f is the applied load in kg, (d1+d2) is the width of the fracture zone on both sides of the sample, and t is the sample thickness.

2.3. Sample Preparation Techniques

Rectangular concrete samples with a central hole are made from suitable mixtures: gravel, sand, and cement according to ASTM standards. The mentioned samples were prepared by considering 15% cement, 10% water, 43% sand, and 32% gravel, and were tested after a period of 28 days. These samples are 19 cm long, 16 cm wide, and 6 cm thick with a central hole diameter of 9 cm, as shown in Figure 4.

Fig. 4. Rectangular samples with a central hole

2.4. Determination Of Concrete Aggregates

First, to make concrete samples, a sand and gravel grading test was done. Therefore, in this topic, the sand and gravel grading test has been done considering standard sieves 12/5, 9/5, 6/3, 4/75, and 3/3 mm. A sand grading test was considered to determine the largest aggregate size and how it is distributed.

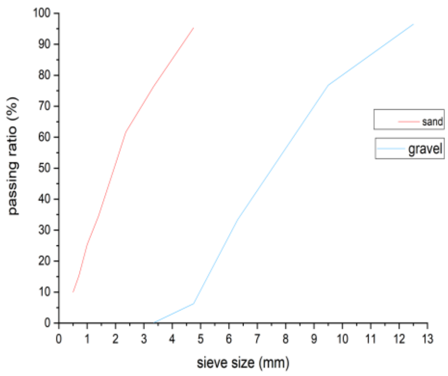

Fig. 5. The graph of the ratio of the percentage of passing the volume of aggregates to the size of the sieve.

From Figure 5, it can be concluded that in the desired mixing design, the size of aggregates (gravel) is between 3.35 and 12.5 mm, and the size of fine aggregates (sand) is between 0.5 and 4.75 mm.

2.5. Calibration Of New Direct Tensile Test Apparatus (CTLC)

CTLC is used to measure the tensile strength of concrete. This apparatus has a capacity of 5 tons of pressure load and records data such as time, load, and displacement to the computer through a cable with Serial Port Monitor software. For the calibration of the new direct tensile test apparatus based on the compressive to tensile load converter, two types of materials— concrete and gypsum— have been used. Rectangular concrete samples with a central hole and Brazilian samples were prepared to measure the tensile strength, considering the same mixing design and the same duration. Rectangular concrete samples with central holes were subjected to direct tensile loading by the CTLC apparatus with a constant loading rate. The results obtained from the direct tensile test were compared with the results of the Brazilian test.

2.5.1. Determining the direct tensile strength test of concrete

Rectangular concrete samples with a central hole were subjected to direct tensile loading by the CTLC apparatus with a constant loading rate of 10 kg/s. This loading rate is within the recommended range for the Brazilian test. All samples were subjected to direct tensile loading, cracks were created along the horizontal line from the center of the hole, and as a result, the said samples were broken. The loading arrangement of a rectangular sample with a central hole under the CTLC apparatus is shown in Figure 6.

Fig. 6. Rectangular specimen with a central hole under CTLC loading

In Figure 7, it can be seen that all the samples were measured under direct tensile loading using the CTLC apparatus. The results indicate that the samples fractured along a horizontal line from the center of the hole.

Fig. 7. Fracture mode of samples under direct tensile loading

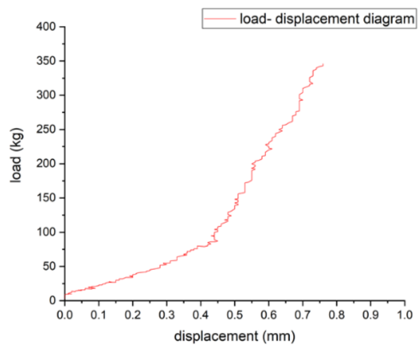

Fig. 8. The diagram of the ratio amount of applied load to displacement

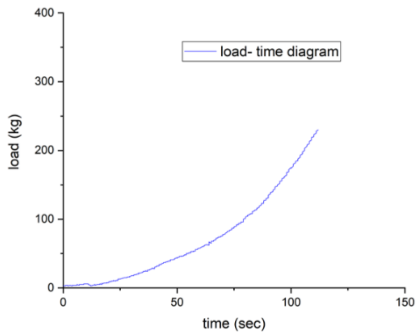

Fig. 9. The graph of the amount of load in relation to time

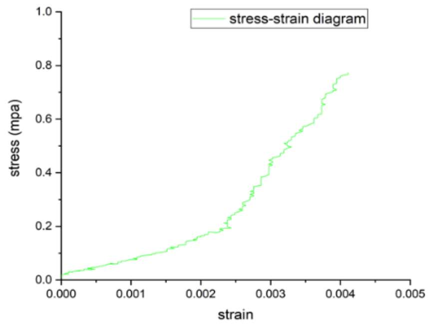

Fig. 10. Diagram of stress-strain ratio

Figures 8 and 9 show that the vertical axis is the load and the horizontal axis is the displacement, and time. The results show that with increasing displacement and time, the load increased. The concrete specimen prepared under tension with a force of 346 kg with a displacement of 0.76 mm in 129 seconds led to failure. Figure 10 also shows the stress-strain ratio, which shows that with increasing strain, stress also increases.

The direct tensile strength of concrete samples has been calculated considering Eq. (2), the results of which are shown in Table 3.

From Table 3, it can be concluded that seven concrete samples in the same loading conditions and dimensions were subjected to the loading of the compressive to tensile load converter apparatus, each of which had different results, and as a result, its average value is 0.65 MPa. This value is the direct tensile strength of concrete.

Table 3. Result of the direct tensile strength test of concrete under CTLC apparatus

Mix design	Components	Values %	Test Method	Tensile strength (MP)
Proper mixing design with Portland cement for 28 days	Water	10	Direct tensile	0.62
	Cement	15	Direct tensile	0.65
	Sand	43	Direct tensile	0.71
			Direct tensile	0.58
			Direct tensile	0.68
	Gravel	32	Direct tensile	0.60
			Direct tensile	0.72
			average	0.65

2.5.2. Determination of the direct tensile strength test of gypsum

Gypsum samples were made as rectangular samples with a central hole, with one-third of water, and then dried at room temperature. These samples were tested under the new direct tensile test apparatus after 48 hours, considering the mixing plan and duration similar to the Brazilian sample. The direct tensile strength of gypsum samples has been calculated considering Eq. (2), the results of which are shown in Table 4. The process of testing gypsum samples under the compressive to tensile load converter test apparatus is shown in Figure 11.

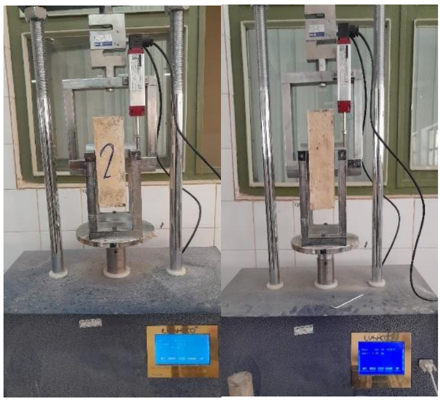

Fig. 11. Rectangular gypsum specimen with a central hole under CTLC loading

The state of failure of the gypsum sample after testing under the direct tensile testing machine of the compressive to tensile load converter is shown in Figure 12. The failure mode of the gypsum samples indicates that the samples were crushed under tension.

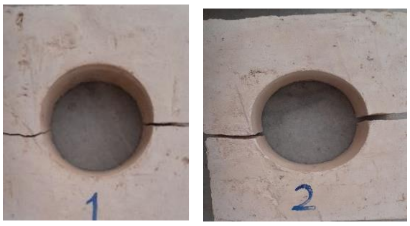

Fig. 12. Fracture mode of samples under direct tensile loading

Table 4. Result of the direct tensile strength test of gypsum under CTLC apparatus

No	Test Method	Time(hour)	Tensile strength(MP)
1	Direct tensile	48	0.58
2	Direct tensile	48	0.51
3	Direct tensile	48	0.65
	average		0.58

Table 4 shows that the average direct tensile strength of gypsum is 0.58 MPa.

2.5.3. Comparison of the Brazilian test and direct tensile test

The Brazilian test is an indirect tensile test used to determine tensile strength. The results show that the Brazilian test determines the tensile strength more. To determine the direct tensile strength of concrete, a new direct tensile test apparatus based on a compressive-to-tensile load converter was used. The failure in the new direct tensile test is the failure that occurred along the horizontal axis with the help of two cylindrical bars. The results obtained from this new direct tension apparatus with a loading speed of 10 kg/s have provided reasonable and acceptable results for determining the tensile strength of concrete compared to the Brazilian test. The comparison of Brazil's test results and direct stress is shown in Table 5. For the validation of the CTLC, about 30 samples were selected, including concrete and gypsum. Different mixing designs were investigated, and the validity of the device was evaluated and confirmed with respect to this wide range of data. A limited number of results are presented in Tables 3 and 4, which are representative of each series of samples. The results of this study show that the CTLC test device is in accordance with reality.

Table 5. Comparison of the results of the new direct tensile test apparatus compared to the Brazilian apparatus

Materials	Concrete	Gypsum
Average direct tensile strength (MP)	0.65	0.58
Average Brazilian tensile strength (MP)	0.88	0.78
Difference between direct and Brazilian tensile strength	26.1%	25.6%

2.5.4. Comparing the results of the direct tension test with the performed work

In this discussion, a direct tensile test device based on a compressive-to-tensile load converter for determining direct tensile strength is reviewed according to the work of researchers.

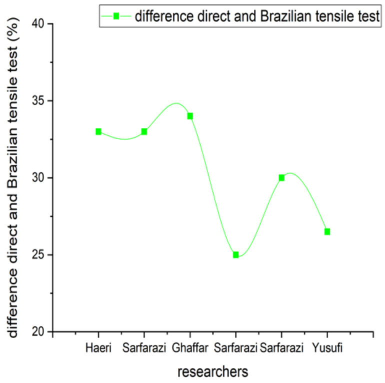

Fig. 13. Diagram of the difference between the direct and Brazilian tensile strength tests based on the researchers' work

Figure 13 shows the difference between direct and Brazilian tensile strength tests performed by researchers in previous years. In this research, the difference of the direct tensile strength test using the compressive to tensile load converter apparatus with the Brazilian sample was 26.1%, which was compared with the works of other researchers.

This difference is usually due to reasons such as loading method, sample size, sample mixing design, and simplifications made by some inventors of these devices. However, the most important issue in validating these results is the common trend in concrete tensile strength and the effect of various factors on its strength.

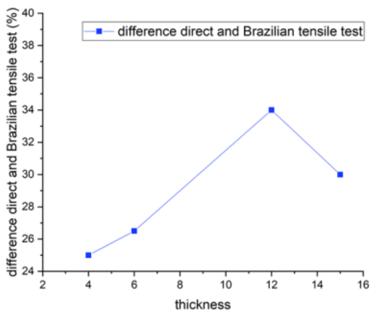

Fig. 14. Tensile strength test diagram according to sample thickness

Figure 14 shows the percentage difference between the Brazilian and tensile strength tests based on the thickness of the concrete samples. As a result, it can be said that by changing the size of the thickness of the sample and the test method, the size of the direct tensile strength of concrete changes. From this graph, it can be concluded that the concrete tensile strength test is influenced by the dimensions of the sample.

3. INVESTIGATING THE EFFECT OF LOADING RATE AND DIFFERENT MIXING DESIGNS ON DIRECT TENSILE STRENGTH

In this section, the effect of loading rate and different mixing designs with the newly developed apparatus was investigated. Rectangular concrete samples with a central hole made of suitable sand, gravel, and cement mixtures with different mixing designs have been prepared and examined. Concrete samples were made according to ASTM standards from four different mixing designs with the same duration. From each type of mixing design, 3 rectangular concrete samples with a central hole were repeatedly tested to increase the accuracy of the results under the CTLC test. A concrete sample with a duration of 7 days has been tested under a new direct tensile testing apparatus, considering the mixing design and different loading rates. The amount of loading considered to determine the direct tensile strength of concrete using the new direct tensile apparatus is 5, 10, and 15 kg/s. The characteristics of the mixing design are shown in Table 6, which shows that the amounts of fine grains (sand) have decreased from the first to the fourth mixing design.

Table 6. Specification of concrete mixing design to investigate tensile strength

Different types of mixing designs to check the tensile strength of concrete				Parameter
m_4	m_3	m_2	m_1	Component
15%	15%	15%	15%	Cement
10%	10%	10%	10%	Water
25%	39%	40%	45%	Sand
50%	36%	35%	30%	Gravel

From Table 6, it can be concluded that four types of mixing design have been considered to investigate the tensile strength of concrete, that the mixing design m1 comprises of 45% sand, 30% gravel, 10% water, and 15% cement. The direct tensile strength of concrete under the CTLC apparatus was calculated from Eq. (1) by considering different loads and different mixing designs, and its average value for each mixing design is shown in Table 7.

Table 7. Direct tensile strength test results under the influence of different loading rates and different mixing designs

Direct tensile strength with different mixing designs (MP)				Variables
m_4	m_3	m_2	m_1	Loading rate
0.43	0.65	0.68	0.8	5kg/s
0.46	0.66	0.69	0.84	10kg/s
0.67	0.67	0.71	0.89	15kg/s

Table 7 shows the direct tensile strength values considering different mixing designs and different loading rates. The results show that the direct tensile strength increased with increasing loading rate and sand aggregates. Therefore, according to Table 7, the tensile strength is increased from m4 to m1 mixing design.

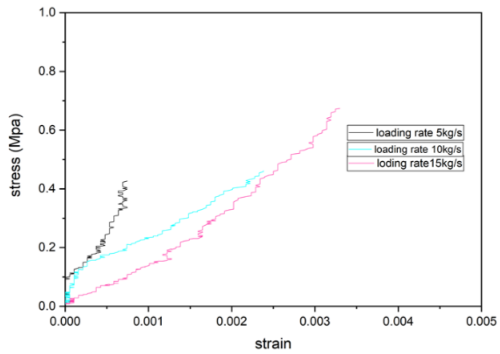

Fig. 15. Diagram of stress-strain ratio

It is shown in Figure 15 that the diagram of the ratio of stress to strain with mixing scheme number 4 is the ratio of sand to sand (25/50), 25% sand and 50% gravel. The results obtained from this graph show that the stress and strain increased with increasing loading rate from 5 to 10 and 15 kg/s.

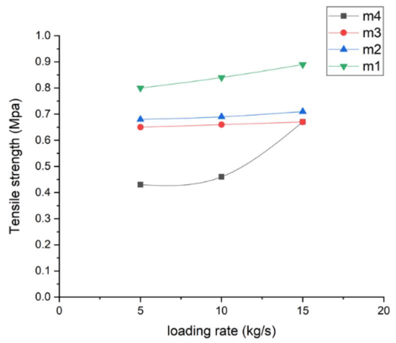

Fig. 16. Diagram of the ratio of tensile strength to loading rate with different mixing designs

Figure 16 shows four types of mixing designs with three loading rates tested under the new direct tensile testing machine. The results show that the direct tensile strength increased with increasing loading rates from 5 to 10 and 15 kg/s and sand to gravel ratios.

4. EFFECT OF LOADING RATE AND MIXING DESIGN ON BRAZILIAN TENSILE STRENGTH

The effect of loading rate and different mixing designs was investigated using the Brazilian tensile test. Brazilian samples of suitable mixtures: gravel, sand, cement, and water have been made, considering four different mixing designs based on ASTM standards. 3 Brazilian samples for each mixing design were subjected to Brazilian testing after seven days, considering different loading rates and different mixing designs. Brazilian tensile strength is calculated from Eq. (1), and its average for each mixing design is shown in Table 8.

Table 8. Brazilian tensile strength test results according to displacement rate and mixing design

Brazilian tensile strength with different mixing designs (MP)				Variables
m_4	m_3	m_2	m_1	Loading rate
0.58	0.68	0.76	0.82	2mm/min
0.61	0.76	0.92	1.1	2.5mm/min
0.68	1.07	1.1	1.24	3mm/min

Table 8 shows that with the increase of loading rate based on displacement from 2 to 2.5 and 3 mm/min according to different mixing designs, the tensile strength of Brazil has an increasing trend. In all mixing designs, the amount of water is 10% and cement is 15%, and only the ratio of sand to gravel changes. In mixing design number 1, the ratio of sand to gravel (45/30), sand is 45% and gravel is 30%.

The following are the mixing designs numbers 1 to 4:

- Mixing design number 1, the ratio of sand to gravel (45/30)
- Mixing design number 2, the ratio of sand to gravel (40/35)
- Mixing design number 3, the ratio of sand to gravel (39/36)
- Mixing design number 4, the ratio of sand to gravel (25/50)

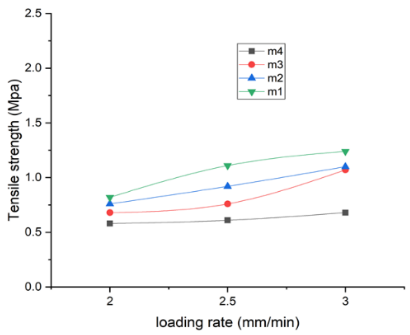

Fig. 17. Graph of the ratio of Brazilian tensile strength to displacement rate with different mixing designs

Figure 17 shows four types of mixing designs with three different loading rates from the Brazilian experiment. The results show that the tensile strength of Brazil increases with the increase in displacement loading rate and sand-to-gravel ratio. Then, by comparing the results of the Brazilian test and the direct tensile test, it has been investigated regarding the effect of loading rate and different mixing designs on the tensile strength of concrete. Brazilian tensile test with different loadings of 2 mm, 2.5 mm, and 3 mm/min, and direct tensile test with different loadings of 5 kg, 10 kg, and 15 kg/s were performed with the same mixing design. The results of the two test methods show that, as shown in Figure 16, the tensile strength increases with the increase in the loading rate.

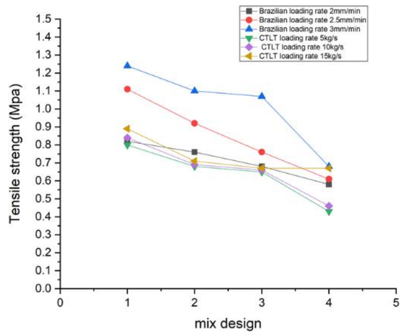

Fig. 18. Graph of the ratio of direct and Brazilian tensile strength to mixing design

From Figure 18, it can be concluded that the direct tension test with a loading rate of 10 kg/s and the Brazilian test with a displacement loading rate of 2 mm/min show similar and suitable results for the tensile strength of concrete.

5. DISCUSSIONS

In the newly developed direct tension apparatus based on the compressive to tensile load converter, it is easy to mount the specimen and apply the load. The amount of tensile strength obtained by this method is close to reality. Also, this apparatus can accurately display the behavior model of brittle materials such as concrete and rock. Then, the effect of loading rate and different mixing designs was investigated with two test methods, a direct tensile test using a compressive to tensile load converter and a Brazilian tensile test. The results obtained from the direct tensile test were compared with the Brazilian test. The results of the Brazilian test show that increasing the displacement-based loading rate from 2 mm/min to 3 mm/min, with a specific mixing design, increases the tensile strength from 0.82 MPa to 1.24 MPa.

The direct tensile test using a compressive to tensile load converter has shown that the tensile strength of concrete with a loading rate of 10 kg/s is 0.84 MPa. When the loading rate was increased to 15 kg/s, the tensile strength of the concrete was 0.89 MPa, close to the Brazilian tensile strength. The tensile strength of concrete was investigated according to different mixing designs. The results showed that the tensile strength of concrete increased with the increase in the ratio of sand to gravel in the mixing design.

In mixing design number 1, the sand-to-gravel ratio is (45/30), the Brazilian test shows the tensile strength of concrete to be 0.82 MPa, and in mixing design number 4, the sand-to-gravel ratio is (25/50), the tensile strength of concrete is 0.58 MPa. In mixing design number 1, the sand-to-gravel ratio is (45/30), The direct tensile test using a compressive to tensile load converter shows the tensile strength of concrete to be 0.8 MPa, and in mixing design number 4, the sand-to-gravel ratio is (25/50). The tensile strength of concrete is 0.43 MPa.

Figure 19 shows that the more homogeneous the material, the smaller the difference between tensile strength and Brazilian strength. The results show the heterogeneity of concrete compared to plaster, and that the percentage difference between tensile strength and Brazilian strength is higher.

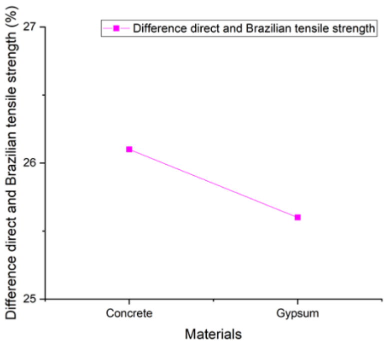

Fig. 19. Percentage difference between direct and Brazilian tensile test results according to material type

In Figure 20, the percentage difference between the direct tensile strength test results under the compressive to tensile load converter apparatus and the Brazilian test apparatus, considering different loading rates, is investigated. The results have shown that by increasing the loading rate of the compressive to tensile load converter test machine and keeping the loading rate of the Brazilian test machine constant, the direct tensile strength results are almost the same as the results of the Brazilian test. Compared to previous laboratory methods, such as the Brazilian method, the CTLC test may better approximate the reality of concrete and rock mass. On the other hand, access to some laboratory tests is limited, but this device has made it possible to determine the tensile strength of concrete and rock.

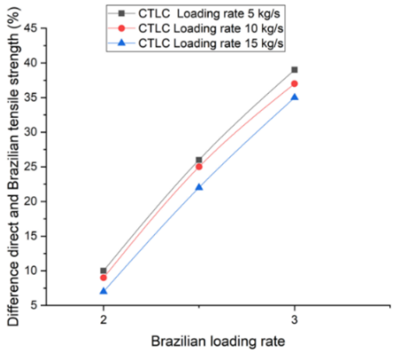

Fig. 20. Percentage difference between direct and Brazilian tensile test results according to loading rate

6. CONCLUSION

The direct tensile strengths of brittle materials such as rocks and concretes can be measured by a new apparatus based on the concept of compressive to tensile load transferring approach. In this research, calibration of the new direct tension apparatus was performed for two types of brittle materials i.e., gypsum and concrete, considering different loading rates and different mixing designs. The rectangular concrete samples with a central hole were prepared for measuring the direct tensile test by a CTLC apparatus at different loading rates. The Brazilian discs were also prepared and tested under vertical force with a constant loading speed of 0.03 mm/s according to standard conditions. The results obtained from the direct tension tests were compared with those gained from Brazilian tensile strength tests, and the following main conclusions were obtained:

- Rectangular gypsum samples with a central hole were tested under a compressive to tensile load converter apparatus with a loading rate of 10 kg/s, and a Brazilian disc sample with a length-to-diameter ratio of 0.5 with a loading rate of 0.03 mm/s. The direct tensile strength is about 25.6% less than that measured by the Brazilian test.
- The results obtained from the direct tensile strength measuring apparatus were compared with the works of other researchers, which showed very close agreement with their results.
- The effects of loading rate and different mixing designs on the tensile strength of concrete specimens were investigated by the two testing methods. It has been shown that the results obtained from the present work demonstrate that tensile strength

increases with the increase in the loading rate and the ratio of sand to gravel.

- The results show that the direct tensile strength test yields significantly lower values (26.1% on average) for the tensile strength of concrete samples compared to the Brazilian tests.

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