Techno-Science Research Journal V14 (1) (2026) P 7-14

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Techno-Science Research Journal

Journal Homepage: http://techno-srj.itc.edu.kh/

Techno-Science Research Journal

Determination of Mechanical Properties of Cambodian Sandstone using the Brazilian Test and the Semi Circular Bending Test

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Received: 16 June 2025; Revised: 26 August 2025; Accepted: 10 September 2025; Available online: April 2026

Abstract: *Sandstone was widely used in Cambodian ancient structures such as temples, bridges, and statues. However, studies on its mechanical properties including tensile strength, Young's modulus, and Poisson's ratio remain insufficiently studied. This study aims to determine the mechanical properties of Cambodian sandstone. Brazilian tests coupled with the Digital Image Correlation (DIC) method, were conducted on seven samples of sandstone to find the tensile strength and analyze the displacement fields of stone samples during applied loading. Furthermore, the strain obtained from DIC was used to determine Poisson's ratio and Young's modulus. The results showed that the tensile strength, Young's modulus, and Poisson's ratio have values of 21.67 MPa, 34.82 GPa, and 0.27 respectively. On the other hand, the fracture path of the samples could not be observed properly because the specimens failed abruptly after reaching peak load. However, the failure patterns of the Brazilian samples were in the center of the specimen which agreed with the literature review. To compare the displacement fields obtained from DIC, the finite element method (FEM) was carried out by using Abaqus software. Moreover, the Semi-Circular Bending (SCB) test was performed to determine fracture toughness using two different notch lengths. In conclusion, tensile strength and fracture toughness can be reliably measured, whereas the determination of Young's modulus and Poisson's ratio using DIC still requires further investigation to improve its accuracy.*

Keywords: Sandstone, Tensile Strength, Mechanical Properties, Digital Image Correlation, Brazilian Test, Finite Element Method

1 INTRODUCTION

Sandstone is a type of rock which is commonly found in Southeast Asia, especially in Cambodia. Sandstone was used for various purposes such as statues and architectural elements, several centuries ago during the reign of the Khmer Empire [1]. On the other hand, understanding the mechanical properties such as tensile strength, Young's modulus and Poisson's ratio of sandstone are essential for engineering applications, particularly in structural design and disaster mitigation. Uchida, Etsuo, et al., 2020 [1] provided an in-depth analysis of the supply ranges of stone blocks used in masonry bridges and their construction period along the East Royal Road in the Khmer empire in Cambodia. However, they noted that less research had been conducted to study the mechanical properties of sandstone used in Cambodian temples. Wedekind et al., 2020 [2] also recommends investigating sandstone mechanical properties to understand their durability and preservation.

There are several methods to determine the mechanical properties of sandstone like compression, three point bending test, and Brazilian tests. The Brazilian test, also known as one of the indirect tensile tests, was introduced to determine the tensile strength of material by applying a diametral compressive loading to a cylindrical stone specimen until it fails [3]. There are several loading configurations of Brazilian test namely (a) type I, flat to point platen [4], (b) type II, arch to arch platen [5], (c) type III, flat to flat [6] as shown in

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DOI : https://doi.org/10.64702/Techno-SRJ.2026.V14.I1.02

Published by Institute of Technology of Cambodia.

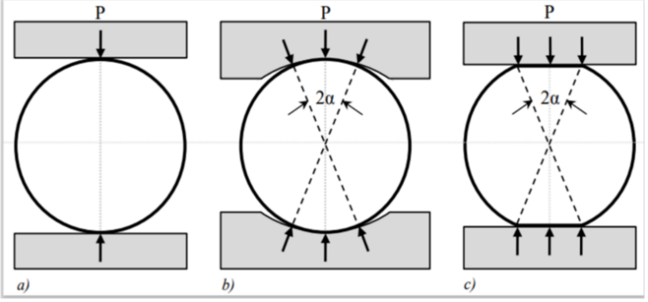

Fig. 1. Type I and Type III loading configuration have shown high strain concentrations at the contact zones between the platens and the specimen. According to [7], Type II has shown good tensile strength results and was recommended to be used among all of three types.

However, one limitation of the Brazilian Test is that it is not possible to measure the fracture properties. A semi-circular bending (SCB) test was suggested by [8], to study the fracture toughness of brittle materials such as stone, by introducing a notch on the middle of specimen and to evaluate the fracture resistance of the material under a specific loading configuration. The SCB test offers advantages over indirect tensile test including simple setup, easy specimen preparation, high fracture sensitivity, and good repeatability [9]. First introduced by [10], and later refined by [11], SCB test involves vertical compressive loading in a three-point bending setup similar to the Chevron notch bending test [20].

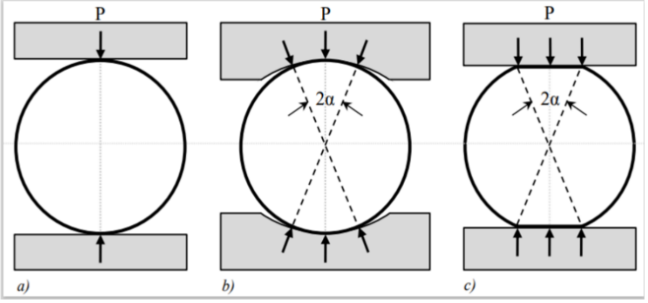

Fig. 1 Loading methods a) flat-point [4], b) arch-arch [5] and c) flat-flat [6].

Moreover, while challenges persist in the observation of strain fields, Digital Image Correlation (DIC) stands out as a non-contact method for detecting full-field displacement measurements. A study by [7] employed the Brazilian test in conjunction with DIC to investigate mechanical properties of rock material. Alternatively, [12] proposed a method based on the displacement field obtained from DIC, using four points on the specimen to estimate the material properties. Furthermore, they conducted a comparison of the Poisson's ratio obtained from the compressive strength test and the Brazilian test. As a result, the two test methods gave practically identical values for determining the Poisson's ratio. Finally, [13] and [21] compared the strain field results from DIC and the Finite Element Method (FEM) to identify differences from the experimental outcomes.

Therefore, the purpose of this study is to identify the mechanical properties of Cambodian sandstone by using Brazilian test coupled with DIC. Furthermore, displacement fields obtained from experiment are compared with FEM. Additionally, SCB test are used to obtain fracture toughness of Cambodian sandstone.

2 METHODOLOGY

2.1 Sample collection and preparation

2.1.1 Brazilian Sample

In this study, sandstone was collected in Cambodia from Chaas Mountain (ភ្នំចាស់, Preah Vihear province) which is located near Preah Khan Kompong Svay (ប្រាសាទព្រះខ័នកំពង់ស្វាយ) temple as shown in Fig. 2. This location was chosen because a sandstone deposit of the same type as that used for the Jayavarman VII statue had been identified [23]. Unfortunately, the collection location shown in Fig. 2 does not correspond to this location [24]. To begin, the stone was washed to remove the dust and was cored by a 54 mm diameter drilling machine and was cut into 7 samples with a thickness of approximately 15 mm as shown in Fig. 3. Then, these seven specimens were stored at room temperature following procedure described in [4] (approximately 25 ± 2°C temperature and 60 ± 5% of humidity).

Fig. 2 Map location (google map) and sample block of sandstones.

White painting was applied on all specimens as background and a black aerosol spray was used to create a speckle pattern for displacement measurement using the DIC method.

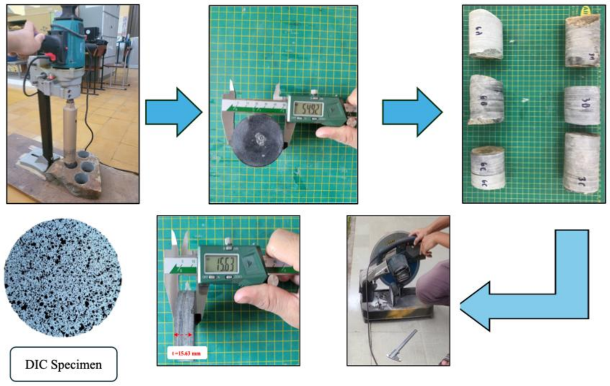

Fig. 3 The Preparation of Brazilian Test Sample.

2.1.2 Semi Circular Bending Sample

SCB samples are obtained by drilling a new core and cutting in two a cylinder of rock with approximately thickness (B)= 30mm and radius (R)= 38mm from the same sandstone block from which the Brazilian test specimens were extracted (Fig. 4). Then, a notch with the desired dimensions is introduced. Two notches lengths (a=16 mm and 18 mm) were made to investigate their influence on the test results. Five specimens were subjected to SCB test to observe their fracture behavior (Fig. 4).

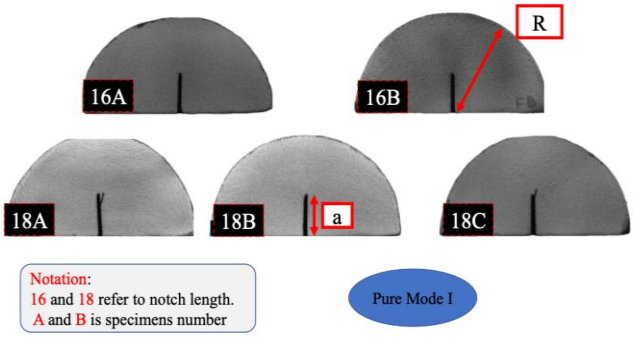

Fig. 4 The Finalize of SCB Test Sample.

2.2 Experimental Setup

The experimental setup recommended by the ISRM [5], in which the Brazilian sample is placed between the loading fixtures, was used (see Fig. 5). The Sandstone specimens were placed and attached with the Brazilian Test setup, compression was applied using a Universal Testing Machine with a displacement control, with a speed of 0.2 mm/min.

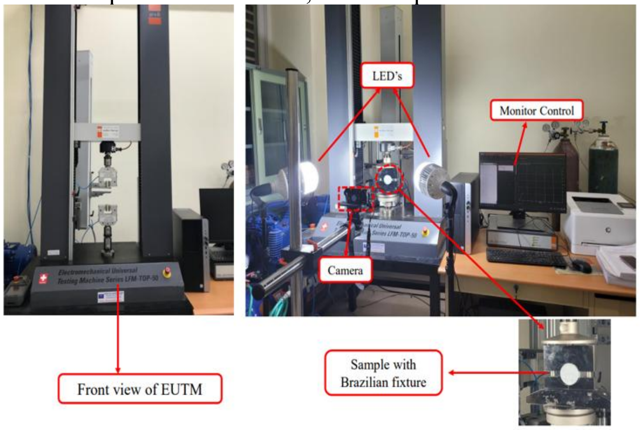

Fig. 5 The Experimental Setup for Brazilian Test.

The DIC apparatus was also set up during the experiment. A high-resolution camera with 100 frames per second (fps) was positioned perpendicular to the specimen surface (at a distance of 0.2 m) to measure the displacement of the specimen's surface. Two LED lights were positioned to ensure homogeneous illumination across the specimen surface, thereby minimizing shadowing effects and enhancing the reliability of DIC data acquisition.

The tensile strength σ_t is defined as the maximum stress that a material can withstand before breaking under tension. The suggested formula for calculating the splitting tensile from Brazilian force-displacement curves is [4]:

$$\sigma_t = \frac{2P}{\pi t D} \qquad \text{(Eq. 1)}$$

where: σ_t=tensile strength [MPa], P=maximum applied load [N], t=specimen thickness [mm], D= specimen diameter [mm].

2.3 SCB Test

SCB tests were conducted to determine the fracture toughness, which cannot be obtained from Brazilian tests. As mentioned in Fig. 6**,** sandstone specimen was placed on the two-roller support and a compressive load was applied at the top center using a rigid compression platen. The applied displacement rate is 0.05 mm/min which is within the range recommended by [8]. The distance between the two lower support is $2S = 60$ mm as recommend by [8].

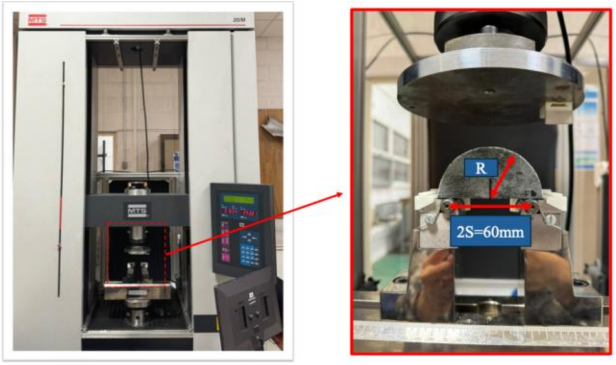

Fig. 6 The Experimental Setup for SCB Test.

The fracture toughness K_{IC} describes the resistance of brittle materials to a crack propagation under a mode I. This mode responds to a crack submitted to tensile load (Fig. 7).

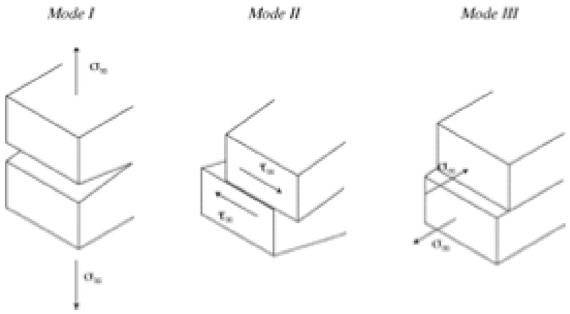

Fig. 7 Crack propagation mode [22].

It is calculated using the equation proposed by [8]

$$K_{IC} = Y' P_{max} \frac{\sqrt{\pi a}}{2RB} \qquad \text{(Eq. 2)}$$

with

$$\begin{aligned} Y' &= -1.297 + 9.516\left(\frac{S}{2R}\right) \\ &-\left(0.47 + 16.457\left(\frac{S}{2R}\right)\right)\left(\frac{a}{R}\right) \\ &+\left(1.071 + 34.401\left(\frac{S}{2R}\right)\right)\left(\frac{a}{R}\right)^2 \end{aligned} \qquad \text{(Eq. 3)}$$

where: K_{IC}=Fracture toughness $[MPa\sqrt{mm}]$, P_{max}=Maximum applied load $[N]$, Y'=non dimensional stress function [8], a=specimen notch length $[mm]$, R=specimen radius $[mm]$, B= specimen thickness $[mm]$.

2.4 *Strain Measurements from DIC*

Based on [12], four points are used on the surface of DIC software to extract the displacement value (see in Fig. 8).

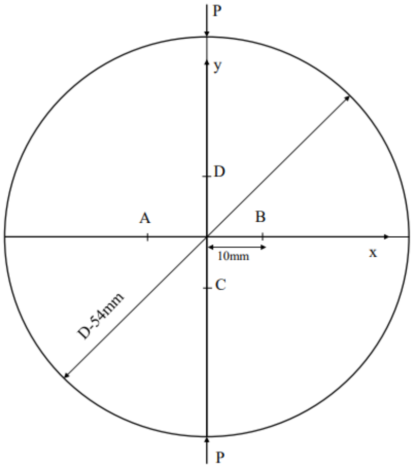

Fig. 8 The reference points for displacement measurement.

The displacements at the corresponding point pairs A–B and C–D were analyzed. The DIC data were examined in terms of horizontal and vertical displacement components (D_{xx} and D_{yy}) as functions of the applied load (P) at the center of the Brazilian disk specimen.

Upon completion of the DIC analysis, the displacements at the four critical points under peak load were extracted. This approach follows the methodology introduced by Hondros (1959). These displacement values were then substituted into the relevant strain calculation (Eq. 4) and (Eq. 5) to determine the corresponding strain values:

$$\epsilon_{xx} = \frac{(x_d^B - x_d^A)}{(x^B - x^A)} \qquad \text{(Eq. 4)}$$

and

$$\epsilon_{yy} = \frac{(y_d^D - y_d^C)}{(y^D - y^C)} \qquad \text{(Eq. 5)}$$

where x_d^A and x_d^B are the x-displacement at points A and B which are symmetric about the origin; x^A and x^B are the x-coordinates at A and B. Similarly, y_d^C and y_d^D are the y-displacements at Points C and D which are symmetric about the origin; y^C and y^D are the y-coordinates at C and D.

2.5 *Poisson Ratio and Young Modulus Calculation*

Using DIC technique, [14] introduced a method to calculate the Poisson's ratio from the displacement along horizontal and vertical lines in the Brazilian Test. These values are then exported into (Eq. 6) and (Eq. 7) which were developed from the continuum mechanic theory:

$$\nu = \frac{(3\epsilon_{xx} + \epsilon_{yy})}{(\epsilon_{xx} + 3\epsilon_{yy})} \qquad \text{(Eq. 6)}$$

in which ϵ_{xx} and ϵ_{yy} are the strain in x-direction and y-direction, respectively. Once the Poisson Ratio has been calculated, the Young's Modulus can be determined by:

$$E = \frac{2P(1-\nu^2)}{\pi t D(\epsilon_{xx} + \nu\epsilon_{yy})} \qquad \text{(Eq. 7)}$$

where: E=Young's Modulus $[MPa]$, P=Maximum applied load $[N]$, ν=Poisson Ratio.

2.6 Finite Element Modeling

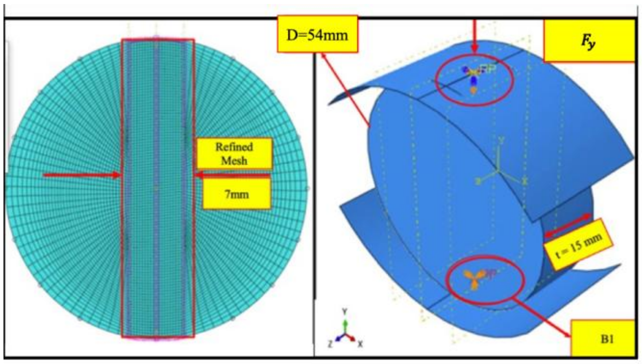

Fig. 9 Mesh Technique and Boundary condition of Brazilian Test.

As a complement to the DIC-based experimental investigations, finite element simulations under static conditions were carried out in Abaqus software [25] to compare with the measured displacement fields. Two rigid bodies and a deformable body were drawn with exactly the same geometry as in the experiment. The elastic material properties were obtained from (Eq. 6) and (Eq. 7), boundary condition are shown in Fig. 9. An applied force has been applied on the upper rigid body, while the lower one has been blocked. Frictionless contact (assumption) has been set between the cylinder and the rigid bodies.

To improve the accuracy of our model, a refined mesh was applied to the disk specimen and the element type C3D8R (3-dimensional linear 8-node elements with reduced integration) was used in this modeling.

Table 1. Boundary condition and material properties.

Parameter name	Characteristic	Description
F_y	Force	Experiment data
E	Young's modulus	
ν	Poisson's Ratio	
$B1$	Fixed BC	Blocked

3 RESULTS AND DISCUSSION

3.1 Tensile Strength by Brazilian test

The Force-Displacement curves for all the specimens (S-1 to S-7, corresponding to specimen identifiers) are shown in Fig. 10. They gradually increased until the peak load is reached and then they dropped, which is typical for brittle failure. The highest peak load can be found for the sample S-4 while the minimum peak load was reached for the sample S-6. Moreover, a small delay at the beginning of the force-displacement curve was observed for specimen S-4, likely due to a longer contact stabilization time between the loading platen and the specimen.

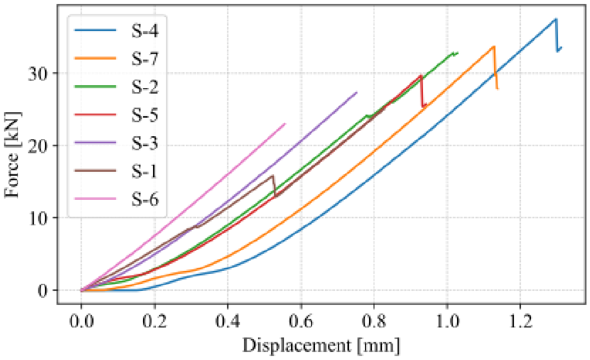

Fig. 10 The force-displacement curves for Brazilian Test.

We can observe that some specimens experience a slight drop in their force-displacement curves (S-1 and S-2), although the specimens continued to sustain load until final failure. This drop may have been caused by the initiation of a small crack at the contact points between the specimen and the loading (stress concentration) and which are temporarily stabilized by stress redistribution during failure.

These cracks can eventually propagate again when enough energy is stored in the sample (S-1 and S-2). At the beginning of the loading process, S-1, S-2, S-4, S-5 and S-7 have non-linear behavior; this is due to system setup defects and clearance suppression.

Table 1 summarizes the results for all the samples; detailing tensile strength which has been calculated by (Eq. 1). The results show that specimen S-6 had the lowest tensile strength at 16.97 MPa with a minimum load 22.99 kN. In contrast, the highest tensile strength and maximum peak load were recorded for specimen S-4 at 27.23 MPa and 37.54 kN, respectively. These results show that tensile stress increases with load until the tensile strength of the material is reached. Nevertheless, the standard deviation (Std) of tensile strength for all samples was 3.58 MPa.

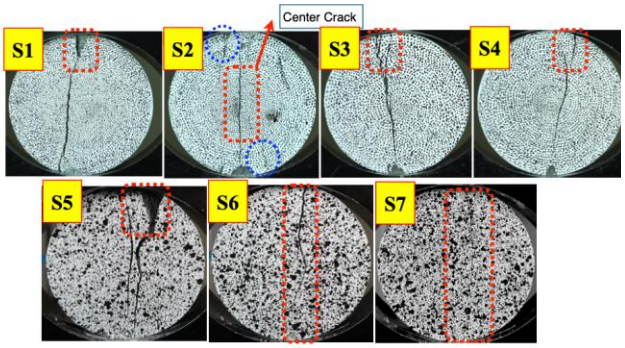

Fig. 11 Failure of all specimens.

Table 2. Total tensile strength results.

Specimens number	D [mm]	t [mm]	P_{max} [kN]	σ_t [MPa]
S-1	54.88	15.75	25.04	18.48
S-2	54.97	15.90	32.86	23.94
S-3	54.89	15.81	27.31	20.04
S-4	54.93	15.98	37.54	27.23
S-5	54.87	15.86	31.41	22.96
S-6	54.90	15.70	22.99	16.97
S-7	54.90	16.08	33.73	23.90
Mean value			30.12	21.93
Std			5.18	3.58

3.2 *Fracture toughness by SCB test*

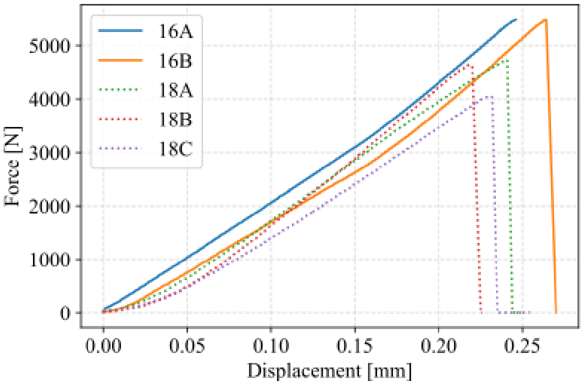

Fig. 12 The Force -Displacement Curves for SCB test.

As a result, the specimen dimensions and failure loads are shown in Table 3. specimens notch length 16A and 16B reached the same peak load of approximately 5.5 kN, and then gradually dropped as shown in Fig. 12.

By using (Eq. 2), the K_{IC} values for specimens 16A and 16B are estimated to 91.17 $MPa\sqrt{mm}$ and 81.80 $MPa\sqrt{mm}$, respectively. The differences in values may be attributed to slight imperfections in the sample geometries. Additionally, for specimens 18A and 18B, the K_{IC} values are nearly the same, except for 18C. Geometric inconsistencies likely influenced the results, highlighting the need for stricter control in future work.

Table 3. Total fracture toughness results.

Specimens	R [mm]	B [mm]	a [mm]	P_{max} [kN]	K_{IC} [$MPa\sqrt{mm}$]
16A	37.73	31.10	15.70	5.48	91.17
16B	39.19	30.56	15.53	5.48	81.90
18A	38.75	31.13	17.25	4.72	81.80
18B	38.95	30.77	17.75	4.62	83.10
18C	39.19	30.79	17.93	4.03	72.06
Mean value				4.84	82.00
Std				0.62	6.78

3.3 *Young Modulus and Poisson Ratio*

Based on the strain value obtained from DIC analysis by using (Eq. 4) and (Eq. 5), Table 4 reports Young's modulus and Poisson's ratio for the seven samples. As indicated by (Eq. 7), greater resistance to applied load reflects a higher Young's modulus of the material. However, the results of this study do not seem to follow this expected trend. This deviation may be attributed to the presence of internal cracks or secondary crack which can significantly impact the material's elastic properties (see in Fig. 11).

Table 4. Results of Young's modulus and Poisson ratio.

Specimens Number	Young's Modulus [GPa]	Poisson Ratio
S-1	31.21	0.29
S-2	33.90	0.18
S-3	22.26	0.28
S-4	37.95	0.25
S-5	35.00	0.33
S-6	40.67	0.22
S-7	35.73	0.35
Mean value	34.82	0.27
Std	3.57	0.05

Nevertheless, the values for Young's modulus and Poisson's ratio can be considered acceptable since they are within expected ranges of previous studies made on sandstone from the Angkor region [14]. However, the results still need to be refined further with different methods and a review of the specimen geometry for the Brazilian Test.

4 CONCLUSIONS

In this study, Cambodian sandstone mechanical properties were determined from the Brazilian test technique in conjunction with DIC. Furthermore, FEM were compared to experimental results. As a result, the average tensile strength of the sandstone was found to be 21.93 MPa. Using the Semi-Circular Bending (SCB) test, fracture toughness values corresponding to two different notch lengths were found to range from 72.06 $MPa\sqrt{mm}$ to 91.17 $MPa\sqrt{mm}$. While the measured fracture toughness seems to decrease with increasing notch length, this is inconsistent with the theoretical nature of K_{IC} which should be independent of specimen geometry. This suggests that further research is required to understand the observed behavior. Other mechanical properties, such as Young's modulus and Poisson's ratio, should be refined in future work to improve accuracy.

ACKNOWLEDGMENTS

The author would like to thanks the Laboratoire des Science des Procédés et des Matériaux (LSPM-CNRS), and Université Sorbonne Paris Nord for the funding of the internship, and support. The mobility to USPN has been funded by the KA171 ERASMUS project 2022-1-FR01-KA171-HED-000077566.

REFERENCES

[1] Uchida, E., Watanabe, R., Murasugi, M., Sakurai, Y., & Shimoda, I. (2020). The sandstone quarries of the Angkor monuments in the southeastern foothills of Kulen Mountain. *Archaeological Discovery*, *8*(3), 207. https://doi.org/10.4236/ad.2020.83012

[2] Wedekind, W., Gross, C., van den Kerkhof, A., & Siegesmund, S. (2016). Contour scaling at the Angkor temples: Causes, consequences and conservation. *Science and Art: A Future for Stone*, 205.

[3] Li, D., & Wong, L. N. Y. (2013). The Brazilian disc test for rock mechanics applications: Review and new insights. *Rock Mechanics and Rock Engineering*, *46*(2), 269–287. https://doi.org/10.1007/s00603-012-0257-7

[4] ASTM International. (2008). *Standard test method for splitting tensile strength of intact rock core specimens (ASTM D3967-08)*. ASTM International. https://doi.org/10.1520/D3967-08

[5] International Society for Rock Mechanics (ISRM). (1978). Suggested methods for determining tensile strength of rock materials. Part 2: Suggested method for determining indirect tensile strength by the Brazilian test. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, *15*(3), 99–103. https://doi.org/10.1016/0148-9062(78)90904-2.

[6] Wang, Q. Z., & Xing, L. (1999). Determination of fracture toughness K_{IC} by using the flattened Brazilian disk specimen for rocks. *Engineering Fracture Mechanics*, *64*(2), 193–201. https://doi.org/10.1016/S0013-7944(99)00080-7

[7] Li, D., Li, B., Han, Z., & Zhu, Q. (2020). Evaluation on rock tensile failure of the Brazilian discs under different loading configurations by digital image correlation. *Applied Sciences*, *10*(16), 5513. https://doi.org/10.3390/app10165513.

[8] Kuruppu, M. D., Obara, Y., Ayatollahi, M. R., Chong, K. P., & Funatsu, T. (2014). ISRM-suggested method for determining the mode I static fracture toughness using semi-circular bend specimen. *Rock Mechanics and Rock Engineering*, *47*, 267–274. http://dx.doi.org/10.1007/s00603-013-0422-7

[9] Zhang, J., Little, D. N., Grajales, J., You, T., & Kim, Y. R. (2017). Use of semicircular bending test and cohesive zone modeling to evaluate fracture resistance of stabilized soils. *Transportation Research Record*, *2657*(1), 67–77. https://doi.org/10.3141/2657-09.

[10] Chong, K. P., & Kuruppu, M. D. (1984). New specimen for fracture toughness determination for rock and other materials. *International Journal of Fracture*, *26*(2), R59–R62. https://doi.org/10.1007/bf01157555

[11] Lim, I. L., Johnston, I. W., Choi, S. K., & Boland, J. N. (1994). Fracture testing of a soft rock with semi-circular specimens under three-point bending. Part 1—Mode I. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, *31*(3), 185–197. https://doi.org/10.1016/0148-9062(94)92678-3.

[12] Li, H., Lai, B., & Liu, H. (2019). Determination of tensile elastic parameters from Brazilian tensile test: Theory and experiments. *Rock Mechanics and Rock Engineering*, *52*(8), 2551–2568. https://doi.org/10.1007/s00603-019-1738-8

[13] Mazel, V., Guerard, S., Croquelois, B., Kopp, J.-B., Girardot, J., Diarra, H., Busignies, V., & Tchoreloff, P. (2016). Re-evaluation of the diametral compression test for tablets using the flattened disc geometry. *International Journal of Pharmaceutics*, *513*(1–2), 669–677. https://doi.org/10.1016/j.ijpharm.2016.09.054.

[14] Patel, S., & Martin, C. D. (2018). Evaluation of tensile Young's modulus and Poisson's ratio of a bi-modular rock from the displacement measurements in a Brazilian test. *Rock Mechanics and Rock Engineering, 51*(2), 361–373. https://doi.org/10.1007/s00603-017-1337-1

[15] Zhang, H., Nath, F., Parrikar, P. N., & Mokhtari, M. (2020). Analyzing the validity of Brazilian testing using digital image correlation and numerical simulation techniques. *Energies*, *13*(6), 1441. https://doi.org/10.3390/en13061441

[16] Hondros, G. (1959). The evaluation of Poisson’s ratio and the modulus of materials of low tensile resistance by the Brazilian (indirect tensile) test with particular reference to concrete. *Australian Journal of Applied Science*, *10*, 243–264. https://link.springer.com/article/10.1007/s00603-017-1345-5

[17] Waragai, T. (2016). The effect of rock strength on weathering rates of sandstone used for Angkor temples in Cambodia. *Engineering Geology*, 207, 24–35. https://doi.org/10.1016/j.enggeo.2016.04.006

[18] Sun, W., Wu, S., & Guo, W. (2023). Study on the semi-circular bend method for characterizing the mixed mode I/II fracture toughness of sandstone: A micro-perspective. *Theoretical and Applied Fracture Mechanics*, *127*, 104064. https://doi.org/10.1016/j.tafmec.2023.104064

[19] Xiao, P., Li, D., Zhao, G., & Liu, M. (2021). Experimental and numerical analysis of mode I fracture process of rock by semi-circular bend specimen. *Mathematics*, *9*(15), 1769. https://doi.org/10.3390/math9151769

[20] Wei, M. D., Dai, F., Xu, N. W., Zhao, T., & Liu, Y. (2017). An experimental and theoretical assessment of semi-circular bend specimens with chevron and straight-through notches for mode I fracture toughness testing of rocks. *International Journal of Rock Mechanics and Mining Sciences*, *99*, 28–38. https://doi.org/10.1016/j.ijrmms.2017.09.004

[21] Chroeun, S. (2022). *Coupling DIC - Finite Elements Method to identify mechanical properties of materials* (Master’s thesis, University Sorbonne Paris Nord).

[22] Charles, Y. (2002). *Identification d’un mode de vieillissement dans un assemblage céramique-métal* [Doctoral dissertation, ENS Cachan]. HAL. https://hal.science/tel-04493265.

[23] Carò, F., & Douglas, J. G. (2013). Nature and provenance of the sandstone used for Bayon style sculptures produced during the reign of Jayavarman VII. *Journal of Archaeological Science*, *40*(1), 723–734. http://dx.doi.org/10.1016/j.jas.2012.06.043

[24] Carò, F. (2023). Personal Communication.

[25] Dassault Systèmes. (2016). *CAE user’s guide* (Version 2016) [PDF manual]. Retrieved from http://130.149.89.49:2080/v2016/pdf_books/CAE.pdf