JP&M Engineering
Journal of Petroleum and Mining Engineering

Experimental Study on Rock Strength Parameters for Brittleness Index Evaluation: A Case Study of the Sitakunda Anticline Area, Bengal Basin

Rana M. Rasel, Miah M. Islam * and Abir M. A. Noor
[a] Department of Petroleum and Mining Engineering, Chittagong University of Engineering & Technology, Chattogam-4349, Bangladesh
*Corresponding author e-mail: islam.m@cuet.ac.bd

Article Info

Received 21 Jun. 2024
Revised 30 Sep. 2024
Accepted 10 Nov. 2024

Keywords

Rock strength; Brittleness, Sandstone Rock; Drillability; Geomechanics; Bengal Basin.

Abstract

Rock strength parameters are vital to measure the rock brittleness index in rock engineering for failure characteristics under geo-stress conditions, such as drillability of rocks, cutability assessment of sedimentary rocks and estimating fracture toughness. In addition, rock strength and brittleness index play a vital role in evaluating the stability of the surrounding rock mass in subsurface underground projects. This study aims to measure the rock strength parameters for brittleness index evaluation by conducting the uniaxial compressive strength (UCS) and tensile strength tests of sedimentary specimens. In this study, rock samples are collected from the anticline structure of "Sitakunda Eco Park and Botanical Garden" in the Chittagong hilly area, and experimental studies are conducted to measure UCS and tensile strength to obtain brittleness index (BI) by following the standard procedures of the American Society for Testing and Materials. From the experimental results, the measured UCS is very high and the tensile strength is relatively low with an average magnitude of about 80 MPa and 1.65 MPa, respectively. Therefore, the BI is very high with an average value of 50.79. Hence, the BI indicates that the collected samples of the studied area are extremely brittle. The drilling performance for this rock is extremely difficult and the stability of the surrounding rock mass in the subsurface underground project is likely to fail due to the extremely high value of BI. These findings can be used to calculate the maximum and minimum wellbore fracture pressure regime for the wellbore failure analysis during drilling operations in geo-energy exploration phases.

Introduction

The rock strength parameters are the most vital in mining, geotechnical, and petroleum engineering projects such as underground excavation, rock slope stability and wellbore failure analysis in geomechanics [1]. Rock brittleness is a physical phenomenon and failure characteristics of rock that determine the failure criteria under different loading and unloading conditions after excavation in mining, drilling, and tunneling operations [2]. Rock brittleness (RB) is a significant indicator of rock mass classification. Having an adequate knowledge on RB in geotechnical fields and rock engineering also help engineers facilitate the case related to brittleness. For instance, the adoption of appropriate knowledge on the rock brittleness through petroleum engineers could help them to performance evaluation of a hydraulic fracturing process as well as evaluate the wellbore stability and failure analysis [3-4]. It is a crucial parameter in the aspects for stable underground design purposes, wellbore stability evaluation and selection of safe drilling parameters to exploring oil and gas as well as mining equipment [5-9]. Kahraman and Altindag [7] examined the raw data collected from the laboratory works of two researchers and correlated the brittleness values with different fracture toughness values. Additionally, it is helps for suitable degree of stability of deep hard rock projects and efficient stimulation of unconventional reservoir of shale gas.

The rock brittleness index (BI) is an effective parameter while performing hydraulic fracturing design and fracture initiation in unconventional shale formation and tight carbonate reservoirs. It is used to indicate whether a formation is brittle or ductile or complex nature of the formation. Brittle formation is more preferable to design complex fracture network under tensile and compressive strength but ductile formation is more resistant to fracture and failure design [10]. Jin et al. [11] investigated a theoretical model to assess the BI with an energy evolution theory to the acid-corroded sandstone. Considering this model, the BI of the studied sandstone is subjected to acid corrosion is evaluated. It is found that the rate of descent of the BI decreases with the increment of the soaking time while the BI of the sandstone is negatively linked with the soaking time. BI can be estimated from experimental study using

 DOI: 10.21608/jpme.2024.298378.1201

core samples through the UCS and Brazilian tests. Alternatively, empirical correlations/models are developed using geophysical log and core data to estimate BI. Several models and techniques have been established at different times to estimate the BI but there is no universe and standard method to measure the BI of rock because it is a complex function of composition, lithology, porosity and geo-mechanical parameters of the formation. The geomechanical laboratory testing on in-situ core samples is the most suitable method to estimate the rock BI using the standard methods which recommended by the ASTM and/or the ISRM (International Society of Rock Mechanics) [12]. Rock strength parameters and brittleness are the crucial parameters as they define the drilling efficiency, wellbore stability, underground excavation performance, fracture network design and influences the hard rock mining. Over the past decades, a few studies have suggested the relations between brittleness index (BI) and petrophysical properties of rocks such as Young's modulus, Poisson's ratio, hardness, quartz content and internal friction angle [13-14]. A great number of studies have been accomplished to develop empirical correlations for estimation of rock brittleness using rock strength parameters. Most of the studies were conducted to estimate brittleness considering the empirical formula between UCS and Brazilian tensile strength (BTS) of the rock samples [15-18]. Khandelwal et al. [16] studied on BI evaluation by coupling intact rock strength parameters, genetic programming (GP) algorithm and non-linear multiple regression (NLMP) approach. They adopted the input variables of UCS and BTS, whereas it is found that GP-based model outer-performed with high correlation coefficient than the NLMR-based model. However, to predict the rock brittleness the geo-mechanical property-based brittleness indices are the most useful indirect tools. Koopialipoor et al. [17] developed predictive equations to estimate rock BI by using P-wave velocity, rock density and Schmidt hammer rebound number as a behavior of intact rock properties. They used the combination of ANN models and firefly algorithm and a hybrid approach. Yagiz derived BI based on punch penetration test which was absolutely strength-based demonstration of BI [19]. Guo et al. [20] investigated the variation of rock brittleness, porosity and mineralogy in the shale formations using non-strength-based rock parameters. Tarasov and Potvin [21] suggested two rock brittleness criteria by following the balance energy between rupture and accumulated elastic energy. Under different loading conditions, the rock brittleness characterization can be done more accurately by these two criteria. The most magnificent analysis was conducted by Meng et. al. [22] that rock strength-based brittleness indices are limited to confining stresses and elastic strain. The amount of energy accumulated during loading conditions prior to failure and energy consumption mechanisms (brittle failure or plastic deformation) are characterized based on confining stress and elastic strain. The rock brittleness's definition, measurement method, eighty different brittleness indices and application to different fields and their applicability limitations are reviewed by Meng et. al. [23]. Cheng et. al. [24] describes reservoir brittleness estimation method by Mohr-Coulomb failure criterion and in-situ effective stresses where this approach integrates a range of reservoir characteristics including lithology, porosity, the sedimentary and tectonic settings of the reservoir, and the condition of stress-bearing of the reservoir. The brittleness can be estimate by considering seismic wave, logging, and geological and geophysical core data. Altindag [25] examined brittleness indices and the relationship between brittleness indices and penetration rate based on uniaxial compressive strength and tensile strength of rocks. Recently a large number of studies used artificial intelligence and machine learning techniques to solve problems related to science and engineering fields [26-30]. Comparatively, a small number of studies have been conducted relevant to this field to predict the rock BI. Kaunda and Asbury [26] adopted artificial neural network (ANN) to estimate the rock BI by using input parameters as P and S-waves velocities, elastic modulus, Poisson's ratio and unit weight. Authors concluded that ANN predictive model performed excellent of intrinsic rock brittleness than conventional destructive strength-test based models. Yagiz and Gokceoglu [31] developed fuzzy inference system model to estimate rock BI by non-linear regression analysis. The models used rock strength parameters (tensile strength and UCS) and unit weight as input parameters. So far, the geomechanical parameters of rock strength and brittleness indices for the Sitakunda anticline area of the Bengal basin have not been studied using core specimens, log data or other rock properties. In this paper, the assessment of rock strength parameters and brittleness index of the Bengal basin can be accomplished to fulfil the knowledge gaps by the experimental study of the clastic sedimentary rock samples. The major objectives of this study are:

a) to measure the rock strength parameters of compressive strength and tensile strength and
b) to estimate brittleness index of sedimentary rocks of the Bengal basin area.

Location of the study

The research study area is "Sitakunda hill range" which is one of the most well-known hill ranges with anticline structures of the Bengal basin in Bangladesh [32]. The coordinates of the Sitakunda upazila is from $22^{\circ}37'\ N, 91^{\circ}39.7'\ E$ to $22.617^{\circ}\ N, 91.667'\ E$. It is an upazila of Chittagong distinct in Bangladesh. It is located in the north western corner of Chittagong district. Sitakunda upazila covers 483.97 square kilometers including 61.61 square kilometers of forest. The Sitakunda range is a 32-kilometers long ridge in the upazila's midsection that rises to an elevation of 352 meters above the sea level to the Sitakunda summit or Chandranath, the maximum elevation in Chittagong Division. The Sitakunda geological structure, 70 kilometers long and 10 kilometers broad, is the most western formations of Chittagong Division and Chittagong Hilly Area, bordered by the Feni and Karnaphuli River in the north and south respectively, and the Chittagong Hill Tracts in the west, the Sandip Channel to the west and the Halda River to the east. The Sandwip Channel is the northernmost point of the Chittagong-Tripura Folded Belt. A deep geological sequence of shale, sandstone and siltstone makes the upper formation. Besides the limestone, the exposed strata of sedimentary rock, 6500 meters thick on average, present little change in general lithology from that of Chittagong Hill Tracts and Chittagong Division. The researched region is located between the latitudes of 22˚30ˊ N and 22˚45ˊ N and the longitudes of 291˚35ˊ E and 91˚50ˊ E. The rock samples for this study have been collected from the Sitakunda anticline area which shown in Figure 1 (the red mark shown in the map). Based on availability, four rock samples have been collected from this location to conduct this study. The low hill ranges cover a portion of Sitakunda, while the majority is covered by the “Bengal River” plain. Rajbari Tila, to the north stands at 274 meters while Sajidhala stands at 244 meters are the highest peaks in this range, which dips precipitously to less than 92 meters in the region of Chittagong City to the north. The Labanakhya saltwater hot spring, located about 5 kilometers north of Sitakunda town, has been considered as geotherm a resource of heat energy [33]. Besides, two waterfalls are located in this hill, they are named as; Sahasradhara Jhorna (Thousand streams) and Suptadhara Jhorna (Hidden streams). In addition, several faulted sysncline and anticline zones were developed in the studied area. Moreover, a limited number of exploration wells were drilled with one discovery Semutang gas prone structure which located near the zone of Sitakunda area [34].

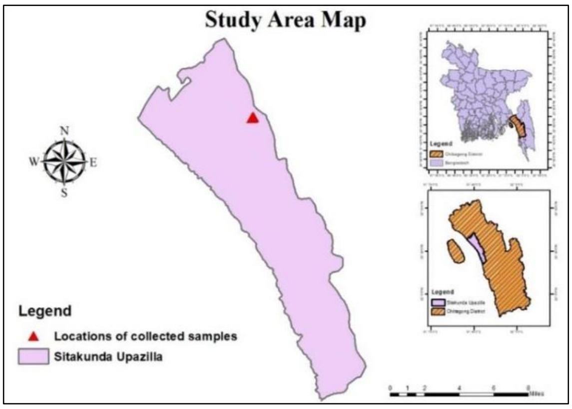

Figure 1 Location map of the studied area at Sitakunda anticline structure in the Bengal basin.

For this study, the raw rock samples are collected from surface exposed area of the Sahasradhara Jhorna which is located in the “Sitakunda Eco Park and Botanical Garden” with an anticline structure. The surface exposed collected rocks were mostly sandstone type, clastic sedimentary rock. In the Bengal basin, oil and gas reservoirs are discovered into the clastic sedimentary rocks within area of eastern fold belt, Bengal basin [34].

Material and Methods

To determine the brittleness indices and asserting the data to fulfill the objectives of this study, methodology of this work strategically overviewed. Two major experimental testing such as uniaxial compression test and tensile strength (Brazilian test) applied for the prepared rock specimen to obtain the required data for rock strength parameters. The uniaxial load will be applied to determine the maximum stress under which the specimen can withstand.

Materials for experimental study

First, the rock specimen samples are collected from the study are shown in Figure 1. The collected rock samples are inspected and transported to the core analysis laboratory. For instance, the specimens are prepared for laboratory testing by cutting, plugging and trimming processes, respectively. Finally, the specimens are tested for uniaxial compressive strength and tensile strength to assessed the brittleness index of the rock formation. The working procedure with major steps of this study is illustrated in Figure 2. In the study, sedimentary rock samples are collected from “Sahasradhara Jhorna” which is located in the “Sitakunda Eco Park and Botanical Garden” in Sitakunda Upazila, Chittagong District’s. Surface exposed sedimentary rock samples are collected from different coordinates along the channel of the waterfall area. The location and elevation of the collected rock samples are recorded by a hand GPS (Global Positioning System) which shown in Table 1.

The samples are visually inspected to investigate presence of joints, and fractures with different degrees of weathering. It is inspected that all samples are mostly dissimilar, slightly fractures. The selected rock samples are transported to the laboratory and prepared the samples for laboratory testing by cutting, plugging and trimming processes, respectively. After that, the collected rock samples are cut by a diamond-saw cutter to obtain suitable dimensions for core plugging. Then the sedimentary rock samples are placed suitably in the core plugging machine as tight as possible so that the sample can’t move while plugging. Sedimentary rocks are very fragile, so samples are plugged with higher degrees of caution. According to the both ISRM (1978) and ASTM (2008b) standards, the length to diameter ratio of the specimens must be between 2.5 to 3.0 and 2.0 to 2.5 respectively [35-37]. The prepared specimen’s length to diameter ratio is taken nearly 2.0 in the study. Finally, the specimens are smoothened by trimming machine. A diamond-saw cutter, a core plugging machine and a core trimming machine is shown in Figures 3, 4 and 5 respectively and all pictures are captured from “core analysis and rock mechanics laboratory” of the Department of Petroleum and Mining Engineering, Chittagong University of Engineering & Technology, Bangladesh.

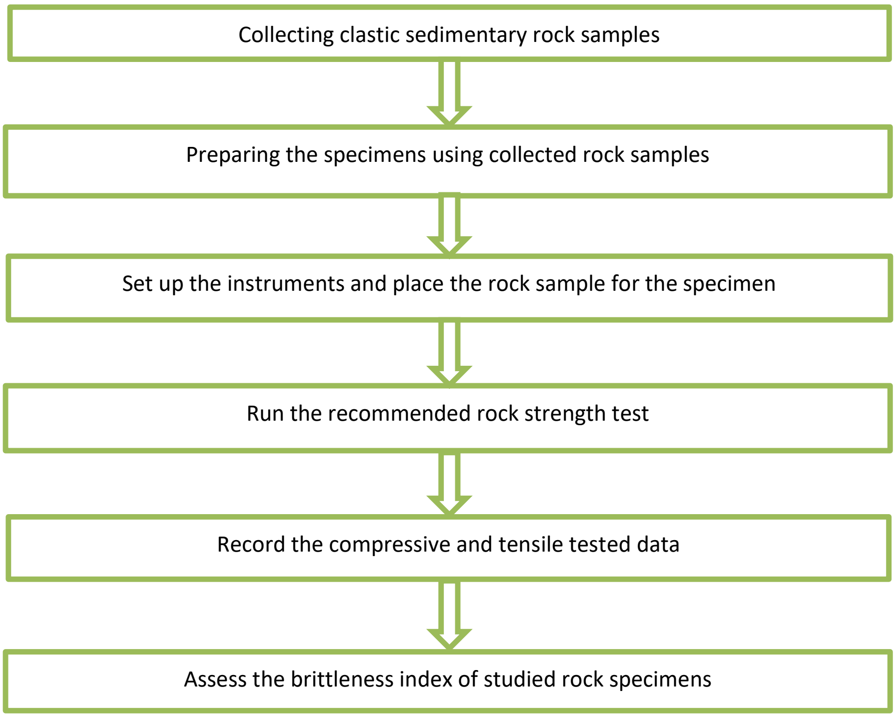

Figure 2 A typical working flow chart to determine of rock brittleness index.

Table 1 Collected samples description of studied specimen.

Sample No.	Lithology	Location	Elevation (Ft)	Image of sample (parent rock)
01	Sandstone	N $22^{\circ}27.65'$ E $91^{\circ}58.54'$	408	
02	Sandstone	N $22^{\circ}27.65'$ E $91^{\circ}58.54'$	435	
03	Sandstone	N $22^{\circ}36.85'$ E $91^{\circ}41.56'$	384	
04	Sandstone	N $22^{\circ}36.85'$ E $91^{\circ}41.56'$	448	

Figure 3 Diamond-saw cutter to cut the rock samples.

Figure 4 Core plugging machine to prepare the cylindrical core specimens.

Figure 5 Core trimming machine to smoothen the rock specimen edge.

Four cylindrical specimens and four-disc specimens have been prepared from the collected sedimentary rock samples. Cylindrical specimen-1 (S1) and disc specimen-1 have been prepared from same sample-1 and consequently others specimens have been prepared. The prepared specimens are shown in Fig. 6.

Figure 6 Cylindrical and disc specimens prepared for rock strength tests.

Experimental procedures of UCS and Brazilian testing

Uniaxial compressive strength (UCS) test

The UCS test is certainly the most reliable geo-mechanical testing to determine rock strength to investigate the formation load behaviour [38]. At zero confining stress condition, the UCS is the maximum compressive stress that a specimen can withstand until the deformation, and also called unconfined compressive strength as the applied stress is along the longitudinal axis [39]. When a material is undergoes load two types of deformation occurs as elastic or plastic deformation. Elastic deformation is characterized by the stress-strain curve. The relationship of stress vs strain for elastic deformation is based on the Hooke's law. Hooke's law is expressed as; stress is proportional to strain in the elastic limit [40]. Therefore, the UCS is calculated for the maximum load applied as;

$$\sigma_{UCS} = \frac{P_{max}}{A_0} \dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

The modulus of elasticity or Young's modulus (E) can be determined by flowing equation or from the gradient on the stress-strain curve;

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where, $\Delta\sigma$ is the change in stress, and $\Delta\varepsilon$ is the change in strain.

The specimens are tested in a loading machine with uniaxial load shown in Figure 7. Flat platens are used to set the cylindrical specimens in the machine. The specimens are kept on the platens as coincidental as possible with the loading axis and the uniaxial load have been applied to determine the maximum load under which the specimens can withstand.

Figure 7 Compression testing machine for rock strength measurement.

After placing the specimens in the loading machine, required parameters i.e., contact area, diameter, length, test speed etc. are set to the software of the loading machine. Then the work of preload is done to place the sensors in between the loading platens carefully and load is applied until the specimens are broken. The maximum load under which the specimen breakdown occurs has been recorded. Figure 8 shows the cylindrical specimens before and after the UCS test.

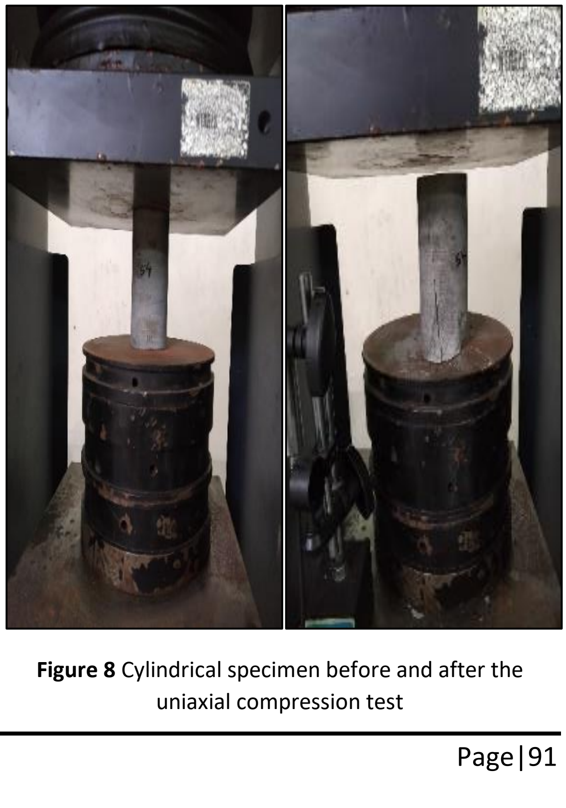

Figure 8 Cylindrical specimen before and after the uniaxial compression test

 DOI: 10.21608/jpme.2024.298378.1201

Tensile strength test

The prediction of tensile strength is a significant aspect to resist the failure of a rock materials or rock mass. It is a measure of the ability of a rock material to resist deformation under tensile stresses or stretching forces. Tensile strength is as the measure of maximum stress that a rock sample can resist any fracture when it is undergoes to pulled or stretched. There are commonly two methods of measure the tensile strength of rock as the direct (more accurate) tensile strength and indirect (Brazilian) tensile strength [41]. The Brazilian method is a common indirect testing method to measure the brittle material's tensile strength such as rock, and rock-like materials. In this method, a small circular disc is compressed diametrically to failure [42]. The Brazilian tensile strength (BTS) is predicted by an indirect testing method recommended by the ISRM (1978) and ASTM (2008b) standards, which explained that the measure of stress at failure, σ_t, is a behaviour of the maximum applied load P, the thickness t and the diameter D at the center of the specimen. The BTS (σ_t) can be obtained by;

$$\sigma_t = \frac{2P}{\pi D t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

The disc specimens are tested in the same universal loading machine with diametrical load. The maximum load has been recorded under which the specimen breakdown. Figure 9 shows the disc specimens before and after the tensile strength test. After preloading, a continuously increasing compressive load have been applied maintaining 0.01 MPa/s of loading rate.

Figure 9 Position of disc specimen before and after to perform the Brazilian text.

Estimation of brittleness index

The UCS (σ_c) and the tensile strength (σ_t) are the most important two basic mechanical strength parameters of rock and can be measured from laboratory samples tests. The brittleness index (BI) can be determined by empirical correlation from the strength parameters of rocks are given as follows;

$$BI = \frac{\sigma_c}{\sigma_t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Results and Discussion

The laboratory experimental data and results are presented in this following section. First, the uniaxial compression tests data are analyzed for four samples and the results are shown in tables. In the same way, the indirect tensile strength tests data are analyzed then presented in table. Finally, the brittleness index (BI) is obtained by coupling UCS and tensile strength.

Rock strength parameters of uniaxial compression and tensile strength

Uniaxial compressive strength test is conducted in a universal testing machine for laboratory experiment with four rock specimens have almost same length to diameter ratio. The length to diameter ratio is near about 2.0 according to the ASTM (2008b) standards. In the following sections the laboratory experimental data and results are presented for four different rock specimens, respectively.

Specimens no. 1 to 4 are prepared from the raw samples 1-4, which is mainly sandstone in terms of lithology type. The detailed specification of specimens is given in the Table 2. Here, scale effect on UCS and TS test is not considered and L/D ratio is kept as ASTM standard for each test. For instance, the UCS and static Young's modulus (E) for four specimens are obtained from the experimental data which shown in Table 3.

After the experiment of uniaxial compressive strength, the loading machine data are recorded in separate time interval. Strain and stress data are calculated by the program set to the loading machine. For instance, the stress-strain curves are generated in Figures 10-13 for specimens-1, 2, 3, 4 respectively. From above stress-strain curve, four specimens show brittle behaviour.

Table 2 Specifications of rock specimens.

Specimen No.	Sample No. (parent rock)	Lithology	Diameter (mm)	Length (mm)	Ratio (L/D)
1	1	Sandstone	54	112	2.07
2	2	Sandstone	54	111	2.06
3	3	Sandstone	54	108	2.00
4	4	Sandstone	54	117	2.16

Table 3 Dimensional and experimental results of rock specimens.

Dimensions	Specimen 1	Specimen 2	Specimen 3	Specimen 4
Load at break (KN)	189.96	164.96	199.95	216.78
Compression at break (µm)	141.1	123.6	198.3	243.5
Compressive strain at break (mm/mm)	0.00126	0.001114	0.001836	0.00208
Uniaxial compressive strength at break (MPa)	82.96	72.03	87.3	92.93
Young's modulus at proportional limit (GPa)	62.5	56.9	45.85	70.9

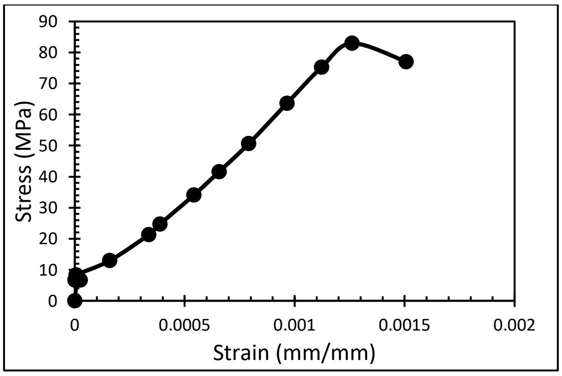

Figure 10 Stress-strain curve for specimen 1.

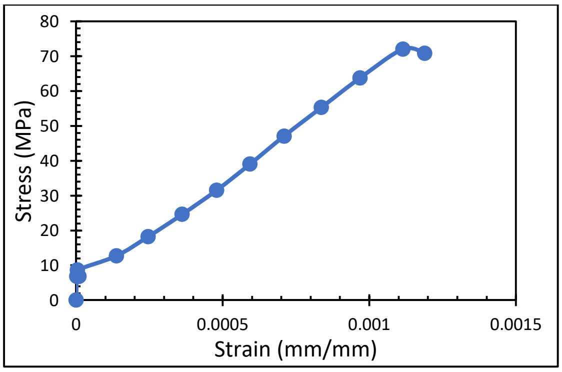

Figure 11 Stress-strain curve for specimen 2.

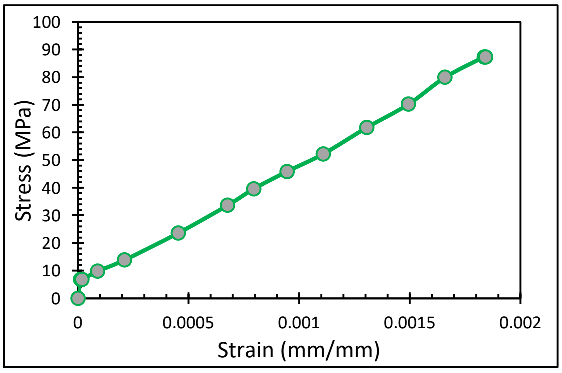

Figure 12 Stress-strain curve for specimen 3.

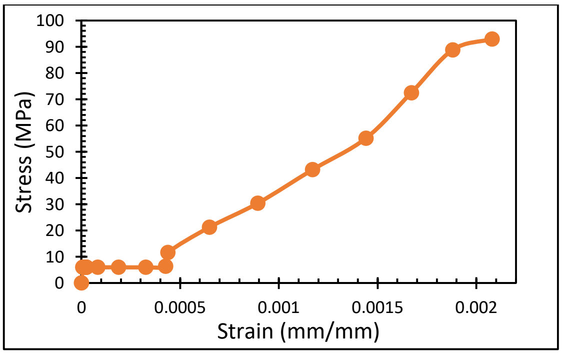

Figure 13 Stress-strain curve for specimen 4.

According to the nature of experimental results in Table 3, and Figures 10-12 and 13, the rock strength of specimens is different due to the heterogeneity behaviour of sedimentary rocks with geological compactness. From the summarized results in Table 3, the maximum UCS is 92.93 MPa, measured from specimen-4 and the minimum UCS is 72.03 MPa, measured from specimen-2. The average UCS of rock specimen is 84 MPa in the studied area of Sitakunda in the Bengal basin.

On the other hand, rock tensile strength is found ranging 1.53 to 1.85 MPa using Brazilian test. The thickness to diameter ratio was kept 0.5 for all the specimens according to ASTM standard. The summarized results of tensile strength for four specimens are given in Table 4. From Table 4, the first three specimens show almost same maximum load at break and nearly same tensile strength. The specimen no. 04, which shows slightly higher maximum load at break hence slightly higher tensile strength. The average maximum load at break and tensile strength are 3.77 KN and 1.65 MPa, respectively. In terms of comparison, Miah et al. [43] investigated on tensile strength using different sizes (such as 25mm, 38mm, 50mm, and 55mm diameter) of clastic sedimentary rocks with a diameter to thickness ratio of 2 and the Brazilian test is performed with loading rate of 0.05 MPa/s. They found that the magnitude of tensile strength significantly varied with rock sample sizes and averaged 1.47-6.72 MPa for sedimentary rocks of the Sahasradhara Jhorna area of Chittagong hill tacks, Bengal basin.

Table 4 Experimental results of tensile strength, sedimentary rock.

Specimen No.	Diameter, d (mm)	Thickness, t (mm)	Max. load (KN)	Tensile Strength (MPa)
1	54	27	3.50	1.53
2	54	27	3.62	1.58
3	54	27	3.74	1.63
4	54	27	4.23	1.85
Average			3.77	1.65

Evaluation of rock brittleness index

In this study, the prediction of brittleness index (BI) is the destructive procedure hence according to the ISRM (1978) and ASTM (2008b) standards, the UCS and the tensile strength (TS) tests are performed in the laboratory. The BI of the studied specimens are found from the ratio of two strength parameters (UCS and TS) and also summarized results are given in Table 5. The graphical representation of the summarize results of geomechanical and rock strength parameters and BI of studied rock samples are shown in Figure 14. Based on the strength properties of rock and the mathematical relationship between brittleness index and rock mechanical properties, BI of sedimentary rock is studied in this research work. For example, brittleness based on rock mechanical strength properties has been accepted to investigate the stability of surrounding and predict the rock drillability performance. This research used rock mechanical strength parameters rather than other properties to predict the BI of sedimentary rock. From recommended both strength tests, the result shows an average value of BI is 50.79 that is greater than 25 which indicates that the samples are extremely brittle compared to the Altindag's brittleness values [25].

Table 5 Summarize results of rock strength and brittleness index of studied samples.

Specimen No.	UCS (MPa)	Tensile Strength (MPa)	BI
01	82.96	1.53	54.21
02	72.03	1.58	45.59
03	87.32	1.63	53.56
04	92.93	1.85	50.23
Average	84	1.65	50.79

Drilling performance is related to BI when BI is very low it is easy to drill the formation and if BI is very high then drilling the formation is extremely difficult. In hard rock mines and tunneling, the stability criteria of the surrounding formation is a major concern of effective and safe drilling. If the formation is very hard and BI is extremely high, the surrounding formation of a void will collapse without any considerable deformation [25]. For more accurate result of rock BI, besides these strength parameters must be consider other reservoir properties such as reservoir lithology, structural and sedimentary environment and other physical properties of rock. BI can also be calculated from logging, coring and seismic data and other formation properties should be considered while conducting BI of rocks.

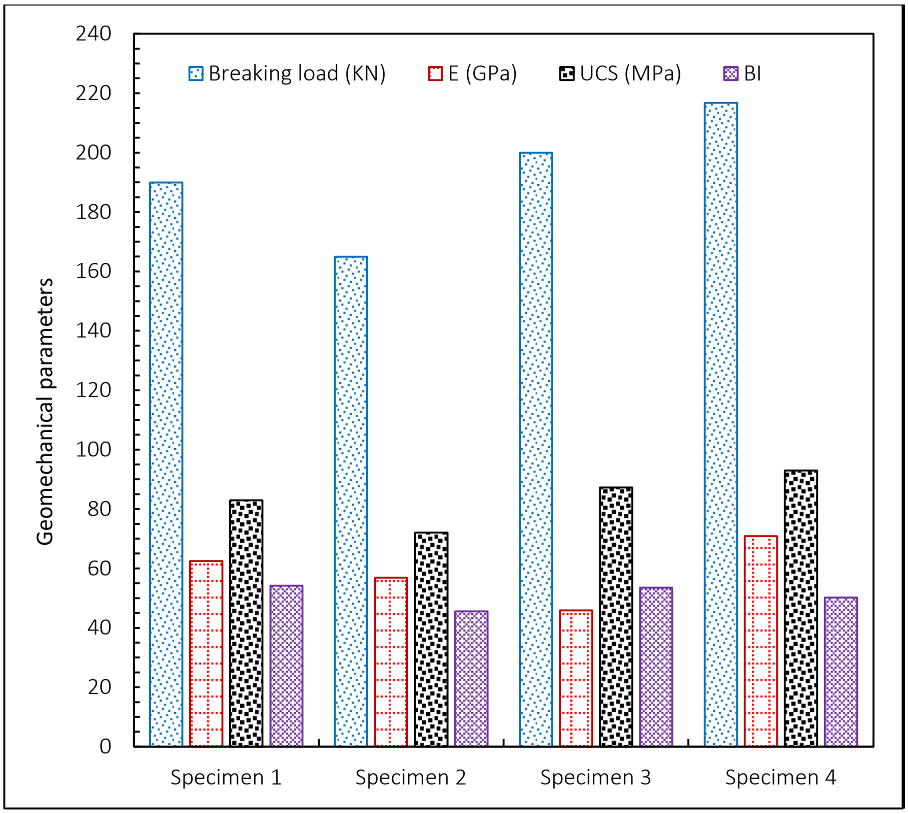

Figure 14 Comparison of geomechanically parameters for different specimens in the studied area.

Conclusions

Accurate estimation of rock strength parameters and brittleness index (BI) are inevitable for any underground excavation project and rock failure analysis in area of rock mechanics studies. In the study, all sedimentary rock samples are collected from the studied area of "Sitakunda Eco Park and Botanical Garden" from Chittagong hilly area in Bangladesh as a case study. Different samples yield similar results with minimal differences, illustrating the integrity of sample collection, preparation, testing, and analysis. The differences may occur due to heterogeneity of rock, effect of weathering as they are collected from exposed formation. The average values for uniaxial compressive strength (UCS) and tensile strength (TS) are found to be 84 MPa and 1.65 MPa, respectively, for the four studied specimens. The estimated average brittleness index is 50.79 for these specimens. Due to the extremely high average UCS and very low tensile strength, the brittleness index value is exceptionally high. Consequently, the stability condition of this brittle formation will be low, and drillability performance will be extremely difficult. This study's outcomes can be used to calculate maximum and minimum wellbore fracture pressure for the wellbore failure analysis during drilling operation in oil and gas exploration for Sitakunda anticline structure as well as underground excavation with same type of sedimentary formation in the Bengal basin and other formations.

Limitations and Scopes of the Future Studies

This study was conducted with a limited number of core specimens, it is recommended to study the size effect of sedimentary rock with a large number of samples with different diameter, height or length sizes with different loading rates. The laboratory test result should have to be compared with known size effect models to assess the applicability of existing models.

Furthermore, the machine learning algorithms can be adopted to predict brittleness index using a large number of datasets of the studied area. Additionally, this study is limited to its application due to the assessment on surface exposed clastic sedimentary rock with ignoring of confining stress. So, the authors recommend to the future investigators for a comprehensive study to investigate the wellbore stability and near wellbore failure criterion for oil and gas field development to the Sitakunda anticline faulted structure area.

Acknowledgement

The authors would like to express gratitude to the people associated with the Rock Mechanics Laboratory, Department of Petroleum and Mining Engineering, and also a funding agency of the Directorate of Research and Extension, Chittagong University of Engineering & Technology, funding no. CUET/DRE/2022-23/PME/002.

Conflicts of interest

There are no conflicts to declare.

References

[1] Miah, M. I. (2020). Predictive models and feature ranking in reservoir geomechanics: A critical review and research guidelines. *Journal of Natural Gas Science and Engineering, 82*, 103493.

[2] Blindheim, O. T., & Bruland, A. (1998). Boreability testing. In *Norwegian TBM tunnelling 30 years of experience with TBMs in Norwegian tunnelling* (pp. 29–34). Norwegian Soil and Rock Engineering Association.

[3] Miskimins, J. L. (2012). The impact of mechanical stratigraphy on hydraulic fracture growth and design considerations for horizontal wells. *Bulletin, 91*, 475–499.

[4] Rickman, R., Mullen, M. J., Petre, J. E., Grieser, W. V., & Kundert, D. (2008). A practical use of shale petrophysics for stimulation design optimization: All shale plays are not clones of the Barnett Shale. In *SPE Annual Technical Conference and Exhibition*. Society of Petroleum Engineers (SPE).

[5] Singh, S. P. (1986). Brittleness and the mechanical winning of coal. *Minerals Science and Technology, 3*, 173–180.

[6] Kahraman, S. (2002). Correlation of TBM and drilling machine performances with rock brittleness. *Engineering Geology, 4*, 269–283.

[7] Kahraman, S., & Altindag, R. (2004). A brittleness index to estimate fracture toughness. *International Journal of Rock Mechanics and Mining Sciences, 40*, 343–348.

[8] Liu, J., Wang, E., Song, D., Wang, S., & Niu, Y. (2015). Effect of rock strength on failure mode and mechanical behavior of composite samples. *Arabian Journal of Geosciences, 8*, 4527–4539.

[9] Shi, L. Z., Wang, Z. Z., Xing, Z. T., Meng, S., Guo, S., Wu, S. M., & Luo, L. Y. (2024). Geological characteristics of unconventional tight oil reservoir (109 t): A case study of Upper Cretaceous Qingshankou Formation, northern Songliao Basin, NE China. *China Geology, 7*(1), 51–62.

[10] Mews, K. S., Alhubail, M. M., & Barati, R. G. (2019). A review of brittleness index correlations for unconventional tight and ultra-tight reservoirs. *Geosciences, 9*(7), 319.

[11] Jin, S., Wang, X., Wang, Z., Mo, S., Zhang, F., & Tang, J. (2021). Evaluation approach of rock brittleness index for fracturing acidizing based on energy evolution theory and damage constitutive relation. *Lithosphere, Special 4*, 2864940.

[12] Brown, E. T. (1981). *Rock characterization testing and monitoring: ISRM suggested methods*. Pergamon Press.

[13] Nejati, H. R., & Moosavi, S. A. (2017). A new brittleness index for estimation of rock fracture toughness. *Journal of Mining and Environment, 8*, 83–91.

[14] Choo, H., Nam, H., & Lee, W. (2017). A practical method for estimating maximum shear modulus of cemented sands using unconfined compressive strength. *Journal of Applied Geophysics, 147*, 102–108.

[15] Wang, Y., Watson, R., Rostami, J., Wang, J. Y., Limbruner, M., & He, Z. (2014). Study of borehole stability of Marcellus shale wells in longwall mining areas. *Journal of Petroleum Exploration and Production Technology, 4*, 59–71.

[16] Khandelwal, M., Faradonbeh, R. S., Monjezi, M., Armaghani, D. J., Majid, M. Z. B. A., & Yagiz, S. (2017). Function development for appraising brittleness of intact rocks using genetic programming and non-linear multiple regression models. *Engineering Computations, 33*, 13–21.

[17] Koopialipoor, M., Noorbakhsh, A., Noroozi Ghaleini, E., Jahed Armaghani, D., & Yagiz, S. A. (2019). A new approach for estimation of rock brittleness based on non-destructive tests. *Nondestructive Testing and Evaluation*, 1–22.

[18] Zhao, Y. X., Li, X., Lin, S., & Wang, X. M. (2023). An improved shear strength model of unsaturated soils over a wide suction range. *Rock and Soil Mechanics, 44*(4), 1.

[19] Yagiz, S. (2009). Assessment of brittleness using rock strength and density with punch penetration test. *Tunnelling and Underground Space Technology, 24*(1), 66–74.

[20] Guo, Z., Chapman, M., & Li, X. (2012). A shale rock physics model and its application in the prediction of brittleness index, mineralogy, and porosity of the Barnett shale. In *2012 SEG Annual Meeting* (pp. 1–5). Society of Exploration Geophysicists.

[21] Tarasov, B., & Potvin, Y. (2013). Universal criteria for rock brittleness estimation under triaxial compression. *International Journal of Rock Mechanics and Mining Sciences, 59*, 57–69.

[22] Meng, F. Z., Zhou, H., Zhang, C., Xu, R., & Lu, J. (2015). Evaluation methodology of brittleness of rock based on post-peak stress-strain curves. *Rock Mechanics and Rock Engineering, 48*(5), 1787–1805.

[23] Meng, F., Wong, L. N. Y., & Zhou, H. (2021). Rock brittleness indices and their applications to different fields of rock engineering: A review. *Journal of Rock Mechanics and Geotechnical Engineering, 13*(1), 221–247.

[24] Cheng, B., Xu, T., & Tang, J. (2022). Reservoir brittleness prediction method based on the Mohr–Coulomb failure criterion and effective in situ stress principle. *Rock Mechanics and Rock Engineering, 55*(10), 5933–5951.

[25] Altindag, R. (2010). Assessment of some brittleness indexes in rock-drilling efficiency. *Rock Mechanics and Rock Engineering, 43*(3), 361–370.

[26] Kaunda, R. B., & Asbury, B. (2016). Prediction of rock brittleness using nondestructive methods for hard rock tunneling. *Journal of Rock Mechanics and Geotechnical Engineering, 8*(4), 533–540.

[27] Zhou, J., Li, E., Yang, S., Wang, M., Shi, X., Yao, S., & Mitri, H. S. (2019). Slope stability prediction for circular mode failure using gradient boosting

machine approach based on an updated database of case histories. *Safety Science, 118*, 505–518.

[28] Huang, L., Asteris, P. G., Koopialipoor, M., Armaghani, D. J., Tahir, M. M. (2019). Invasive weed optimization technique-based ANN to the prediction of rock tensile strength. *Applied Sciences, 5372*.

[29] Miah, M. I. (2020). Predictive models and feature ranking in reservoir geomechanics: A critical review and research guidelines. *Journal of Natural Gas Science and Engineering, 82*, 103493.

[30] Miah, M. I. (2021). Improved prediction of shear wave velocity for clastic sedimentary rocks using hybrid model with core data. *Journal of Rock Mechanics and Geotechnical Engineering, 13*(6), 1466–1477.

[31] Yagiz, S., & Gokceoglu, C. (2010). Application of fuzzy inference system and nonlinear regression models for predicting rock brittleness. *Expert Systems with Applications, 37*, 2265–2272.

[32] Alam, M., Alam, M. M., Curray, J. R., Chowdhury, M. L. R., & Gani, M. R. (2003). An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history. *Sedimentary Geology, 155*(3-4), 179–208.

[33] Khan, K. A., & Rasel, S. R. (2018). Prospects of renewable energy with respect to energy reserve in Bangladesh. *International Journal of Advanced Research in Innovative Engineering, 4*(5), 280–289.

[34] Imam, B. (2013). *Energy resources of Bangladesh*. University Grants Commission of Bangladesh.

[35] ISRM. (1978). Suggested methods for determining tensile strength of rock materials. *International Journal of Rock Mechanics and Mining Sciences, 15*, 99–103.

[36] ASTM. (2008b). D3967-08: Standard test method for splitting tensile strength of intact rock core specimens. ASTM International.

[37] Attewell, P. B., & Farmer, I. W. (1976). Composition of rocks. *Principles of Engineering Geology*, 1–29.

[38] Liang, M., Mohamad, E. T., Khun, M. C., & Alel, M. M. (2015). Estimating uniaxial compressive strength of tropically weathered sedimentary rock using indirect test. *Jurnal Teknologi, 72*(3), 49–58

[39] Hoek, E., & Brown, E. T. (1997). Practical estimates of rock mass strength. *International Journal of Rock Mechanics and Mining Sciences, 34*(8), 1165–1186.

[40] ASTM A. (1986). Standard test method of unconfined compressive strength of intact rock core specimens. ASTM Publication.

[41] Perras, M. A., & Diederichs, M. S. (2014). A review of the tensile strength of rock: Concepts and testing. *Geotechnical and Geological Engineering, 32*, 525–546.

[42] 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*, 269–287.

[43] Miah, M. I., Bormon, T., Iqbal, R., & Abir, M. A. N. (2023). Experimental study of rock size effects on tensile strength using the Brazilian test. In *7th International Conference on Engineering Research, Innovation and Education* (Paper ID 154). School of Applied Sciences & Technology, SUST, Sylhet, Bangladesh.

NOMENCLATURE

Abbreviation

ASTM	American Society for Testing and Materials
BI	Brittleness index
BTS	Brazilian tensile strength
GPS	Global positioning system
ISRM	International Society of Rock Mechanics
MPa	Mega pascal
RB	Rock brittleness
UCS	Unconfined compressive strength

List of symbols

σ_{ucs}	Uniaxial compressive strength
σ_t	Tensile strength
A_o	Area
P_{max}	Maximum load applied
D	Specimen diameter
t	Disc thickness
$\Delta\sigma$	Change in stress
$\Delta\varepsilon$	Change in strain