Acta Geodyn. Geomater., Vol. 18, No. 2 (202), 241–252, 2021
DOI: 10.13168/AGG.2021.0017

journal homepage: https://www.irsm.cas.cz/acta

ORIGINAL PAPER

MACRO-MECHANICAL CHARACTERISTICS AND THEIR CONTROL ON THE STRENGTH OF SANDSTONES OF WESTERN INDO-BURMESE RANGES, NE INDIA

Raghupratim RAKSHIT [1)] *, Devojit BEZBARUAH [1)], Bubul BHARALI [2)], Pradip BORGOHAIN [3)] and Kaustubh RAKSHIT [4)]

[1)] *Department of Applied Geology, Dibrugarh University, Dibrugarh-786004, Assam, India*
[2)] *Department of Geology, Pachhunga University College, Aizawl-796001, Mizoram, India.*
[3)] *Department of Petroleum Technology, Dibrugarh University, Dibrugarh-786004, Assam, India*
[4)] *Centre for the Environment, Indian Institute of Technology Guwahati, Guwahati-781039, India*

**Corresponding author's e-mail:* raghupratim@gmail.com

ARTICLE INFO

Article history:
Received 25 September 2020
Accepted 16 April 2021
Available online 30 April 2021

Keywords:
Sandstone
Macro-mechanical
Indo-Burmese Ranges
Bhuban Formation
FETEM

ABSTRACT

Mechanically strong sandstones consider as a potential construction material which can withstand modest load and not associated with any geologic fractures. This work is about understanding the macro-mechanical properties of sandstones by studying several petrographic parameters, which could provide evidence of their influence on mechanical strength. Here the authors were considered the Bhuban sandstones of western Indo-Burmese Ranges (IBR) of north-eastern India to investigate the above criteria. The result shows that sandstones have a mean grain size between 108 to 208 µm. Moderate to poorly sorted (phi scale ranges 0.56–1.5) grains show greater content of rounded constituents (43–68 %) with sphericity between 0.65–0.85; along with moderate packing properties (packing density 54–77 %; packing proximity 32–70 %). The grains join by mostly straight (20–54 %) and concavo-convex (13–45 %) contacts; with lesser point (5–13 %) and sutured contacts (8-44 %). Schmidt Hammer rebound values (R-values) were used to calculate and analyse the uniaxial confined stress (UCS); which again validated with UCS testing of core samples. The comparison between macro-mechanical parameters and the UCS shows interrelationship among rock constituents which hold the key to the mechanical strength of the rock. The presence of angular grains and semi-angular spherical grains diminish the macro-mechanical strength to some extent. Moreover, FETEM-EDX analysis confirms the micro-weathering of the angular grains, which have a deformed lattice setting. These findings show that macro-mechanical and micro-nano scale properties of sandstones influence the rock strength.

1. INTRODUCTION

Geotechnical engineers prefer mechanically strong rocks to build different structures. Use of sedimentary rocks in civil engineering constructions is diverse. These rocks serve various purposes like foundation rock, building blocks, aggregates along with crushed sand to make concrete and rock pieces to build roads (Bouafia, 2003). In many regions where other rock types are not accessible, sedimentary rocks are the only available material for construction. In civil engineering works sandstone and limestones are the two most used rock types along with limited use of siltstones. They formed in different geological conditions and might not be available in the same place (Blatt, 1982). However, sandstone and siltstone are the two main construction materials found to occur in north-east India, especially around the Indo-Burmese Ranges (IBR) due its sedimentary basin setting (Bharali et al., 2017; 2021). Sandstones have an explicit demand for its geotechnical characteristics. High mechanical withstand capacity, corrosive resistance, compressive and tensile strength, water absorption and porosity are some essential qualities that depend on their macro- and micro- stage arrangements of constitutional grains (Reddy and Elumalai, 2016; Ansari et al., 2021). Therefore, geotechnical characterisation of sandstones depends on various rock properties.

In this study, such rock properties are discussed and their correlation with mechanical strength have been persuade. This would provide the insight into our prime objective: how macro-mechanical properties control the strength of Bhuban rocks of western IBR. This knowledge would then can be utilised for various applications include engineering construction, earthquake resistive capacity of rocks and landslide vulnerability among others. Geomechanical rock strength is mostly expressed in terms of uniaxial confined stress (UCS). It provides the withstand capacity of rocks under various loading conditions such as buildings, road etc. in natural setting which, on the contrary influence the vulnerability (Obert and Duvall, 1967; Sardana et al., 2019). To evaluate UCS, both *in-situ* and laboratory tests were performed to obtain and establish the strength values and their correlation between in-field and laboratory data (Saptono et al., 2013; Matthews et al., 2016).

Cite this article as: Rakshit R, Bezbaruah D, Bharali B, Borghain P, Rakshit K: Macro-mechnical charakteristics and their control on the strenght of sandstones of western Indo-Burmese Rangers, NE India. Acta Geodyn. Geomater., 18, No. 2 (202), 241–252, 2021. DOI: 10.13168/AGG.2021.0017

Fig. 1 A. Bhuban sandstone rocks as a foundation block for the bridge constructed near Aizawl, India; B. massive sandstone in a rock quarry, at Aizawl; C. different rock types and their variations are existing in the area; D. small clay balls on the sandstone blocks can cause engineering problems because of their geotechnical property.

A point-based method (Proceq, 2004) has been employed using a Schmidt Hammer test in the IBR of northeast India. This efficient approach involves measurement of rock hardness using the Schmidt Hammer rebound values (R-values) that would give the rock strength measurements. This technique is now widely used because of its reliability, broad application, cost-effectiveness, and, importantly, its ease of use. The strength of a rock calculated from the R-values is like that of UCS for the same sample types (Matthews et al., 2016). UCS values for hard sedimentary rocks like Bhuban Sandstones of IBR, in Aizawl, India (in this study), are like other igneous and metamorphic rocks around the region (Nandy et al., 1983). UCS values obtained from the R-values are correlated with the core samples collected from the same sample sites. This correlation is important to validate the use of the R-values as UCS measurement technique, as some researchers do not endorse this direct *in-situ* technique (Sachpazis, 1990; Aggistalis et al., 1996; Katz et al., 2000; Kilic et al., 2008). Moreover, formulation of empirical equation describing the UCS is also proposed by many authors, e.g., Cargill and Shakoor (1990); Aggistalis et al., (1996); Aydin and Basu (2005); Kilic et al., (2008); Cobanoglu and Celik (2008), if the range between two methods are vastly different.

Petrographic study reveals that grain size, packing properties and interlocking of grains have a constructive effect on the macro-mechanical conditions including mechanical strength (Ersoy and Waller, 1995; Zorlu et al., 2008; Demirdag et al., 2009). Modification of this condition can cause weathering, decomposition, and scouring in these rocks (Sun et al., 2017). Moreover, attention to inter- and intra-granular behaviour provides an understanding of its effect on rock strength. This article focuses on the macro-mechanical properties of mechanically strong massive and non-massive sandstones of western IBR, in the Aizawl city, India. Morphology and interdependence of rock constituents along with their distribution, have a significant effect on mechanical properties (Bukowska, 2015). To understand such rock characteristics different microscopic techniques are essential. Reflected light optical microscopy (OM), scanning electron microscopy (SEM) and field emission transmission electron microscopy (FETEM) showed their competency in similar studies for microstructural observations (Rekik et al., 2009). The FETEM images have been used here for understanding the morphological perspective of quartz grains and Energy Dispersive X-Ray or EDX technique to know the compositional variability, which both affect the strength of the rocks. This is the reason behind using FETEM over SEM or OM.

In the IBR, researchers have studied different aspects of the geology and seismology with an emphasis on sedimentary basin analysis and tectonic studies (e.g., Nandy et al., 1983; Gahalaut et al., 2013;

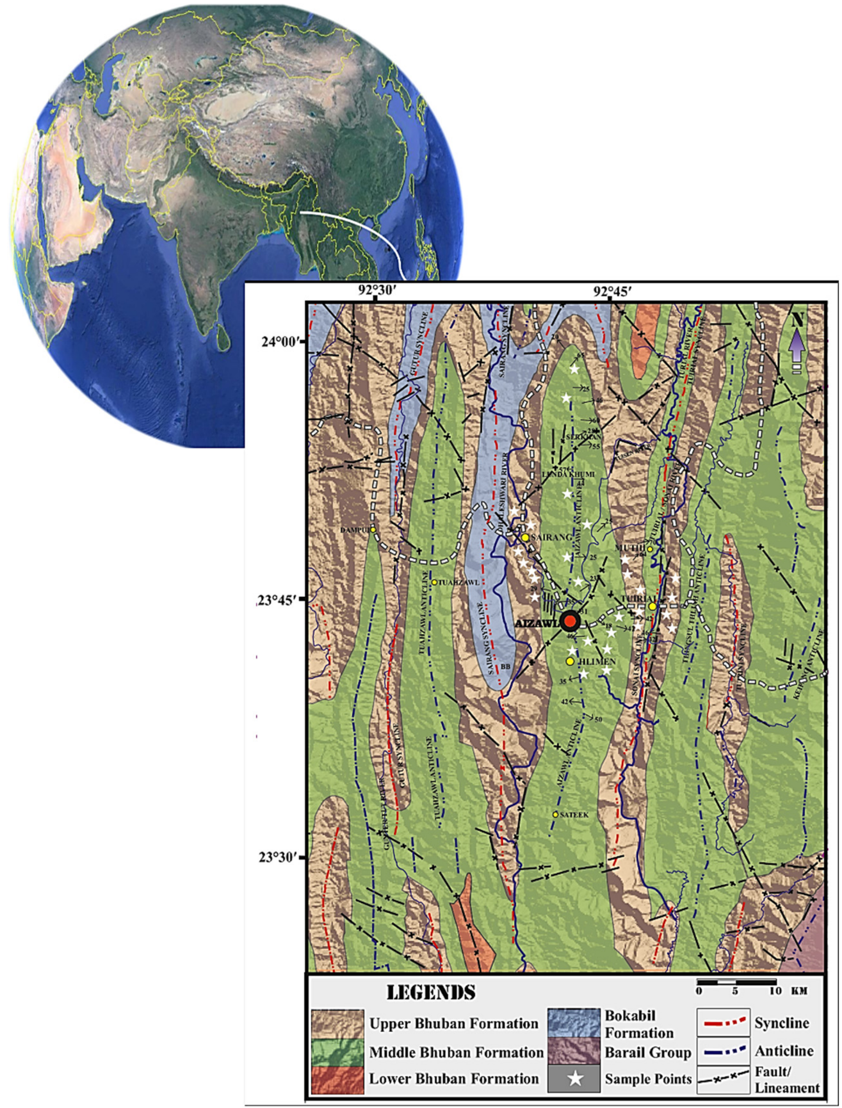


Fig. 2 Geological map of the study area showing the location of the sample points and major geological features.

Bharali et al., 2017, 2021; Zaman and Bezbaruah, 2019; Rakshit et al., 2020). Dominant lithologies of Bhuban rocks around Aizawl anticline (23°28′–24°00′ N, 92°38′–92°48′ E) are interbedded sandstone, siltstone, mudstone and shale (Fig. 1). The presence of clay minerals, encountered in many Bhuban sandstone samples, can cause engineering issues if used (Fig. 1 D). The area is seismically active and bounded by many geologic and tectonic features (Rakshit and Bezbaruah, 2016; Rakshit et al., 2018; Zaman et al., 2019). Construction of a geological map using GIS techniques is useful for understanding aforesaid engineering challenges, including thickness of the near surface sediments (Rupar and Gosar, 2020) around the sample area as shown in Figure 2. These active tectonic features affect the strength of the sandstones in some places by altering the lithostratigraphic positions of silt-clay units. This influences the propagation of fractures and cracks in the rocks which only visible in high resolution microscope (Khormali and Amini, 2015). The sampling for the macro-mechanical study was carried out in areas where sandstone dominates, with good exposure to maximise the quality of the result; as the sandstone rocks are only focused, at the present study. In contrast to sandstone zones, the argillaceous dominated areas that primarily have siltstone, shale rocks and soils, are erodible by precipitation and hydro-geochemical factors which is dealt in a separate research work.

2. MATERIALS AND METHODS

2.1. R-VALUE MEASUREMENTS

Rebound or R-value measurements using a standard NR-type Schmidt hammer on sandstone surfaces were recorded on a paper roll. Periodic testing of the hammer for defects has ensured no deterioration in the values during the entire period of field measurements. Rock surfaces cleaned of dust, lichen, and moss, and areas with cracks, uneven relief, or

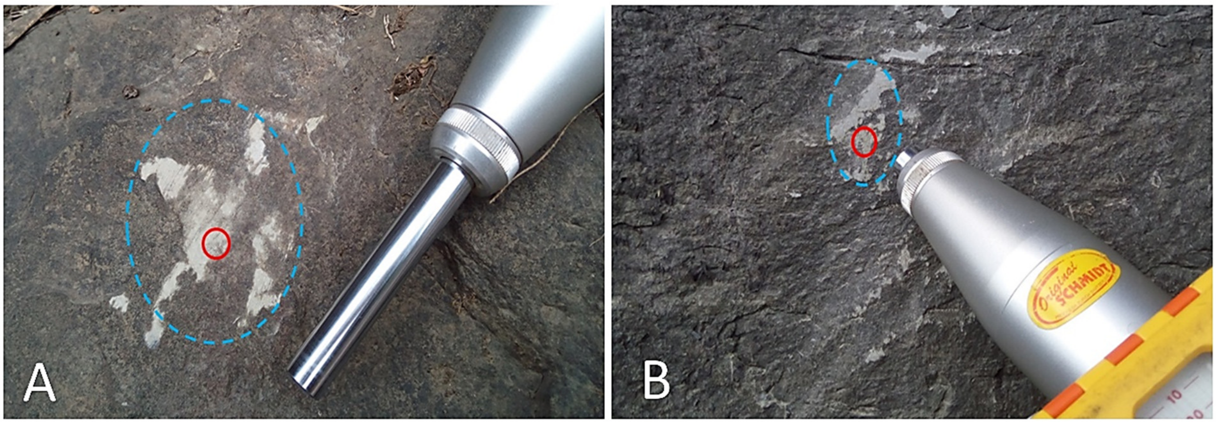


Fig. 3 A. Unweathered sandstone bedrock outcrop on Sairang road (Aizawl, Mizoram, India). Blue dotted line is the area cleaned and Red solid line area showing one sample point; B. An unweathered surface of Bhuban sandstone at the Hlimen road section, Aizawl.

other visible structural ambiguities such as plumose structure and joint systems, are ideal impact sites (Fig. 3). Such ambiguous surfaces were avoided in the present context. The measurements were made under dry conditions, away from any water seepages or drainage systems (Matthews et al., 2016; Saptono et al., 2013). These measurement points represent unweathered outcrops from various localities, over an area of 457 km^2 (Fig. 2). Unweathered surfaces are fresh outcrops with no sign of disintegration, soil and/or vegetation. The R-values converted to UCS by using the graphical chart available along with the hammer (Proceq, 2004). Authors utilised these readings along with different petrographic parameters to understand the macro-mechanical properties.

2.2. UNIAXIAL COMPRESSION TEST

Uniaxial compressive strength, which is also known as unconfined compressive strength is symbolised as UCS (Goodman, 1989; Sivakugan et al., 2014). It is measured by the uniaxial compression test or unconfined compression test. In this test a uniform stress is increased to failure (Jaeger and Cook, 1976; Wyllie and Norrish, 1996). This normal stress which is applied vertically on the circular horizontal edge of a cylindrical shaped core sample, provides the failure value as the UCS (Goodman, 1989; Piratheepan et al., 2012). UCS derived from R-values and that from core test generally show different values which would be acceptable for changes within 10-15 units (Sivakugan et al., 2014). The representative samples are collected and the test have been carried out for same samples as R-value readings. The tests were done for standard length of 9.5 cm with 4.9 cm diameter. The test is followed the standard procedure of American Society for Testing and Materials (ASTM D7012) as shown in Figure 4. The core samples are tested in uniaxial mode in the Triaxial testing machine (Aimil Ltd. Instrumentation and Technologies).

2.3. MACRO-MECHANICAL ASPECTS

Forty number of samples were collected from the locations, where the R-value measurements are available and their thin sections were studied under a Leica DM4500 polarising microscope. Only twenty-one samples found suitable as some were very fine-grained and others show similarity with neighbouring samples from the same rock Formation. Seven parameters were calculated for macro-mechanical properties to provide insight into the relationship between rock strength and mechanical characteristics. In all the thin sections, measurement of a hundred random grains gives the mean grain size and the average value of measurements along two perpendicular grain axes provided the average grain size (Folk, 1980). Visual classification chart by Compton (1962) is widely accepted for calculating the degree of sorting. Roundness and sphericity have calculated in fifty randomly selected grains. The degree of roundness was calculated according to the comparison chart of Powers (1953). The grade to which a particle approaches a sphere would provide the grain sphericity (Folk, 1980). Packing density (PD), packing proximity (PP) and degree of interlocking were calculated along grain traverses. PD and PP were calculated based on the following equation:

PD = (sum of grain length along traverse/ total traverse length) X 100; and

PP = sum of grain-to-grain contact /total number of contacts

The last parameter is the grain contact types, which are determined according to Blatt (1982). The percentage of four types of grain contacts; point (tangential), straight (long), concavo-convex and sutured are measured. Moreover, micro to nano-size imaging technique explains the role of all the identified factors. Scanning Electron Microscopes (SEM) and Transmission Electron Microscopes (TEM) have apportioned to similar geotechnical purposes (e.g., Khormali and Amini, 2015). Field

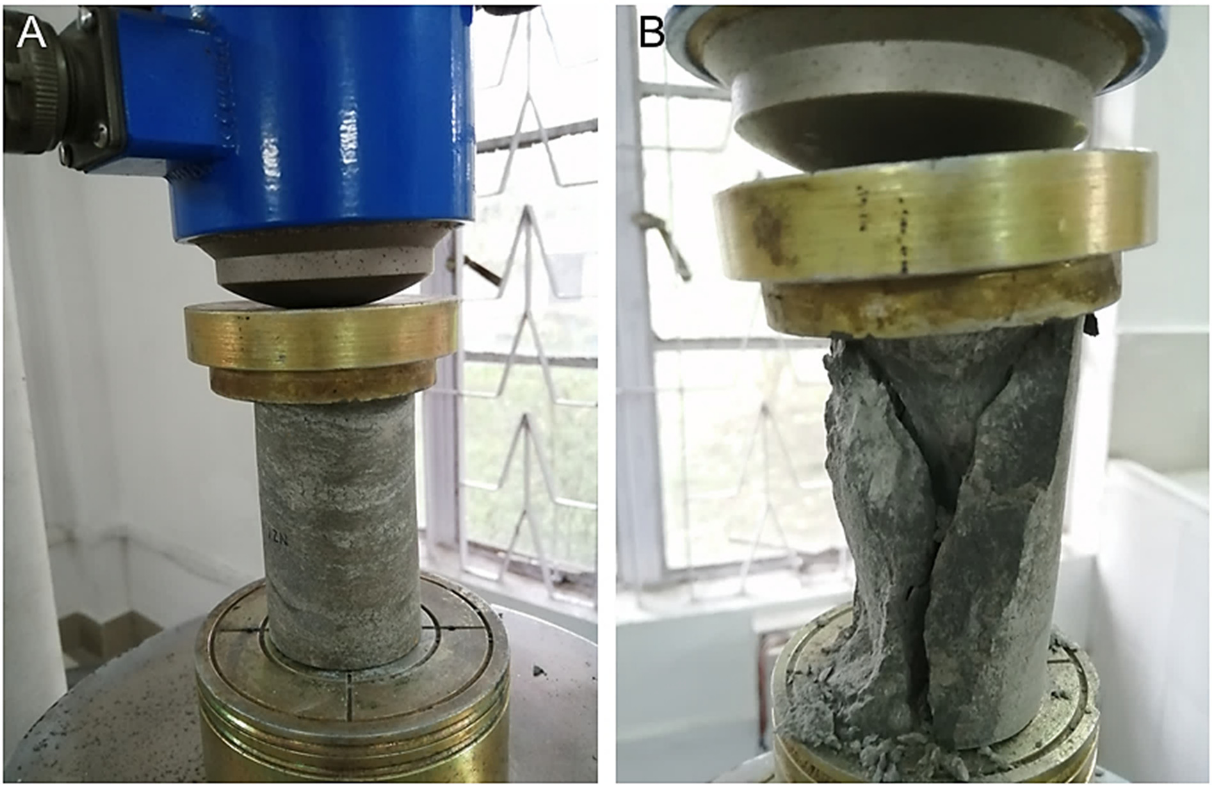


Fig. 4 Core samples are used to evaluate the uniaxial compression test results for same samples as that of the R-value sites. (A) before and (B) after the test.

Table 1 UCS (in MPa) value differences between R-values and core test show similar results.

Sample	UCS (from R-values)	UCS (from core test)	Difference
SAS 1	38.6	45.4	6.8
SAS 14	34.4	38.7	4.3
SAT 15	34.2	40.8	6.6
SBD 13	37.5	42.1	4.6
SAH 1	54.3	56.4	2.1
SWB 5	44.6	42.1	-2.5

Emission Transmission Electron Microscopy or FETEM (JEM-2100F, HR, JEOL at the Central Instruments Facility, Indian Institute of Technology Guwahati, India) imaging was available using 200 kV class analytical TEM with a probe size under 0.5 nm. FETEM enables the characterisation of rock and mineral grains to sub-nanometre scale. It provides an imaging and identification tool to detect lattice defects and grain surface undulations (Lee, 2010). Energy Dispersive X-Ray or EDX (X Flash 4010 SDD Detector) method detected the changes in the chemical composition of the grains. Again, Python 3.7 language software has enhanced in the FETEM images through its image processing tool.

3. RESULTS AND DISCUSSION

To understand the influence of microscopic aspects on the macroscopic strength of rocks, different factors were studied such as grain size, particle packing relationships along with grain-to-grain associations and overall sorting of the grains.

3.1. UCS CALCULATION FROM R-VALUES AND CORE TEST

The R-values are used to calculate UCS values for all the sample locations (Table 1 and Table 2). The values are then confirmed and validated by the UCS core sample test, by following the standard procedure and methodology. The results indicate that the difference between Schmidt hammer values show similar range which are within acceptable range (Table 1). This indicate that the values show moderate to high geotechnical strength of the Bhuban sandstones.

3.2. MACRO-MECHANICAL PROPERTIES

Measurement of grain size distribution by Folk (1980), degree of sorting by Compton (1962), grained roundness (Powers, 1953) and sphericity (Folk, 1980); packing density and packing proximity (Kahn, 1956) and grain contacts (Blatt, 1982) are important factors to understand the mechanical properties of sandstone rocks (Table 2). In the studied samples mean grain size

Table 2 Macro-mechanical properties of the sandstone from the same R-value sample points.

UCS	Sample No.	Grain Size (in µm)		Sorting	Grain shape (%)		Sphericity	Packing Density (%)	Packing Proximity (%)	Types of Contacts (%)			
		Mean	Average	(Phi units)	Round	Angular				Point	Straight	Concavo-convex	Sutured
38.6	SAS1	208.13	166.41	0.75	44.75	55.25	0.77	68.75	48.21	7.69	53.85	30.77	7.69
26.6	SAS4	155.48	120.50	1.3	66.67	33.33	0.74	60.83	58.33	4.96	45.35	24.72	24.97
36.2	SAS5	153.42	121.35	0.75	60.35	39.65	0.72	68.32	38.45	12.3	26.3	20.8	40.60
17.8	SAS10	151.49	121.78	0.56	53.85	46.15	0.79	59.59	69.97	9.8	21.3	24.6	44.30
34.4	SAS14	165.35	110.71	1.5	45.36	54.64	0.65	67.35	47.35	8.5	20.6	26.5	44.40
30.5	SAT2	157.54	174.40	0.56	67.2	32.8	0.66	57.12	42.31	12.5	31.25	31.25	25.00
24.2	SATA1	139.27	114.82	1.5	54.6	45.4	0.81	56.29	32.01	6.67	39.95	13.33	40.05
34.2	SAT15	145.35	121.32	0.58	65.2	34.8	0.75	55.89	35.15	5.85	38.55	14.35	41.25
28.2	SAT16	153.61	141.23	1.5	55.8	44.2	0.82	54.41	38.21	10.2	28.6	32.57	28.63
34	SBD1	130.32	98.59	1.5	68.35	31.65	0.78	65.69	35.36	11.3	38.6	28.65	21.45
32.2	SBD7	125.71	103.57	0.63	58.39	41.61	0.81	69.71	33.79	12.65	26.45	25.16	35.74
35.5	SBD9	120.56	102.49	0.75	42.93	57.07	0.83	68.51	34.27	10.35	46.57	28.43	14.65
37.5	SBD13	126.45	109.54	1.5	45.67	54.33	0.78	63.41	32.95	9.80	30.16	28.95	31.09
28.4	SBD16	119.46	101.95	1.5	59.31	40.69	0.75	62.85	33.59	10.54	34.2	26.6	28.66
28.2	SWB1	129.56	107.42	0.62	43.33	56.67	0.82	77.18	31.98	10.53	47.37	26.32	15.79
26.5	SWB4	128.65	109.65	0.75	60.38	39.62	0.84	68.54	38.62	7.69	38.95	24.86	28.50
48.4	SWB5A	127.49	112.36	0.75	58.95	41.05	0.78	61.75	35.62	8.69	29.45	43.19	18.67
35.6	SWB5B	107.86	101.25	1.5	62.14	37.86	0.85	58.84	32.56	6.15	36.85	45.26	11.74
54	SAH1	118.42	94.79	0.75	60.15	39.85	0.79	62.59	33.33	10.2	21.1	28.8	39.90
52.4	SAH5	120.21	98.65	0.62	61.21	38.79	0.86	59.94	39.48	11.3	25.98	44.36	18.36

ranged from 108 to 208 μm, which indicates that the samples are medium-grained sandstones. They are moderate to poorly sorted, having phi scale ranges 0.56-1.5. Most of the grains show rounded surfaces with an average of 56 % (43-68 %), although a considerable number of angular grains is also present.

Sphericity for the samples is around 0.65-0.85, which is typical for such sedimentary conditions. Packing density (average 66 %, range 54-77 %) shows higher values compared to the packing proximity (average 51 %, range 32-70 %) which reveals the tightly pack setting of sandstones. Straight contacts (20-54 %) are most abundant, followed by concavo-convex contacts (13-45 %) (Fig. 5). The ranges for point and sutured contacts are 5-13 % and 8-44 % respectively. This shows that the samples have undergone stress attributable to intermediate burial and compaction. Examination of the interrelationship among all the attributes and the UCS values by plotting their variations (Fig. 6). It shows the dependencies, for example, grain shape = f (UCS), packing density = f (UCS), etc. The relationship UCS = f (macro-mechanical parameters) is good, because uniaxial strength depends on many factors, or doesn't depend on them, among others, those studied by the authors.

The results show that mechanically strong sandstones are unaffected by most of the macro-mechanical parameters. Grain shape (with rounded grains showing slight positive, angular grains showing negative and non-linear relationships with increasing strength of rocks), sphericity, point contacts and packing density (but not packing proximity) have shown a slight positive relationship with strength (Fig. 6). Interestingly, the migration of soluble products has occurred without disturbing the structures such as bedding, layered textures (Fig. 3), granularity, and grain distribution (Fig. 5). Petrographic studies reveal this fact clearly as the intergranular spaces have been replaced by solution materials.

3.3. FETEM ANALYSIS

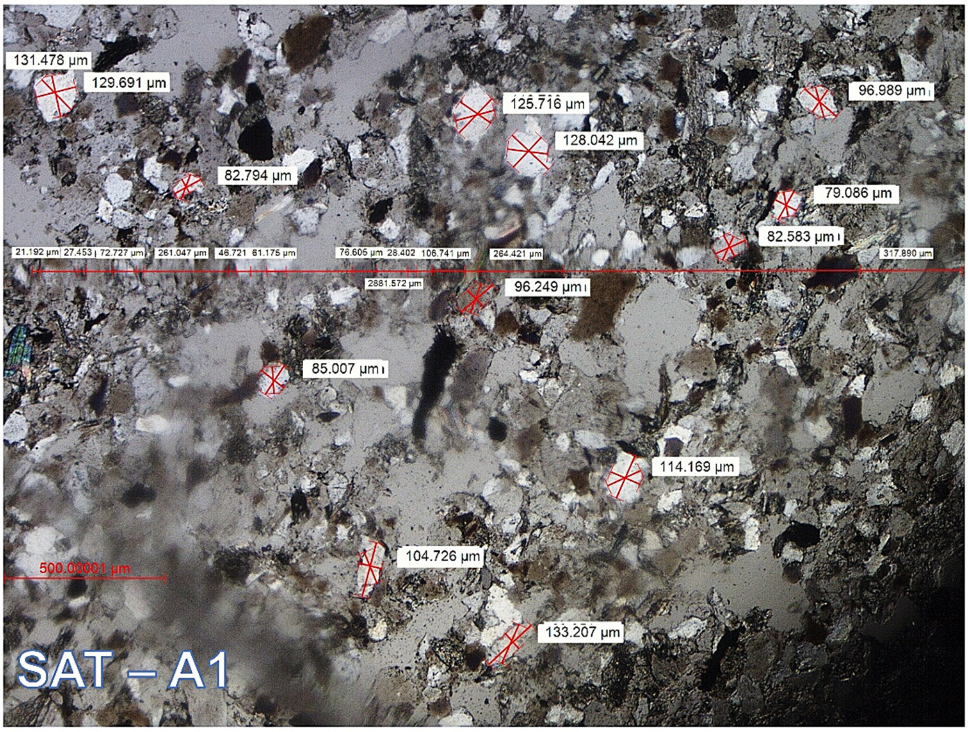
FETEM is a useful tool for analysing any defects and changes in micro-level processes. FETEM images show angular quartz grains with preferential micro-weathering at sites of lattice defects (Fig. 7). The grain surface is undulatory and rugged, inferring variable and non-uniform surface distribution along the inter-granular spaces. Calcareous cement and matrix fill these spaces. Mineral constituents showing non-uniform layer stacking also resulted in declining macro-mechanical strength. The angular quartz grains also verified the micro-level association of the processes that already discussed in the above section. EDX chemical analysis shows that SiO_2 and Al_2O_3 are major components in the rocks (Table 3). Quartz (SiO_2) content detected in the range of 73.92-83.67 wt% and Al_2O_3 shows the range of 8.62-13.43 wt%. The presence of alumino-silicate components indicates the appearance of some clay content in the rocks because of micro-level weathering. Therefore, changes in the chemical composition can affect the macro-mechanical properties and strength of the rocks. EDX analysis infers Fe_2O_3, MgO, CaO, Na_2O, and K_2O in a good amount are there in the samples. The higher amount of iron content (1.42-4.35 wt%) has resulted from the presence of different rock constituents, which might link with the leaching of the rock. Quartz grains have sprawled by weathered materials (Fig. 7a) confirming micro-weathering in the surfaces. However, the occurrence of other oxides, MgO (1.28-2.01 wt%), CaO (2.28-6.55 wt%), Na_2O (1.21-2.16 wt%), and K_2O (1.53-2.06 wt%) show feldspar and other weatherable materials in the samples. Overall, we observe that clay and weathered materials could bring changes in the macro-mechanical properties. Therefore, rugged morphology, uneven lattice distribution and chemical changes are lowering the mechanical strength of the grains. The mixture of rounded and angular grains in moderate to poorly sorted rock is the reason for their strength. This is clear by the dominance of straight to concavo-convex grain contacts where packing density is high. However, this process causes the uneven surface distribution of the mineral grains, which itself has stacked layers of deformed lattices. Even though the framework is strong, argillaceous rock components cause some 'weakness' in the sandstones which enhances lowering in the macro-mechanical strength.

4. CONCLUSIONS

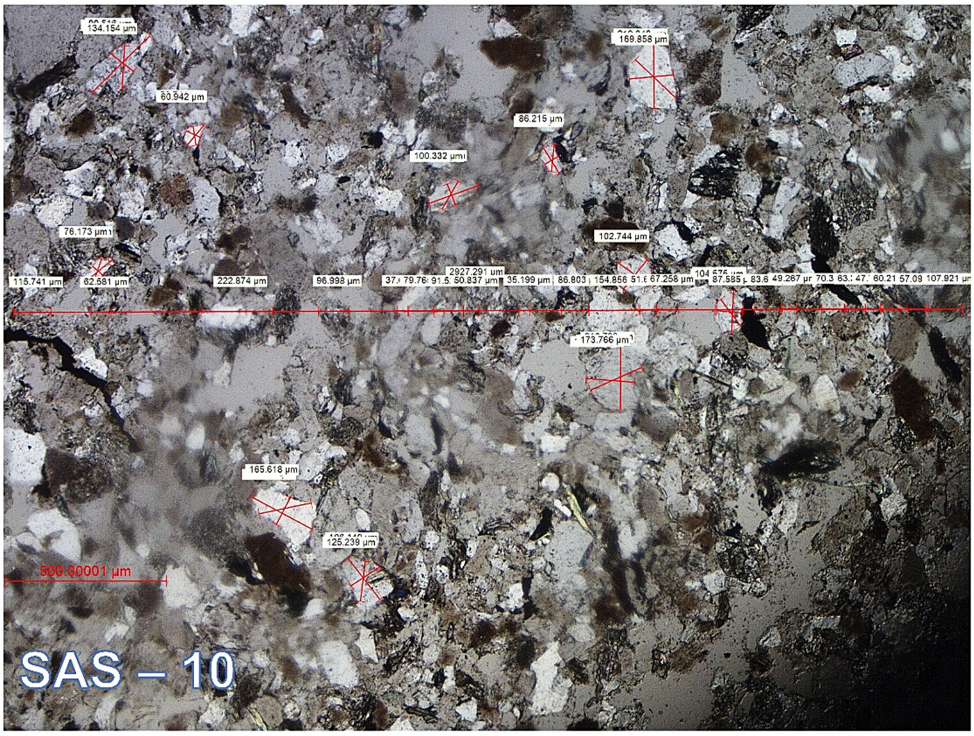
Mechanically strong sandstone rocks are found in many places around the world, including the Indo-Burmese Ranges of NE India. This sedimentary rock has geotechnical strength comparable to any hard

Table 3 Semi-quantitative EDX results for the sandstone samples.

Sample No.	SAT-A1	SAS-10	SBD-16	SWB-5A
SiO_2	83.67	83.01	73.92	78.21
Al_2O_3	8.62	9.32	10.61	13.43
Fe_2O_3	1.42	2.31	4.35	3.61
MgO	1.28	2.01	1.47	1.49
CaO	2.28	2.74	6.55	3.65
Na_2O	2.05	2.16	1.21	1.95
K_2O	1.94	2.06	1.53	2.02



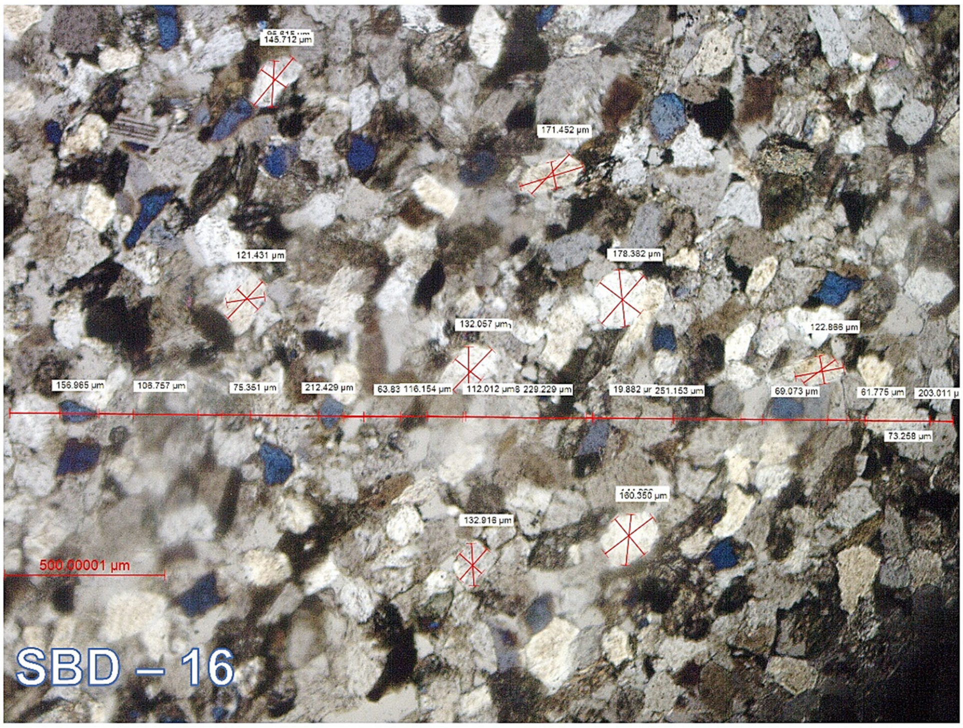
5A



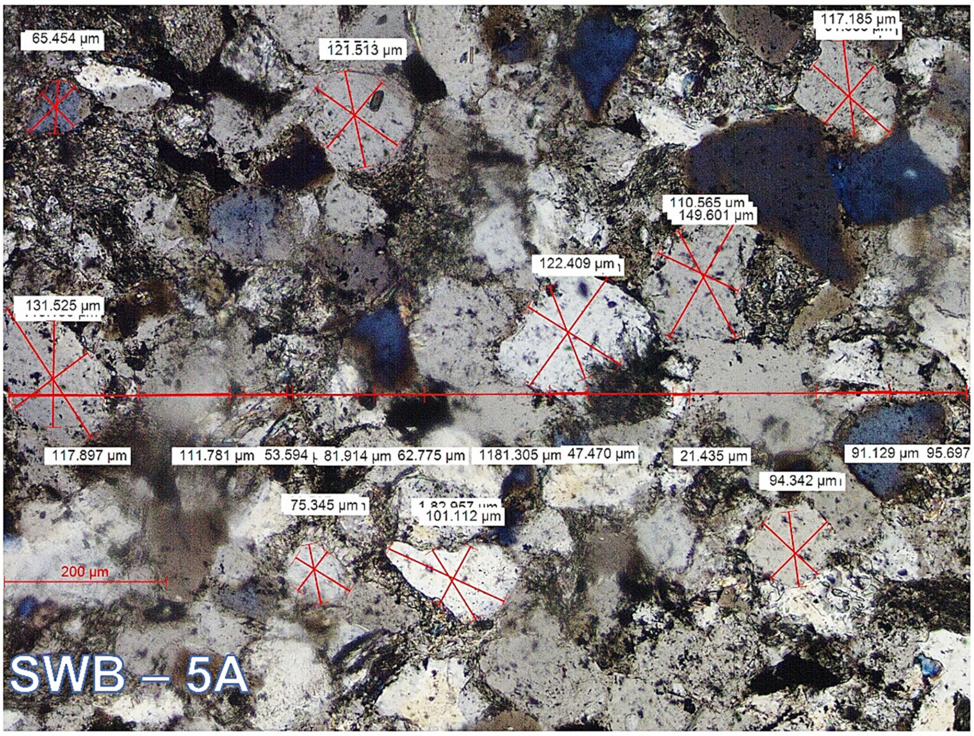
5B

Fig. 5 Photomicrograph of sandstone slides. The readings are for the macro-mechanical properties. Magnification of (A) SAT-A1: 4X, (B) SAS-10: 4X, (C) SBD-16: 4X and (D) SWB-5A: 10X.

rocks of the region. This study was carried out to understand the macro-mechanical properties of the sandstone rocks and their relationship with mechanical strength. OM studies for macro-mechanical parameters and FETEM-EDX analysis have been performed on the samples where the Schmidt hammer R-values have provided the *in-situ* UCS measurements for these rocks. These UCS values hold good for the region as confirmed by the uniaxial laboratory tests for the same samples. It is evident from the observation



5C



5D

Fig. 5 Continued

that many macro-mechanical properties do not relate to the rock strength. The inter-locking grains glued to each other by cement provided the resistive strength. Although, the angular grains have a negative relationship with the UCS values and a considerable amount (average 44%) of their presence might reduce the rock strength. The sphericity parameter infers that other grains are semi-spherical to semi-angular, which again shows that spherical grains are not rounded enough. FETEM images confirm such semi-angular grains. Differential force distribution would result around the grain networks because of various grain contact types that are cohering the grains. Unweathered rock is slowly deteriorating because of

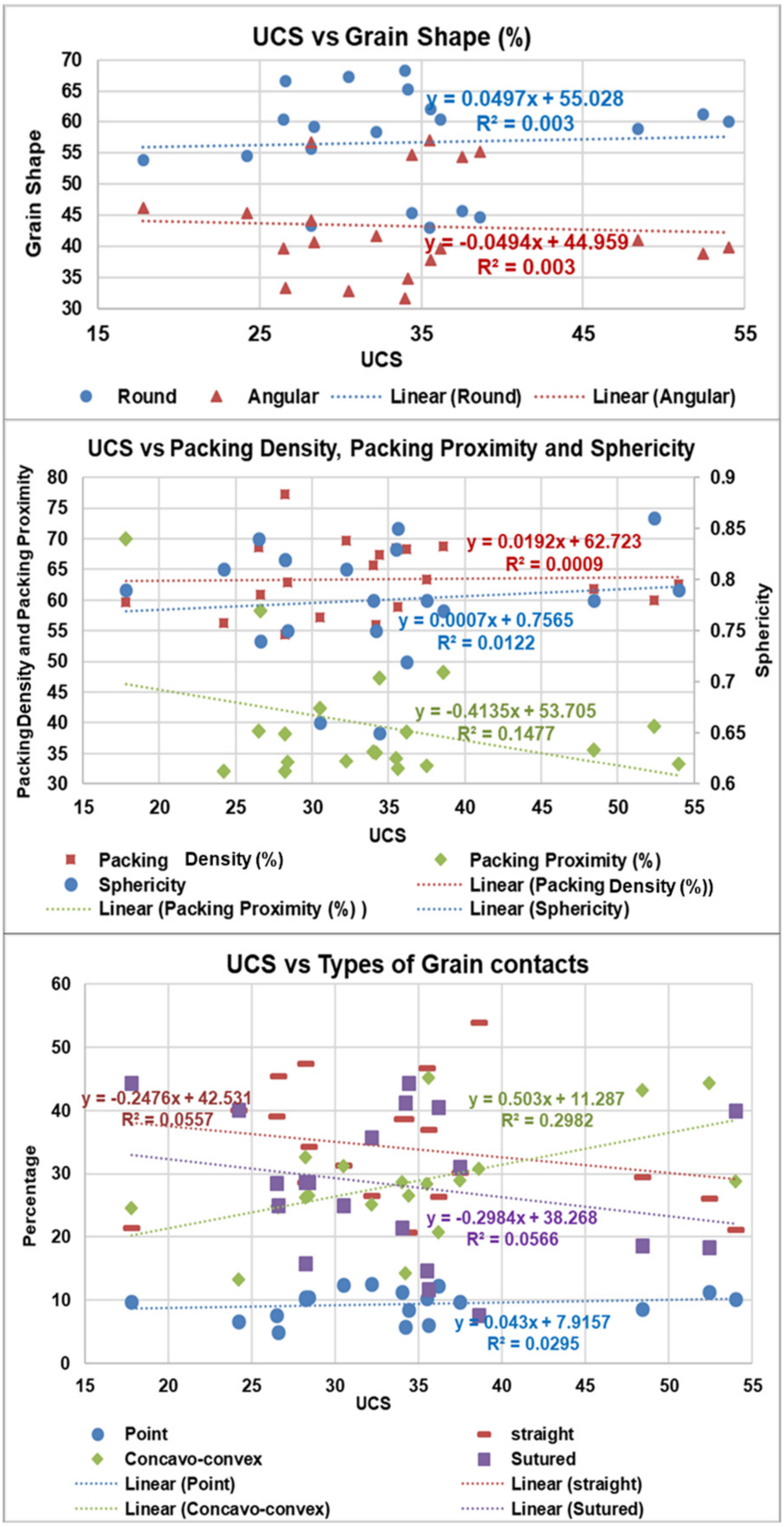


Fig. 6 Micro-mechanical parameters against the UCS plot for the studied samples. The equations for the lines are determined by linear regression with R^2 values.

micro-weathering conditions that prevailed in the rock materials as confirmed by the FETEM-EDX analysis. Moreover, the presence of clay in micro and small visible ball shape units cause real problems as it can swell and/or shrink depending on the availability of water. Therefore, micro-mechanical parameters have influence in the sandstones of western IBR which shows mean rock strength of 34.2 MPa. Although, while making engineering decisions, consideration of other rock types along with sandstone is desirable.

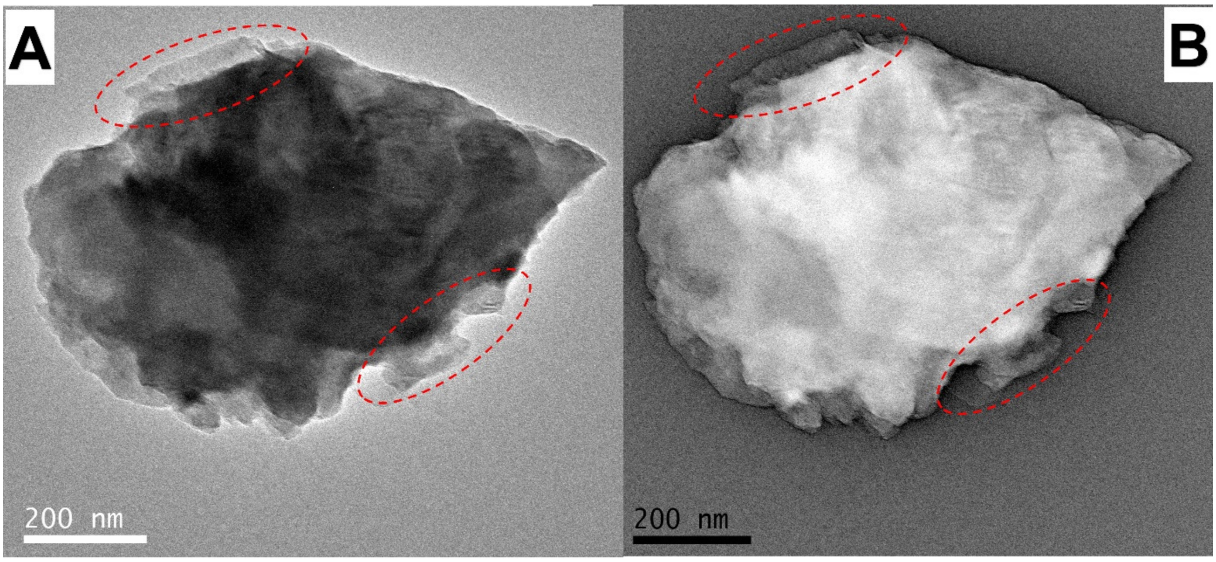


Fig. 7 FETEM images (A) angular quartz grain with multiple SiO_2 layers showing evidence of both weathering effect (red dotted area) and mechanical ambiguities (as layer stacking is not uniform) in the grain, (B) The same image processed by Python software to enhance the surficial view of the grain infers its sphericity and sharp morphology.

ACKNOWLEDGMENT

First author is greatly acknowledging the suggestions and support by Prof. R. J. Wasson. The authors are grateful to the Central Instruments Facility, Indian Institute of Technology Guwahati, India, for providing analytical facilities. The NET-SRF fellowship from University Grant Commission (UGC), India to R. Rakshit is also gratefully acknowledged.

Authors are grateful to executive editor Dr. Monika Supova and two anonymous reviewers for their support and suggestions.

REFERENCES

Aggistalis, G., Alivizatos, A., Stamoulis, D. and Stournaras, G.: 1996, Correlating uniaxial compressive strength with Schmidt Hammer Rebound Number, Point Load Index, Young's Modulus, and mineralogy of gabbros and basalts (Northern Greece). Bull. Eng. Geol., 54, 3–11. DOI: 10.1007/BF02600650

Ansari, T., Kainthola, A., Singh, K.H., Singh, T.N. and Sazid, M.: 2021, Geotechnical and micro-structural characteristics of phyllite derived soil; implications for slope stability, Lesser Himalaya, Uttarakhand, India. Catena, 196, 1–14. DOI: 10.1016/j.catena.2020.104906

Aydin, A. and Basu, A.: 2005, The Schmidt hammer in rock material characterization. Eng. Geol., 81, 1–14. DOI: 10.1016/j.enggeo.2005.06.006

Bharali, B., Borgohain, P., Bezbaruah. D., Vanthangliana, V., Phukan, P. and Rakshit, R.: 2017, A geological study on Upper Bhuban Formation in parts of Surma Basin, Aizawl, Mizoram. Sci. Vis., 17, 3, 128–147. DOI: 10.33493/scivis.17.03.02

Bharali, B., Hussain, M.F., Borgohain, P., Bezbaruah, D., Vanthangliana, V., Rakshit, R. and Phukan, P.: 2021, Reconstruction of Middle Miocene Surma Basin by two arcs derived sedimentary model as evident by provenance, source rock weathering and Paleo-environmental conditions. Geochem. Int., 59, 265–289. DOI: 10.1134/S0016702921030022

Blatt, H.: 1982, Sedimentary petrology. W. H. Freeman and Company, 564–565.

Bouafia, A.: 2003, Load-settlement behaviour of socketed piles in sandstone. Geotech. Geol. Eng., 21, 389–398. DOI: 10.1023/B:GEGE.0000006054.41844.53

Bukowska, M.: 2015, Influence of grain size, humidity and state of stress on the mechanical properties of sandstones. Acta Geodyn. Geomater., 12, 2 (178), 187–195. DOI: 10.13168/AGG.2015.0015

Cargill, J.S. and Shakoor, A.: 1990. Evaluation of empirical methods for measuring the uniaxial compressive strength of rock. J. Rock Mech. Min. Sci. Geomech. Abstr., 27, 6, 495–503. DOI: 10.1016/0148-9062(90)91001-N

Cobanoglu, I., and Celik, S.B.: 2008, Estimation of uniaxial compressive strength from point load strength, Schmidt hardness and P-wave velocity. Bull. Eng. Geol. Environ., 67, 491–498. DOI: 10.1007/s10064-008-0158-x

Compton, R.R.: 1962, Manual of field geology. John Wilex and Sons. Inc., New York, 5–29.

Demirdag, S., Yavuz, H. and Altindag, R.: 2009, The effect of sample size on Schmidt rebound hardness value of rocks. Int. J. Rock Mech. Min. Sci., 46, 725–730. DOI: 10.1016/j.ijrmms.2008.09.004

Ersoy, A. and Waller, M.D.: 1995, Textural characterisation of rocks. Eng. Geol., 39, 123–136. DOI: 10.1016/0013-7952(95)00005-Z

Folk, R.L.: 1980, Petrology of sedimentary rocks. Hemphill Publishing Company, 25–36.

Gahalaut, V.K., Kundu, B., Laishram, S.S., Catherine, J., Kumar, A., Singh, M.D., Tiwari, R.P., Chadha, R.K., Samanta, S.K., Ambikapathy, A., Mahesh, P., Bansal, A. and Narsaiah, M.: 2013, Aseismic plate boundary in the Indo-Burmese wedge, northwest Sunda Arc. Geology, 41, 235–238. DOI: 10.1130/G33771.1

Goodman, R.E.: 1989, Introduction to rock mechanics, 2nd edn, New York, Wiley, 207–216.

Jaeger, J.C., and Cook, N.G.W.: 1976, Fundamentals of rock mechanics. Chapman and Hall, London, 580–585.

Kahn, J.S.: 1956, The analysis and distribution of the properties of packing in sand-size sediments: 1. On the measurement of packing in sandstones. J. Geol., 64, 4, 385–395. DOI: 10.1086/626372

Katz, O., Reches, Z. and Roegiers, J.C.: 2000, Evaluation of mechanical rock properties using Schmidt Hammer. Int. J. Rock Mech. Min. Sci., 37, 723–728. DOI: 10.1016/S1365-1609(00)00004-6

Khormali, F. and Amini, A.: 2015, Clay mineralogy of the Jurassic-Tertiary sedimentary rocks of the Kopet Dagh basin (northeastern Iran): implications for paleoclimate. Acta Geodyn. Geomater., 12, 4(180), 387–398. DOI: 10.13168/AGG.2015.0036

Kilic, A. and Teymen, A.: 2008, Determination of mechanical properties of rocks using simple methods. Bull. Eng. Geol. Environment, 67, 237–244. DOI: 10.1007/s10064-008-0128-3

Lee, M.: 2010, Transmission electron microscopy (TEM) of earth and planetary materials: a review. Mineral. Mag., 74, 1–27. DOI: 10.1180/minmag.2010.074.1

Matthews, J.A., Owen, G., Winkler, S., Vater, A.E., Wilson, P., Mourne, R.W. and Hill, J.L.: 2016, A rock-surface microweathering index from Schmidt hammer R-values and its preliminary application to some common rock types in southern Norway. Catena, 143, 35–44. DOI: 10.1016/j.catena.2016.03.01

Nandy, D.R., Gupta, S.D., Sarkar, K. and Ganguly, A.: 1983, Tectonic evolution of Tripura - Mizoram Fold Belt., Surma Basin, North East India. Quart. J. Geol. Min. Met. Soc. India, 55, 186–194.

Obert, L. and Duvall, W. I.: 1967, Rock mechanics and the design of structures in rock. John Wiley & Sons, New York.

Piratheepan, J., Gnanendran, C.T. and Arulrajah, A.: 2012, Determination of c and φ from an IDT and unconfined compression testing and numerical analysis. J. Mater. Civ. Eng., 24, 9, 1153–1163. DOI: 10.1061/(ASCE)MT.1943-5533.0000493

Powers, M.C.: 1953, A new roundness scale for sedimentary particles. J. Sed. Petrol., 23, 117-119. DOI: 10.1306/D4269567-2B26-11D7-8648000102C1865

Proceq: 2004, Operating instructions Betonprüfhammer N/NR-L/LR.

Rakshit, R. and Bezbaruah, D.: 2016, Morphotectonic aspects in and around Aizawl, Mizoram of NE India. S. E. Asian J. Sediment. Basin Res., 2-3–4, 28–36.

Rakshit, R., Bezbaruah, D. and Bharali, B.: 2018, Oblique slip faulting associated with evolving central Indo-Burmese region from Early Pleistocene deformational sequences. Solid Earth Sci., 3, 67–80. DOI: 10.1016/j.sesci.2018.04.002

Rakshit, R., Bezbaruah, D., Zaman, F. and Bharali, B.: 2020, Variability of orographic architecture of Indo-Burmese Ranges NE India, constraint from morphotectonic and lineament analysis. Geol. Q., 64, 130–140. DOI: 10.7306/gq.1522

Reddy, T.C.S. and Elumalai, J.K.: 2016, Study of macro mechanical properties of ultra high strength concrete using quartz sand and silica fume. Int. J. Res. Eng. Technol., 6, 391–395.

Rekik, B., Boutouil, Md. and Pantet, A.: 2009, Geotechnical properties of cement treated sediment: influence of the organic matter and cement contents. Int. J. Geotech. Eng., 3, 2, 205–214. DOI: 10.3328/IJGE.2009.03.02.205-214

Rupar, L. and Gosar, A.: 2020, Mapping the thickness of Quaternary sediments in the Iška alluvial fan (Central Slovenia) using microtremor method. Acta Geodyn. Geomater. 17, 2 (198), 177–190. DOI: 10.13168/AGG.2020.0013

Sachpazis, C.I.: 1990, Correlating Schmidt hammer rebound number with compressive strength and Young's modulus of carbonate rocks. Bull. Int. Assoc. Eng. Geol., 42, 75–83.

Saptono, S., Kramadibrata, S. and Sulistianto, B.: 2013, Using the Schmidt hammer on rock mass characteristic in sedimentary rock at Tutupan Coal Mine. Procedia Earth Planet. Sci., 6, 390–395. DOI: 10.1016/j.proeps.2013.01.051

Sardana, S., Verma, A.K., Verma, R., and Singh, T.N.: 2019, Rock slope stability along road cut of Kulikawn to Saikhamakawn of Aizawl, Mizoram, India. Nat. Hazards., 99, 753–767. DOI: 10.1007/s11069-019-03772-4

Sivakugan, N., Das, B.M., Lovisa, J., and Patra, C.R.: 2014, Determination of c and φ of rocks from indirect tensile strength and uniaxial compression tests. Int. J. Geotech. Eng., 8, 1, 59–65. DOI: 10.1179/1938636213Z.00000000053

Sun, Q., Chen, S., Gao, Q., Zhang, W., Geng, J. and Zhang, Y.: 2017, Analyses of the factors influencing sandstone thermal conductivity. Acta Geodyn. Geomater., 14, 2 (186), 173–180. DOI: 10.13168/AGG.2017.0001

Wyllie, D.C. and Norrish, N.I.: 1996, Chapter -14: Rock Strength Properties and Their Measurement. Landslide: Investigation and Mitigation. Transportation Research Board Publications, 372–390.

Zaman, F. and Bezbaruah, D.: 2019, Morphotectonic aspects in a part of Naga-Schuppen belt, Assam Nagaland region, Northeast India. Sci. Vis., 19, 1, 6–11. DOI: 10.33493/scivis.19.01.02

Zaman, F., Bezbaruah, D., Sangi, L. and Rakshit, R.: 2019, Morphotectonic study in a part of Indo-Burmese Ranges in Eastern Mizoram, India. Senhri J. Multidiscip. Stud., 3, 81–92.

Zorlu, K., Gokceoglu, C., Ocakoglu, F., Nefeslioglu, H.A. and Acikalin, S.: 2008, Prediction of uniaxial compressive strength of sandstones using petrography-based models. Eng. Geol., 96, 141–158. DOI: 10.1016/j.enggeo.2007.10.009