Journal of Mountain Area Research
Vol. 7, 2022
https://doi.org/10.53874/jmar.v7i0.143

Full length article

EXPERIMENTAL INVESTIGATION OF DURABILITY AND STRENGTH OF SANDSTONE AND SHALE OF UNITED MINERAL COAL COMPANY SOR-RANGE, BALOCHISTAN

Tufail Ahmed[1], Syed Hafeez ur Rehman[1], Fahim Ahmed Ibupoto[1,], Asif Abbas[2], Sami Ullah[1], Abbas Hussain[1], Shehzad Usman[1]*

1. Department of Mining Engineering, BUITEMS, Quetta, Pakistan.

2. Department of Geological Engineering, BUITEMS, Quetta, Pakistan.

ABSTRACT

Mining operations deal mainly with hard and soft rocks with different mechanical properties and varying strengths. The aim of the slake durability test is to present an index related to degradation resistance of rock when exposed to standard cycles of wetting and drying. Research in geology and rock mechanics is done to explain the influence of the rock index properties in determining the strength, durability and pulse velocity of the rock. This paper enlightens the prediction of the rock's behavior and nature of the degradation of rocks The index values obtained for sandstone are varying from 97.36 to 99.04% and for shale it ranges from 10.21 to 14.06%. The slake durability index test for sandstone sample indicates that it is high durable and the shale indicates very low durability. The average value of uniaxial compressive strength was calculated to be 83.144 MPa.

KEYWORDS: Slake durability index test (SDI), Uniaxial Compressive Test (UCS), Ultrasonic pulse velocity test (UPV)

*Corresponding author: (Email: fahim.ahmed@buitms.edu.pk, Phone: 0092-332-2623850)

1. INTRODUCTION

Safety in the mining industry is considered highly important. Hence the stability of the mine excavation and mine working is deeply considered, therefore the geotechnical analysis is done. Geotechnical analysis involves, surface and subsurface structures, their strength evaluation and deformability of rock or rock mass [1, 2]. Physical properties, strength and durability are essential properties that help to assess the rocks for various applications [2]. Durability of sandstone and shale are affected by stresses and weathering which causes the instability of excavation hence making the working unsafe [3].

For checking the durability of the rock materials slake durability is considered. Franklin and Chandra, firstly developed the slake durability index (SDI) test for shale [4] and was later upgraded by Kolay and Kayaba [5]. The slake durability test is a standard test for rock durability by ISRM and it also became an ASTM standard [6]. The slake durability test is to supply an index that is associated with the resistance of rock against degradation when subject to standard cycles of wetting and drying [7].

The amount of water absorbed by a stone can be indicated by porosity and saturation coefficient. Pore size may also impact the durability as those with fine pores tend to be less durable compared to those with coarse pores [8, 9]. Shapes of the specimens have an impact on degradation due to different mechanisms in the slaking processes. In

particular, irregular shapes tends to give lower index values, when compared to specimens that had rounded shapes [10-12]. The weathering process is very slow it takes hundreds or thousands of years. Weathering process can be divided into two types, that is physical or mechanical weathering and chemical weathering [13].

Hence in this study we predicted the rocks behavior and nature of the rocks when they are subjected to varying conditions of wetting and drying of slake durability index and sudden impacts of load. The results of this study will have implications in designing and safely extracting the minerals from the mine where the strata are of sandstone or shale. The application of this study will be in designing and running the safe mine excavation by providing the knowledge of the durability of the rock strata. In this manuscript we show, by comparison that how safe the mine is for extraction in sandstone compared to the shale rock.

2. METHODOLOGY

2.1 Sample Preparation

2.1.1 Slake Durability Index Test

Two rock type samples, shale and sandstone were collected in block form underground coal mine at United Mineral Coal Company Sor-range with depth of 4000 ft. Samples are collected from the working face above and below the coal seams. 40 Specimens of sandstone and shale each were prepared by reducing size with hammering while breaking sharp edges for slake durability index test as shown in figure 1(a) & figure 1(b). Whereas the geological map of UMC Sor-range is shown in figure 2.

Figure 1. Sor-range (a) Sandstone (b) Shale

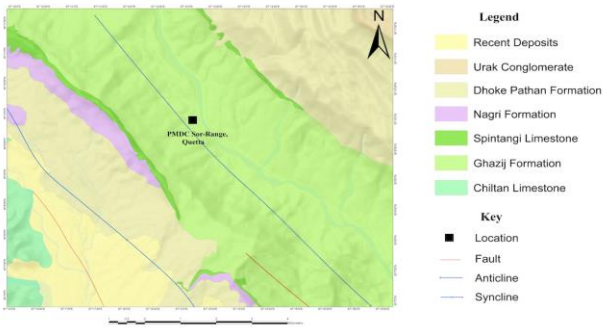

Figure 2. Geological Map of UMC Sor-range

The samples were brushed to remove fine particles pre-weighing. The samples were first weighed and then dried in oven for 16 hours at 105C, after that they were cooled for 20 mins at 25 C, the samples were intact and weighing between 40-60 grams each. Whereas total test specimens weigh 450g to 550g [ASTMD-4644, 2008] [6].

2.1.2 Uniaxial Compressive Strength (UCS) Test

The Uniaxial Compressive Strength (UCS) test samples were prepared by coring following the procedure in ASTM D-2938 [14]. In order to get standard accurate results, the ASTM was followed. The core cylinder having smooth flat surface with L/D ratio 2-2.5 as shown in figure 3. Core samples were prepared for both sandstone and shale. The same sample were utilized for Ultrasonic Pulse Velocity (UPV) testing prior to UCS.

Figure 3. UCS testing core samples

Figure 4. Slake durability index test Apparatus

2.1.3 Ultrasonic Pulse Velocity (UPV) tester

The UCS test rock core samples were utilized for UPV testing prior to UCS testing.

2.2 Experimental Procedure

2.2.1 Slake durability index test

For determining the slake durability of the rocks ASTM D-4644-87 is adopted. Standard Slake durability device shown in figure 4 is used for testing. Testing procedure essentially consists of cycles of wetting and drying. Slaking fluid utilized was the tap water. The prepared samples were placed in a test drum then it was weighed. The drum is then dried for 16 hours and cooled off for 20 minutes at room temperature and weighed again. Then drum was mounted and rotated for 10 minutes at 20 rpm. Water temperature is checked at beginning and ending of the rotation period. After which we dry the drum using previous technique and time. After cooling, the sample were weighed.

2.3 Uniaxial compressive strength (UCS) test

According to ASTM D-2938 [14], in this research the length to diameter ratio of a specimen is 2 and a continuous load of 12 KN/s is applied on the specimen.

The universal testing machine used for this research from UTEST model number UTC-5431 4000 KN shown in figure 5.

Figure 5. Uniaxial compressive (UCS) test Apparatus

2.4 Ultrasonic Pulse Velocity (UPV) Test

UPV testing is non-destructive method that we adapted for our laboratory testing, in this research the ultrasonic pulse velocity of a sandstone samples were determine by ultrasonic concrete tester that measure time of propagation of ultrasound pulses with an accuracy +/- 0.1 µs with two 55kHz probes with connection cables (figure 6).

The Shale sample were not tested for UPV because they are soft in nature and its core samples cannot be prepared.

Figure 6. Ultrasonic pulse velocity (UPV) tester.

3. RESULTS & DISCUSSIONS

3.1 Slake Durability Index Test Results

The slake durability index test was carried out with two different types of rocks sandstone and shale. The initial and final weights of the samples were taken before and after the test.

Table 1. Results of Sandstone Slake Durability Index test.

Test No.	Initial Weight (gm)	Water Content	Weight after 1st Cycle	Weight after 2nd Cycle	Percentage Retained after 2nd Cycle Sandstone
01	444.47	0.085	442.30	438.39	98.71
02	457.38	0.039	454.84	451.28	99.04
03	502.87	0.072	499.96	479.29	97.36
04	480.55	0.054	478.76	474.67	97.67
05	510.43	0.086	507.72	501.58	98.32
06	486.44	0.059	484.26	481.12	98.56
07	496.23	0.081	495.02	491.85	97.69
08	462.46	0.052	461.03	458.21	98.36

The weight reduction in sandstone after each cycle can be seen in figure 7 for each test. Similarly, the weight reduction in shale can be seen in figure 8. The retention percentage of the samples was also obtained after the two cycles. The data is provided in table 1 and table 2 subsequently.

The sandstone samples retention was found to be ranging from 97.36 % to 99.04 %. Whereas the retention percentage of the shale samples was found to be ranging from 10.21 % to 14.06 %. The results are shown in figure 9 & figure 10.

According to the classification of gamble [15] the sandstone of sor-range show a high durability. So-range sandstone is showing the retention percentage to that of the sandstone of Dalmatia, Croatia [16].

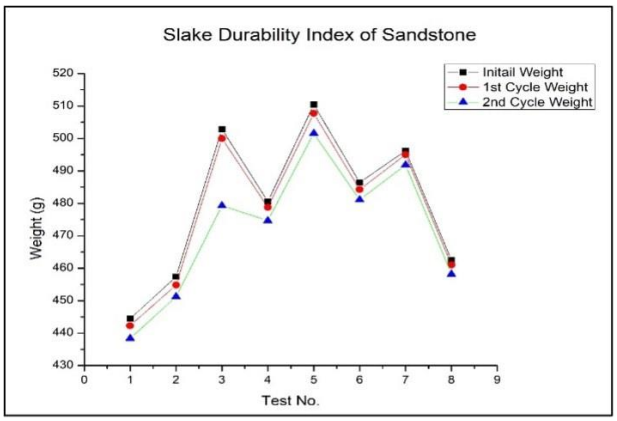

Figure 7. Sandstone Slake Durability Index

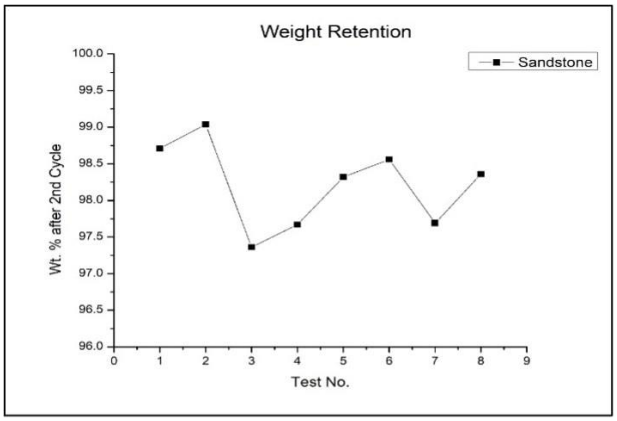

Figure 8. Sandstone Slake Durability Index

Table 2. Results of Shale *Slake Durability Index* test.

Test No.	Initial Weight (gm)	Water Content	Weight after 1st Cycle	Weight after 2nd Cycle	Percentage Retained after 2nd Cycle Sandstone
01	444.47	0.085	442.30	438.39	98.71
02	457.38	0.039	454.84	451.28	99.04
03	502.87	0.072	499.96	479.29	97.36
04	480.55	0.054	478.76	474.67	97.67
05	510.43	0.086	507.72	501.58	98.32
06	486.44	0.059	484.26	481.12	98.56

07	496.23	0.081	495.02	491.85	97.69
08	462.46	0.052	461.03	458.21	98.36

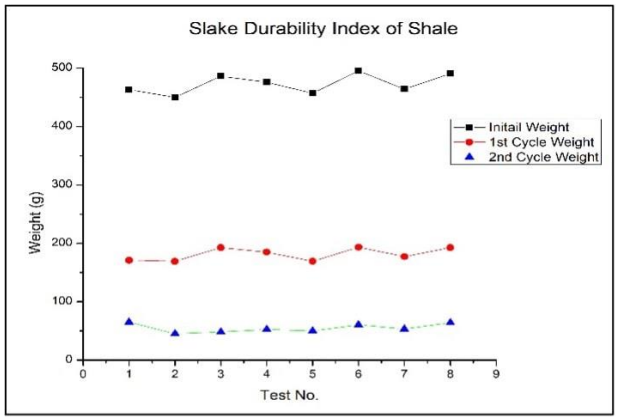

Figure 9. Shale Slake Durability Index

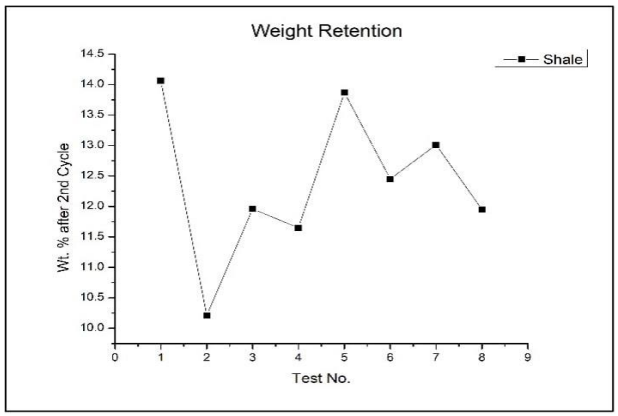

Figure 10. Shale Slake Durability Index

3.2 Uniaxial Compressive Strength Test Results

The UCS of the sandstone is determined in the laboratory. The UCS results are portrayed in the Table 3. The results of the UCS for sandstone are in the ranges already studied by Eren for natural stones [17]. The relationship between the peak load and UCS of sandstone is provided in Figure 11.

Table 3. Results of Uniaxial Compressive Strength (UCS) test.

Test No.	Length (mm)	Diameter (mm)	L/D	Loading rate (KN/s)	Peak load (KN)	UCS (MPa)
1	109	54	2.0	12	106.9	48.78
2	108	54	2.0	12	134.9	59.65
3	109	54	2.0	12	198.8	87.20
4	108	54	2.0	12	209.3	98.547
5	109	54	2.0	12	237.8	121.5

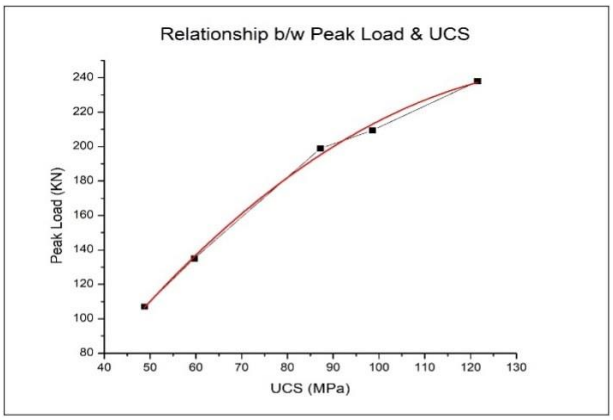

Figure 11. Relationship between Peak Load & Uniaxial Compressive Strength (UCS)

The peak load shows a parabolic behavior with respect to the uniaxial compressive strength. As it is provided with a polynomial fitting in the graph.

3.3 Ultrasonic Pulse Velocity (UPV) Test Result

An UPV of the sandstone is measured with the help of ultrasonic concrete tester. The natural frequency of 55 KHz is passed through five cores. That results obtained are given in the Table 4. The UPV results show similar output as already studied by Eren for natural stones [17].

Table 4. Results of Ultrasonic Pulse Velocity (UPV) Test

S. No.	No. Of Cores	Length Of Cores L(m)	Velocity Travel in Time T(10^{-5}s)	Velocity V (m/s)	Velocity V (km/s)
01	A	0.109	1.174	5580.60	5.5806
02	B	0.108	1.870	5561.49	5.5614
03	C	0.109	1.888	5349.57	5.3495
04	D	0.108	1.830	5355.19	5.3551
05	E	0.109	1.858	5543.59	5.5435

As we can see in Figure 12 that in each test sample velocity is varying even though we have a standard size of the core and length. This may be explained that due to different internal anomalies in the sample such as

fissures and cracks are affecting the ultrasonic.

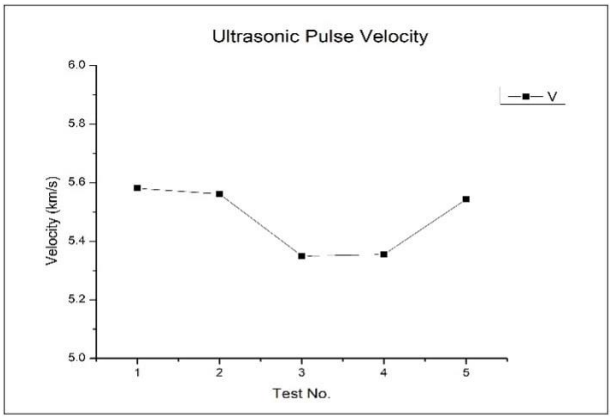

Figure 12. Ultrasonic Pulse Velocity Results

CONCLUSIONS

In this study the Slake durability index test was performed on shale and sandstone. The uniaxial compressive strength and UPV test were conducted on sandstone. The main conclusions that were drawn from the findings of this study are

- Sandstone sample percentage retention after the second cycle was obtained to be in range of 98.71 % - 97.36 %.
- Shale sample percentage retention after the second cycle was obtained to be in range of 14.06 % to 10.21 %.
- It was concluded that the results of Ultrasonic Pulse Velocity (UPV) Test for sandstone varies due to internal anomalies in the sample such as fissures and cracks.
- The slake durability index test for sandstone sample indicates that it is high durable and the shale indicates very low durability.

DECLARATIONS

Funding: No financial support.

Conflicts of interest/Competing interests: The authors declare no any conflict of interest/competing interests.

Data availability: Not applicable

Code availability: Not applicable

Authors' contributions:

The roles are defined as per the order of authors: Conceptualization, Tufail Ahmed; Methodology, Tufail Ahmed, F.A. Ibupoto, Syed Hafeez Ur Rehman, Shehzad Usman; software, Tufail Ahmed, F.A. Ibupoto; formal analysis, Tufail Ahmed, F.A. Ibupoto, Asif Abbas.; investigation, Tufail Ahmed, F.A. Ibupoto, Sami Ullah and Abbas Hussain; resources, Tufail Ahmed, Syed Hafeez Ur Rehman and Shehzad Usman.; data curation, Tufail Ahmed and F.A. Ibupoto.; writing—original draft preparation, F.A. Ibupoto, Tufail Ahmed and Asif Abbas.; writing—review and editing, F.A. Ibupoto and Sami Ullah; supervision, Tufail Ahmed and F.A. Ibupoto,

REFERENCES

[1]. P. Zhang, S. Peterson, D. Neilans, S. Wade, R. McGrady, and J. Pugh, "Geotechnical risk management to prevent coal outburst in room-and-pillar mining," *International journal of mining science and technology,* 26 (2016)9-18.

[2]. S. Bhattarai and N. K. Tamrakar, "Physical Properties, Strength and Durability of Selected Rocks from the Central Nepal Lesser Himalaya, Malekhu River Area for Building Stones," *American Academic Scientific Research Journal for Engineering, Technology, and Sciences,* 35(2017) 236-250.

[3]. P. Miščević and G. Vlastelica, "Impact of weathering on slope stability in soft rock mass," *Journal of Rock Mechanics and Geotechnical Engineering,* 6(2014) 240-250.

[4]. J. Franklin and R. Chandra, "The slake-durability test," in *International Journal of*

Rock Mechanics and Mining Sciences & Geomechanics Abstracts, (1972) 325-328.

[5]. E. Kolay and K. Kayabali, "Investigation of the effect of aggregate shape and surface roughness on the slake durability index using the fractal dimension approach," *Engineering geology,* 86(2006) 271-284.

[6]. A. Standard, "D4644. Standard Test Methods for Slake Durability of Shales and Similar Weak Rocks," *Annual Book of ASTM Standards,* 4(2008) 880-88.

[7]. Z. A. Erguler and A. Shakoor, "Quantification of fragment size distribution of clay-bearing rocks after slake durability testing," *Environmental & Engineering Geoscience,* 15(2009) 81-89.

[8]. D. T. Nicholson, "Pore properties as indicators of breakdown mechanisms in experimentally weathered limestones," *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group,* 26(2001) 819-838.

[9]. P. A. Hale and A. Shakoor, "A laboratory investigation of the effects of cyclic heating and cooling, wetting and drying, and freezing and thawing on the compressive strength of selected sandstones," *Environmental & Engineering Geoscience,* 92003117-130.

[10]. D. S. Agustawijaya, "Modelled mechanisms in the slake-durability test for soft rocks," *Civil Engineering Dimension,* 5(2004) 87-92.

[11]. H. Ankara, S. Y. Kandemir, and F. Çiçek, "Compression of Slake Durability Index (SDI) Values of Sphere and Rounded Marl Samples," *Procedia Earth and Planetary Science,* 15(2015) 93-98.

[12]. H. Ankara, F. Çiçek, İ. T. Deniz, E. Uçak, and S. Y. Kandemir, "Determination of Slake Durability Index (Sdi) Values on Different Shape of Laminated Marl Samples," in *IOP Conference Series: Earth and Environmental Science*, (2016)022006.

[13]. D. G. Price, *Engineering geology: principles and practice*: Springer Science & Business Media, (2008).

[14]. D. ASTM, "Standard test method for unconfined compressive strength of cohesive soil," *ASTM standard D,* (2006)2166.

[15]. J. C. Gamble, *Durability-plasticity classification of shales and other argillaceous rocks*: University of Illinois at Urbana-Champaign, (1971).

[16]. P. Miščević and G. Vlastelica, "Durability Characterization of Marls from the Region of Dalmatia, Croatia," *Geotechnical and Geological Engineering,* 29(2011) 771-781.

[17]. E. PAMUK and A. BÜYÜKSARAÇ, "Investigation of strength characteristics of natural stones in Ürgüp (Nevşehir/Turkey)," *Bitlis Eren University Journal of Science and Technology,* 7(2017)74-79.

Received: 16 Nov. 2021. Revised/Accepted: 15 April 2022.