Evaluation of Weathering Effect on Engineering Properties of Sri Lankan Gneissic Rock

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Abstract

Weathering is a natural process common for all kinds of rock types that may occur due to either physical, chemical, or biological reasons. The applicability of rock in different engineering applications has a primary concern with their engineering properties that might have a significant influence from weathering effect. Characterizing such properties based on weathering effect on gneissic rocks of Sri Lanka is essential due to the wide existence and utilization of gneissic rocks. This study was conducted to understand the behavior of engineering properties such as uniaxial compressive strength, durability, hardness, pulse wave velocity, and mineralogical properties of gneissic rock with weathering effect. Engineering properties of gneissic rocks were determined using laboratory tests according to ASTM (American Society for Testing and Materials) for rocks in fresh and weathered states.

Keywords: Durability, Gneissic Rock, UCS, Weathering of rock

1. Introduction

The applicability of rock in different engineering applications has a primary concern with their engineering properties that might have a significant influence from the weathering effect. Hence, weathering is one of the parameters that alter the engineering properties of rock [1]–[3]. Therefore, its effect is a considerable factor for engineering applications to meet their expected perspectives.

Weathering of rocks happens due to physical, chemical, and biological reasons [4]. The collection of minerals creates rocks, and mineral compositions can be altered, replaced, or destroyed by any of the above-mentioned weathering effects over time, resulting in discoloration and staining, changes in texture and fabric, disintegration, decomposition, and weakening of their relative strength [5]. Although weathering reflects changes in the rock that are visible to the naked eye, it may alter physical, mechanical, and mineralogical indices quantitatively and qualitatively [3], [6]–[8]. In Sri Lanka, hornblende biotite gneisses, migmatite, biotite gneiss, charnockite, granitic gneiss, and charnockitic gneiss are the most common rocks used for aggregate production. These are Precambrian metamorphic rocks that can be found across the country in various regions [9]. Since gneissic rocks play a major role in industry, only gneissic rocks are considered in this study. Furthermore, the relationship between the slake durability index of gneissic rock for fresh and weathered in Kaduwela and Kudayala Quarry locations were determined due to presence of common two types of gneissic rocks. Further, physical-mechanical properties were tested, and elemental contents of the samples have also been investigated by scanning electron microscope (SEM) analysis.

2. Methodology

2.1 Study Area

The study area is in the western province of Sri Lanka, not far from the city of Colombo. Representative gneissic rock samples were collected from two active quarry sites located in Kaduwela (N 6.912, E 80.005) and Kudayala (N 6.627, E 80.09) respectively.

Figure 01: Sampling locations (quarry locations)

According to the geological map (No.16) for Colombo (issued by GSMB), Kaduwela (in Colombo district) situated in Wanni complex and rock type of location has Hornblende biotite gneiss, while Kudayala (in Kalutara district) situated in Highland complex with rock type of Garnet bearing biotite gneiss.

2.2. Sample collection

Weathered and fresh rock samples were distinguished in the field and samples were collected from quarry sites in the Kaduwela and Kudayala area. 3-4 numbers of boulders (approximately 20kg each) were collected from weathered and fresh rocks from each quarry site. When collecting rock samples existence of foliation planes were considered because it influences the rock properties and drilling is intended to conduct perpendicular to foliation planes.

2.3. Sample preparation and Laboratory testing

According to selected laboratory tests, sample preparation was done for each test; Uniaxial Compressive strength (UCS), Point load, Slake Durability, Rebound Hammer test, Ultrasonic Pulse Velocity (UPV) based on ASTM standard and SEM analysis, three specimens from each fresh and weathered samples were obtained for mechanical and physical analysis except the mineralogical analysis. The sample prepared for UCS was used to test the Schmidt hammer (rebound hammer) test and Ultrasonic Pulse Velocity (UPV).

NX type core samples were cut from each boulder, avoiding weak plains within it and perpendicular to existing foliation plains. UPV measurements were obtained twice; before and after the rebound hammer testing (Table 01). Because of that the impact of the hammer can cause generation of fractures in the specimens and the difference between those two readings is useful to be measured to determine the possible fracture generations. According to ASTM standards for slake durability test, sharp edges were removed prior to the test. Slake durability tests were performed for four cycles to obtain more accurate results. For mineralogical analysis, 20mg powder samples were prepared passing through 63µm sieve size.

Visually assessed weathered and fresh gneissic rock were physically, mechanically, and mineralogically evaluated using standard testing procedures for above selected index properties of rocks. Average value was calculated for each of fresh and weathered samples, for tests shown in Table 2.

Slake durability test results for four cycles were calculated (table 3) using following equation (equation 1) and plotted data for a regression analysis (Figure 02 and 03). Test results were analyzed using simple regression analysis and were compared results.

$$Id\ (2) = B/A \times 100 \qquad \dots (01)$$

Where,

Id (2) = slake durability index (second cycle)

A = mass of s oven-dried sample before the first cycle, (g)

B = mass of oven-dried sample retained on the drum after the second cycle (g).

Images were taken of the specimens after each and every cycles.

3. Results

Following tables and figures represent the results obtained from above analytical methods after the calculation.

Table 01: Calculated test results

Laboratory Testing		Hornblende Biotite Gneiss (Kaduwela area)		Garnet bearing Biotite Gneiss (Kudayala area)	
		Fresh	Weathered	Fresh	Weathered
UCS(MPa)		45.73	9.59	58.06	17.54
Point Load strength (MPa)		1.03	0.15	0.70	0.21
Pulse Velocity (m/s)	Before Rebound Hammer	5638.37	3242.86	4707.68	2603.54
	After Rebound Hammer	5529.56	1823.14	4705.24	-
Rebound Hammer Value		34	19	40	N/A

Table 02 – Test results for slake durability test

Location	Sample Description	Sample Number	Id (1)	Id (2)	Id (3)	Id (4)
Hornblende biotite gneiss (In Kaduwela area)	Fresh	1	99.59	99.38	99.19	99.06
		2	99.94	99.78	99.64	99.58
		3	99.53	99.38	99.11	98.96
	Weathered	1	98.74	98.09	97.56	97.27
		2	97.77	96.70	95.81	95.26
		3	98.51	97.81	97.26	96.95
Garnet bearing biotite gneiss (In Kudayala area)	Fresh	1	99.66	99.43	99.25	99.08
		2	99.66	99.40	99.19	99.04
		3	99.48	99.25	99.07	98.91
	Weathered	1	94.39	89.88	87.11	85.02
		2	91.73	88.06	85.11	82.71
		3	95.44	92.36	89.68	87.34

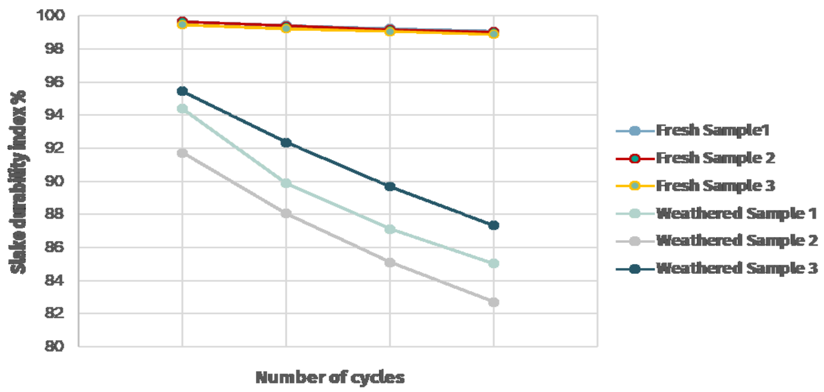

Figure 02 - Regression Analysis of Garnet Bearing Biotite Gneiss – Kudayala,

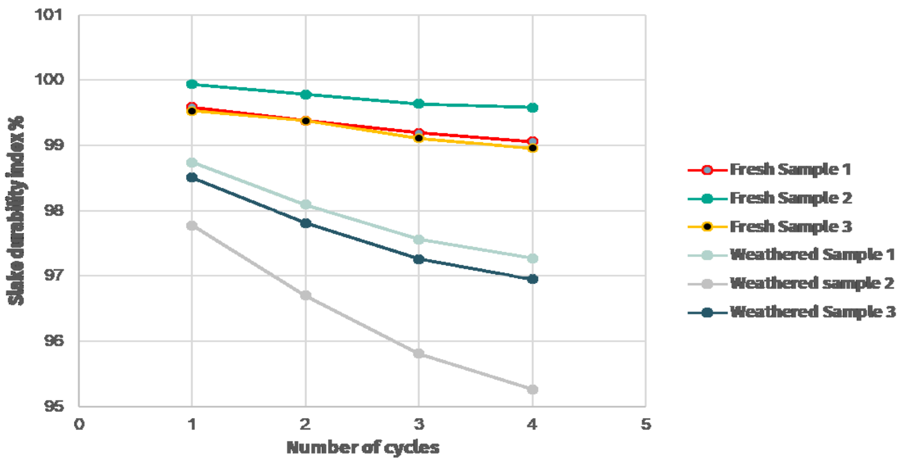

Figure 03- Regression Analysis of Hornblende Biotite Gneiss - Kaduwela, Colombo

Table 03 – Test results for SEM analysis

Element	Hornblende biotite gneiss-Fresh Sample 02	Hornblende biotite gneiss-Fresh Sample 03	Hornblende biotite gneiss-Weathered
	Weight%	Weight%	Weight%
O K	45.04	45.85	47.70
Na K	2.81	2.82	2.97
Mg K	2.47	1.76	-
Al K	9.45	8.94	11.16
Si K	28.4	31.32	30.95
K K	4.06	2.84	3.94

Elements	Garnet bearing biotite gneiss Fresh	Garnet bearing biotite gneiss Weathered
	Weight%	Weight%
O K	46.10	48.15
Na K	2.02	1.45
Mg K	1.89	0.63
Al K	8.62	8.87
Si K	29.33	23.69
K K	4.12	3.00

4. Discussion

Weathering effect decrease significant amount of strength, and rock presented in Kudayala quarry site has strength more than rock presented in Kaduwela area, as reveal as the results for UCS and point load test. Since UCS values are not accurate when any cracks present in the core specimen, some specimens were rejected by the visual observation, and also impact from rebound hammer may cause to occur cracks within the sample, pulse velocity was determined again after the rebound hammer test. Test results on this shows high difference between two pulse velocities for weathered samples (Velocity has changed from 3059.00 m/s to 1823.14 m/s in Kaduwela weathered sample 03), weathered samples were not used to determine hardness values and tested specimen were rejected.

Regression analysis of slake durability test provided good measure about the durability of rock in the study area, when preform 4 cycles. Obtained results reveals fresh rock durability is higher than the weathered samples, and considerable decrease of Id with cycles can be observed from the graphs. In Kaduwela, Hornblende biotite gneissic rock of fresh and weathered has higher durability than Garnet bearing biotite gneiss fresh and weathered rock. Weathered gneissic rock in Kudayala exhibits considerable loss of durability within 4 cycles to Id at 85.02. The findings of the pulse velocity test demonstrate that the velocity of Kudayala Garnet bearing Biotite Gneiss is lower than that of Hornblende Biotite Gneiss in Kaduwela, signifying that the porosity of the sample is higher in the rock in Kudayala area.

Elementary constituents from SEM analysis offer useful information about the weathering. The weathering of gneissic rock samples from both regions has resulted in a considerable decline in Mg percentage (from 1.76 - 2.47% to null in Kaduwela and from 1.89% - 0.63% in the Kudayala area). Deterioration of engineering properties such as strength, durability, and pulse velocity with the weathering can be justified using element alteration, shown in results. Visual observations and rock description use for identifying of minerals, can be explained using presence of elements. Above mentioned strength value for Kaduwela gneissic rock core specimen (Sample 03) can be justified by the high percentage of Si compared to rest specimen (Sample 02). This happens by specimen named sample 03, has high amount of quartz and feldspar minerals, which can be clearly observed in visual observation too. Similarly, weathering reduces the existence of Si, which explains the deterioration of strength.

According to Matthias & Celestine, 2021, [10] weathering has great effect on generation of clay minerals in the rock.

This can be justified by significant growth of Al percentage observed in SEM analysis results. As its opposite has happened in Garnet bearing Biotite Gneiss in Kudayala, formation of clay minerals is not special a characteristic for that region with the weathering. Removal of mineral component may increase the porosity of gneissic rock in Kudayala area. Pulse velocity results also confirm same by its lower values, hence high porosity of the gneissic rocks can be expected in Kudayala region.

5. Conclusions

Chemical weathering may have influenced gneissic rocks in both Kaduwela and Kudayala quarry sites since Mg percentage has decreased by the weathering effect. Formation of clay minerals with weathering is a significant characteristics of hornblende biotite gneiss in Kaduwela area, rather than the Garnet bearing biotite in Kudayala area. Physical properties such as hardness, and Ultrasonic Pulse Velocity have decreased in weathered gneissic rock in both of the areas. Furthermore, proper evaluation of weathering effect on engineering properties is needed by selecting rock types that commonly used in industry and get samples from each weathering grade sections.

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References

[1] T. Y. Irfan and W. R. Dearman, “Characterisation of Weathering Grades in Granite,” pp. 67–69, 1979.

[2] H. Arman *et al.*, “Predicting Weathering Characteristics of Carbonate Rocks under Different Geo-Environmental Conditions,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 362, no. 1, 2019, doi: 10.1088/1755-1315/362/1/012016.

[3] A. L. Lewis *et al.*, “Effects of mineralogy, chemistry and physical properties of basalts on carbon capture potential and plant-nutrient element release via enhanced weathering,” *Appl. Geochemistry*, vol. 132, Sep. 2021, doi: 10.1016/j.apgeochem.2021.105023.

[4] H. W. WELLMAN & A.T. WILSON, "Salt Weathering, a Neglected Geological Erosive Agent in Coastal and Arid Environments," *Nat. Publ. Gr.*, vol. 205, no. 5007, pp. 498–499, 1965.

[5] A. S. Gupta and K. S. Rao, "Index properties of weathered rocks: inter-relationships and applicability," Springer-Verlag, 1998.

[6] G. R. Khanlari, M. Heidari, and A. A. Momeni, "Assessment of weathering processes effect on engineering properties of Alvand granitic rocks (west of Iran), based on weathering indices," *Environ. Earth Sci.*, vol. 67, no. 3, pp. 713–725, Oct. 2012, doi: 10.1007/s12665-011-1518-6.

[7] D. S. Jaques, E. A. G. Marques, L. C. Marcellino, M. F. Leão, E. P. S. Ferreira, and C. C. dos Santos Lemos, "Changes in the Physical, Mineralogical and Geomechanical Properties of a Granitic Rock from Weathering Zones in a Tropical Climate," *Rock Mech. Rock Eng.*, vol. 53, no. 12, pp. 5345–5370, Dec. 2020, doi: 10.1007/s00603-020-02240-x.

[8] D. Biondino *et al.*, "A multidisciplinary approach to investigate weathering processes affecting gneissic rocks (Calabria, southern Italy)," *Catena*, vol. 187, Apr. 2020, doi: 10.1016/j.catena.2019.104372.

[9] U. D. S. Jayawardena and D. M. S. Dissanayake, "Identification of the most suitable rocks types for manufacture of quarry dust in Sri Lanka," *J. Natl. Sci. Found. Sri Lanka*, vol. 36, no. 3, pp. 215–218, 2008, doi: 10.4038/jnsfsr.v36i3.157.

[10] O. Matthias and N. Celestine, "Geotechnical evaluation of the quality and durability of argillites from Abakaliki Metropolis (Southeastern Nigeria) as road aggregates," *Arab. J. Geosci.*, 2021, doi: 10.1007/s12517-021-08613-y.