Correlations between Durability, Mineralogy and Strength Properties of Limestone

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Abstract
Durability is used to depict the obstruction of rock to weathering and the pace of events of such changes. Wetting and drying cycles cause evaluation of physical changes and slaking behaviour of rocks, and that can be appraised by the slake durability test. Correlations between durability, mineralogy, and other physical-mechanical properties are different with the rock. Physical and mechanical characteristics of High-grade limestone samples and Low-grade limestone samples from the Aruwakkalu mine were determined according to ASTM standard methods. X-ray diffractometer (XRD) analysis and scanning electron microscope (SEM) analysis were used to determine the mineralogical contents of the studied samples. Regression analyses were performed between the slake durability index and the physical-mechanical properties of limestones to identify the best wetting and drying cycle to assess the relationships. Differences between the physical, mechanical properties, and mineralogical contents of High-grade limestone and Low-grade limestone were also identified from the laboratory test results. Finally, this study will help to understand any rock engineering problem relating to durability, mineralogy, and other physical-mechanical properties of areas with limestone.

Keywords: Limestone, Regression analysis, SEM analysis, Slake durability, XRD analysis

1. Introduction

Physical properties, strength, and durability are essential properties that help to assess the rocks for various applications. Determining the suitability of rocks for use under various environmental and stress conditions is mostly rely on these physical properties. The durability and strength of rocks generally help to categorize different types of rocks. The ability of a material to resist deformation induced by an external force is known as Strength [1]. Durability is an indicator of the ability of rocks to withstand and sustain their distinctive strength and resistance characteristics.

Rocks are subjected to alternate dry and wet conditions and undergo repeated water absorption and dehydration steps. This cycle is called the Wetting and Drying cycle of rocks [2]. Many physical and mechanical properties of the rocks are changing with these cycles. The load of past durability characterizations depends on the subsequent cycles' durability index [1]. The most immediate control on durability is provided by the mineralogical composition of the network in rocks. The existence of expansive clay minerals has a strong connection with the effect of wetting and drying cycles on durability [3].

In this study, the relationship between the slake durability index of high-grade and low-grade limestone and the physical-mechanical properties of limestone has been investigated. Mineralogical contents of the limestone samples have also been investigated by X-ray diffraction (XRD) analysis and scanning electron microscope (SEM) analysis.

2. Methodology

2.1 Sample Preparation

High-grade limestone and Low-grade representative samples were extracted as boulders (Approximately 30kg each) from the Aruwakkalu limestone mine (Figure 1). Polythene covers were used to wrap the samples to avoid the loss or gain of moisture during transport and storage.

For the Point load test, core samples were extracted from the boulders using a rock coring machine. For the Los Angeles Abrasion test and Aggregate Impact Value test, limestone boulders were first crushed using a hammer and then from the jaw crusher. Then the limestone samples were sieved into the required sizes for the tests. For SEM analysis and XRD, limestone samples were first crushed using a jaw crusher and then crushed using the laboratory Tema mill to reduce average grain size. Powdered samples were sieved using a 63 µm sieve.

Ten representative limestone specimens were prepared, each weighing 40 g to 60 g by breaking limestone fragments using a hammer for slake durability tests. Sharp corners were broken off and dust was removed from those specimens before performing the Slake durability test. All samples were oven-dried for more than 24 hours at a temperature of 105° C to avoid the effect of pore water on the results.

Figure 1: Sample locations.

2.2 Testing

All the tests were performed according to the ASTM standard testing procedures. Strength properties of high-grade and low-grade limestone were obtained by performing a point load test. The aggregate degradation properties of both types of limestones were obtained by the Los Angeles Abrasion Value test (LAAV) and Aggregate Impact Value test (AIV). Prepared limestone powder samples were analyzed using SEM and XRD to identify the mineralogical content difference between high-grade limestone and low-grade limestone. Durability indexes of all limestone samples were obtained using a slake durability test using tap water as the slaking fluid. Slake durability test was performed up to 2 cycles for each limestone sample.

2.3 Regression Analysis

In this research, slake durability test was done for up to 2 cycles. Linear regression analyses were undertaken for the two cycles of the Slake durability test and the relationship between the Slake durability index and Uniaxial Compressive Strength (UCS). By analyzing in MATLAB via linear regression analysis with a 95% confidence level, the best correlations between parameters were obtained.

3. Results

3.1 Results of strength and degradation tests

Point Load test, LAAV test, AIV test, and Slake durability test were performed on high-grade limestone and low-grade limestone to obtain material properties. The average values of the results are shown in Table 1.

Table 1: The results of laboratory tests.

Laboratory Tests	High-grade limestone	Low-grade limestone
Point load index (kPa)	746.6	328.6
Calculated UCS (MPa)	16.6	7.3
Aggregate Impact Value	23.4	41.2
Los Angeles Abrasion Value	59.7	75.8
Slake Durability Index 1 [Id(1)]	95.5	93.4
Slake Durability Index 2 [Id(2)]	93.9	90.5

3.3 XRD Analysis

Mineralogical contents of both High-grade limestone and Low-grade limestone were determined by the results of XRD. The difference between the mineralogical content of two limestones was identified with these results, as shown in Table 2.

From these results, a slight difference between mineralogical contents of high-grade limestone and low-grade limestone was identified. The percentage of Ettringite was much higher in low-grade limestone.

Table 2: The results of limestone analysis by XRD

Compound	High-grade Limestone %	Low-grade Limestone %
Calcite	95	94.2
Portlandite	1.3	1.2
Ettringite	0.7	3.2
Mullite	1.3	1.4
Quartz	0.9	0.1

3.4 SEM-EDX Analysis

Scanning electron microscopy-energy dispersive X-ray analysis (SEM-EDX) provides a quick nondestructive determination of the elemental composition of the samples. Both high-grade limestones and low-grade limestones were analyzed by SEM-EDX analysis. According to the weight percentage differences of high-grade limestone and low-grade limestone of SEM analysis, C K, O K, AlK and CaK were higher weight percentages in high-grade limestone than low-grade limestone. According to the atomic percentage, C K and O K have higher percentages in high-grade limestones, and SiK and CaK have a higher percentage in low-grade limestones. FeK was only identified in the high-grade limestones as per the SEM-EDX analysis.

4. Discussion

4.1 Physical-mechanical properties and mineralogical content

According to the results of strength and degradation tests, high-grade limestones are tougher, more impact resistant and have more strength than low-grade limestone. But both high grade and low grade have LAAV and AIV values which are higher than the specified maximum values for road construction aggregates. As per the results of the Slake durability test, the % reduction of durability with drying and wetting cycle is higher in low-grade limestone than high-grade limestone, which implies low-grade limestone subjected to weathering effect or durability degradation. According to the Slake durability Index classification [4], Low-grade limestones have high durability (76-90), and High-grade limestones have very high durability (91-95).

When it comes to XRD analysis, there was a slight difference between mineralogical contents of high-grade limestone and low-grade limestone. Basically, the Calcite and Quartz percentage of high-grade limestone is quite higher than low-grade limestone. The percentage of Ettringite was much higher in low-grade limestone. According to the SEM-EDX analysis, C K, O K, AlK and CaK have higher weight percentages in high-grade limestone than low-grade limestone. Although FeK was only identified in the high-grade limestones as stated by the SEM analysis.

4.2 Regression Analysis

Regression analyses were performed between the lake durability index and physical, mechanical properties. The correlation coefficient (r^2) was obtained using MATLAB via regression analysis with a 95% confidence level.

For the two cycles of the Slake durability test and the relationship between the Slake durability index and UCS, linear regression analyses were performed.

The value of the Correlation Coefficient (r^2) of the second cycle of durability for high-grade limestone (Figure 3) is much closer to 1 than the first cycle of durability (Figure 2).

The value of the Correlation Coefficient (r^2) of the second cycle of durability for low-grade limestone (Figure 5) is much closer to 1 than the first cycle of durability (Figure 4).

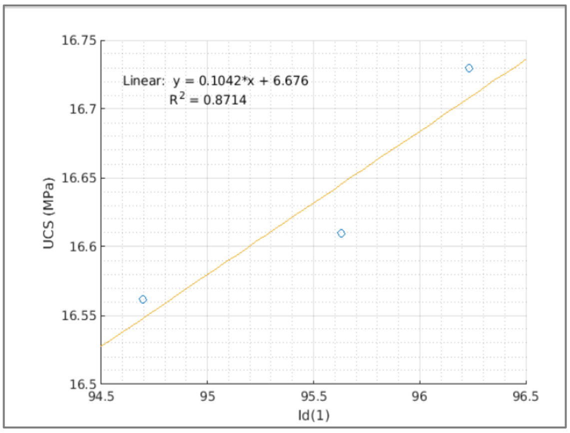

Figure 2: Durability index 1 (Id(1)) and Strength regression analysis of high-grade limestone.

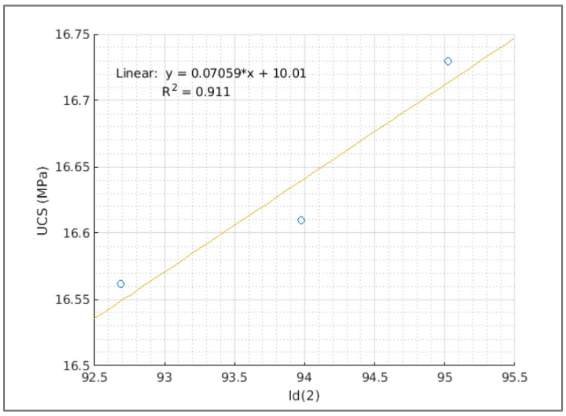

Figure 3: Durability index 2 (Id(2)) and Strength regression analysis of high-grade limestone.

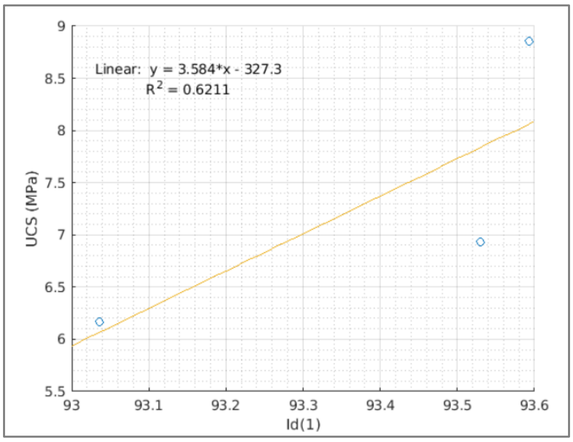

Figure 4: Durability index 1 (Id(1)) and Strength regression analysis of low-grade limestone.

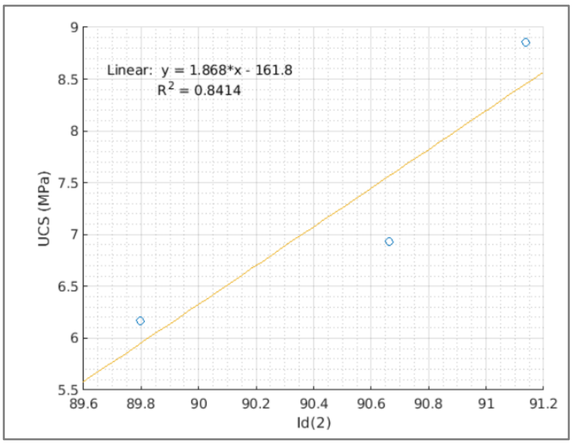

Figure 5: Durability index 2 (Id(2)) and Strength regression analysis of low-grade limestone.

According to the Correlation Coefficient (r^2), UCS values for the second cycle of durability indicated a stronger relationship between the variables than the first cycle.

5. Conclusions

Durability and weathering characteristics of rocks are the key factors in determining the suitability and usefulness of them as different engineering materials, and they also control the stability of surficial and underground excavations.

Low-grade limestone is subjected to weathering effect or durability degradation than high-grade limestone.

Based on LAAV and AIV, this limestone is not suitable for the construction of roads as a base course material. Also, it is insufficient for use as highway surface material or railroad ballast.

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