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The Role of Mineralogy on Durability of Weak Rocks

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Abstract: The effect of mineralogy on durability of 36 weak rock samples was investigated. Samples were obtained from six different sites with distinct lithologies that included 12 mudstones from two sites, 14 mudshales from two sites, 6 clayshale and 4 siltstones. Slake durability tests were continued to fifth cycle to study the effect of different cycles on durability of weak rocks such as shale. The highest value of slake durability was measured for siltshale and the lowest for clayshale. The slake durability results of this study also indicate that there is no single parameter that can be used to predict the durability of weak rocks. The results show that durability is closely related to the quantity of clay minerals. Therefore, it can be concluded that variation in durability within weak rocks is controlled predominantly by mineralogy. A decrease in the slake durability was associated with an increase in clay content. It seems that other geological parameter such as fabric and weathering also affected durability of weak rocks.

Key Words: Durability, Mineralogy, Weak Rocks

Introduction

Weak rocks including shale rocks that are very fine-grained argillaceous sedimentary rocks in which more than 50% of the clastic grains are smaller than 0.06 mm diameter (Blatt *et al.*, 1980). Hence, the fine particles dominate the mechanical behaviour and durability.

Durability is the most important engineering property of shales in projects that involve exposure of shales to the weathering environment. It has value for many applications, such as for using shale as a construction material or as a foundation material. Koncagul and Santi (1999) using slake durability for predicting the unconfined compressive strength of the Breathitt shale. Many studies on slaking mechanisms have been done (Terzaghi and Peck, 1967; Taylor and Spears, 1970). Vallejo *et al.* (1993) reported that the predominant slaking mechanism of shale is pore air compression, which takes place when the shales are immersed in water and is the result of capillary suction pressures. However, the mechanisms causing slaking breakdown are far from completely understood.

Slake durability is widely used in shale and these materials are characterised by a wide variation in their engineering properties, particularly their resistance to short term weathering by wetting and drying. One of the most common forms of breakdown in shale is slaking and it has value in many applications, because these rocks are seriously affected by wetting and drying. For example, some shales slake almost immediately in moist air (Underwood, 1965 and Dick *et al.*, 1994), while others can withstand many cycles of wetting and drying. They take years of exposure before showing any signs of deterioration, and are roughly as durable as sandstone or limestone. Because of this problem, the durability of shales is a major concern in engineering construction and has been the focus of shale research. Franklin (1983) reported that perhaps the most important mechanical characteristic of a shale, which distin-guishes it from other rocks, is its general lack of durability.

Sampling: Thirty six shale specimens were taken from different sites that represent a variety of depositional environment. The majority of the samples were obtained from fresh excavation. Other samples obtained from borehole coring. In order to minimize the effect of weathering on the durability test results, great care was taken to obtain relatively fresh samples. The sampled shales range in age from Upper Ordovician to Upper Carboniferous.

According to the ISRM (1981) suggestion, ten representative shale lumps, roughly spherical in shape and with rounded corners, each with a mass in the range of 40 to 60 grams, to give a total sample mass of 450 and 550 grams, were prepared for each slake durability test.

Mineralogy: The mineralogy of weak rock or shales influences on durability. The bulk mineralogy of different shale samples was assessed by X-ray diffraction. The test was performed on a Hilton Books DG2/Philips X-ray diffractometer. The samples were scanned from 3° to 80° 2θ with at steps of 0.02° at speed of 0.02°/s.

The means of the resulting mineralogical data of 36 different samples of shales (5 samples from the Ashfield shale, 6 samples from Queenston shale and 25 samples from the Coal Measures shales) are summarised in Table 1. The results show a variation in composition of these rocks and are discussed Table 1.

The shales exhibit variations in mineralogy. The X-ray diffraction analysis of the Ashfield shale shows that this rock contains no chlorite, no mixed-layer clays, and no smectite. The analysis of the less than 2μm fraction of the Ashfield shale indicated that illite and kaolinite are dominant clay minerals, and that on average kaolinite is more abundant. Quartz is the major component of the non-clay constituent of this shale (generally 50% to 60%).

From the results in the Table (1) it can be seen that the Queenston shale contains about 45% clay minerals, of which illite and chlorite are dominant and no mixed-layer clays, and no smectite. Minor amounts of expansive montmorillonite also reported in occasional samples from the Queenston formation by Franklin (1983). Quartz is a major component of the non-clay constituent of these rocks with calcite and dolomite grains and intergranular cement contributing also to their mechanical competence.

The Coal Measures shale includes different types of shale with a wide range of clay content. The X-ray diffraction analyses of this shale show no mixed-layer clays, and no smectite. The X-ray trace at less than 2 µm shows that kaolinite and illite are the dominant clay minerals in the Coal Measures shales except siltshale. Chlorite can be seen in a minor amount of clay fractions of these rocks. Quartz is the major non-clay constituent in the Coal measures shales. Quartz and illite are stable allogenic minerals transported to their site of deposition. The other minerals are of diagenetic origin, formed during deposition and subsequent consolidation of the shales.

In general, the results of the X-rays have shown that tested shales vary in quartz and clay minerals contents. Based on the range of quartz and clay minerals contents the samples studied can be classified in the range from siltshale to clayshale based on the proposed geological classification.

Slake Durability Test: There are many test procedures for estimating the slake durability of weak rock. Almost all methods essentially consist of cycles of drying and wetting by water. Franklin (1970) and Taylor and Spear (1970) discussed the results of different methods of durability testing. The slake durability index (Id) test was developed by Franklin and Chandra (1972) is recommended by the International Society for Rock Mechanics (ISRM 1979) and the American Society for Testing and Material (ASTM 1990). They used the two-cycle slake durability index (Id2) to classify shales. Bell *et al.* (1997) reported that one cycle slake durability testing did not appear to offer an acceptable indication of the durability of shale when compared with cyclic wetting and drying. Hopkins and Deen (1984) used two 25 min cycles for the slake durability classification of Kentucky shales. Russell (1982) and Taylor (1988) suggested that a three-cycle, rather than a two-cycle test, is more likely to produce a constant value for the shale durability index. Oakland and Lovell (1986) used the results of five cycle slaking test for shale classification.

In this research, the slake durability test was performed in accordance with the procedure given in ISRM (1981). The testing, was carried out to five cycles. Tap water and in some tests distilled water at room temperature were used as the slaking fluid. There was not any significant between the results of slake durability using tap water or distilled water.

Results and Discussion

Slake durability was calculated as the percentage ratio of the amount of shale remaining after each cycle to the initial dry sample weight as follows:

$$I_{d2} = \frac{C - D}{A - D} \times 100$$

where:

I_{d2}= slake durability index

C = the weight of drum plus the retained portions of sample

D = the weight of drum was brushed clean

A = the weight of drum plus sample.

All slake durability test in this study were continued to fifth cycle to study the effect of different cycles on the durability of tested samples. The results of different cycles of durability are shown in Fig. 1.

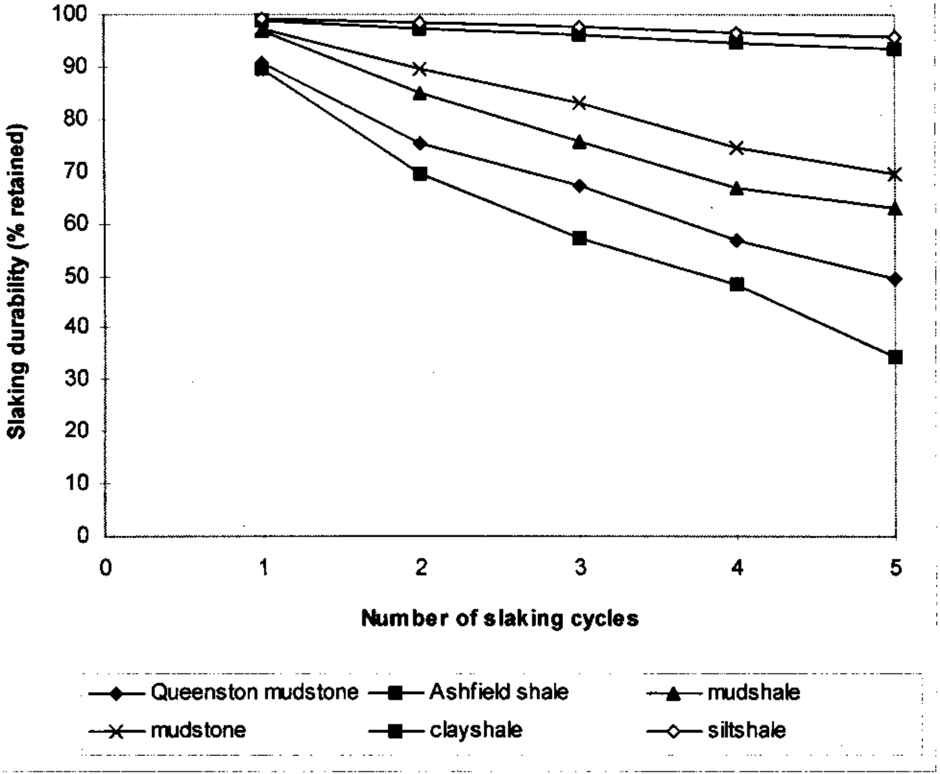

Fig. 1: The Effect of Number of Slaking Cycle for Tested Samples

Table 1: Results of Mineralogical Analysis of Clay and Quartz Fractions

Rock type	Geological sequence	No.	Quartz (%)	Clay (%)	Type of clay
Mudshale	Ashfield	5	57.0	43.0	ill, kao
Mudstone	Queenston	6	47.8	45.3	chl, ill, kao
Mudshale	Coal Measures	7	53.7	39.6	kao, ill, chl
Mudstone	Coal Measures	8	47.1	50.3	kao, ill, chl
Clayshale	Coal Measures	6	26.0	71.7	kao, ill
Siltshale	Coal Measures	4	66.3	18.3	kao, chl
All samples		36	49.4	45.7	kao, ill, chl

ill = illite, kao = kaolinite, and chl = chlorite.

Many studies on slaking mechanisms have been done (Terzaghi and Peck, 1967; Taylor and Spears, 1970). Vallejo *et al.* (1993) reported that the predominant slaking mechanism of the shales is pore air compression, which takes place when the shales are immersed in water and is the result of capillary suction pressures. However, the mechanisms causing slaking breakdown are far from completely understood.

The results of this research show that there is no single parameter that can be used to predict the durability of shale. Different factors affect the slake durability of this type of rock. Mineralogy is a major parameter that control variation in shale durability. A decrease in slake durability of tested shale was associated with an increase in clay content.

Dick and Shakoor (1990) found that slake durability of shales is closely related to the rock fabric as expressed by void ratio and absorption. Ghafoori (1995) and Tugrul and Zarif (1998) reported the influences of weathering on durability. Hence this test is also a good indicator for evaluating the weathering resistance of shales. According to Van Eekhout (1976), the presence of montmorill-onite indicates that a shale material will slake more rapidly. Moon and Beattie (1995) reported that the amount of clay-size material in shales provides the most direct control on durability. Bell and Lindsay (1998) found that the lithological factors which govern the durability of shales include the degree of induration, the nature of laminations, the degree of fracturing, the grain size distribution and mineralogical composition, especially the nature of the clay mineral fraction. Candan *et al.* (2000) reported that the type and amount of clay minerals are the main factors influencing the variation of the slake durability in weak rocks.

The slake durability results of this study show that there is no single parameter that can be used to predict the durability of shales. The results indicate that durability in shales is closely related to the quantity of clay minerals, but in those shales which contained less than 50% clay size minerals, the influence of clay slaking diminishes and the micro fractures are the dominant lithological characteristic controlling durability.

Conclusion

The durability of weak rocks such as shale is one of the their most important engineering properties. One of the most common forms of breakdown in shale is slaking and it has value in many applications. These rocks are seriously affected by wetting and drying. Samples were subjected to five cycles of slake durability. The results indicate that no single parameter can be used to predict durability of all types of shales. For those shales that are similar in age, depositional environment and stress history but different in composition (such as Coal Measures shales), increasing slake durability was associated with increasing quartz content and decreasing clay content. The results indicate that the type and amuont of clay minerals are the main factors influencing the variations of the slake durability index in all shale samples.

It seems that other geological parameter such as fabric and weathering also affected durability The shales used in this study were relatively fresh. Since shales of varying degrees of weathering are often encountered in engineering projects, it is important to consider the effects of weathering on durability behaviour.

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