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LABORATORY ASSESSMENT OF LONG-TERM DURABILITY OF SOME DECORATING AND CONSTRUCTION ROCKS

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บทคัดย่อ

การทดสอบดัชนีความคงทนต่อความผุกร่อนได้ดำเนินการจำนวน 100 รอบใช้หิน 13 ชนิดโดยมีวัตถุประสงค์เพื่อหาความคงทนของหินในระยะยาว ตัวอย่างของหินแบ่งออกเป็น 4 กลุ่มคือ กลุ่มหินบะซอลต์ หินคาร์บอเนต หินทรายและหินแกรนิต การทดสอบในระยะยาวมุ่งเน้นเพื่อหาความแตกต่างระหว่างอัตราการผุกร่อนของหินที่มีกำลังกดใกล้เคียงกัน การทดสอบมี 3 ชุดคือ ภายใต้สภาวะแห้ง เปียกและสภาวะความเป็นกรด ผลที่ได้ระบุว่าการเสื่อมสภาพของหินคาร์บอเนตโดยเฉพาะอย่างยิ่งหินทรเวอร์ทีนเพิ่มขึ้นอย่างมากเมื่อหินเหล่านี้สัมผัสน้ำและกรดในระยะยาว ปริมาณสนิมและความพรุนเป็นตัวการสำคัญในการเร่งอัตราการผุกร่อนของกลุ่มหินบะซอลต์ ชนิดและพันธะยึดติดของวัสดุเชื่อมประสานเป็นปัจจัยสำคัญต่อความคงทนของกลุ่มหินทรายที่นำมาทดสอบ น้ำและกรดมีผลกระทบน้อยต่อความคงทนของกลุ่มหินแกรนิต

ABSTRACT

Slake durability index tests have been performed up to 100 cycles in an attempt to assess long-term durability of thirteen rock types, divided here into four groups: basalt, carbonate, sandstone and granite groups. This long-term test is intended to distinguish the degradation rates of the tested rocks with similar strengths. Three series of the slaking cycles are performed under dry, wet and acidic conditions. The results indicate that degradation of carbonate rocks, particularly travertine, significantly increase when they subject to water and acid. Ferrous oxide contents and amount of vesicles and pore spaces clearly accelerate the degradation rate of the tested basaltic rocks. Types and cohesive bonding of the cementing materials are important factors controlling the durability of the tested sandstones. Water and acid have insignificant impact on the durability of the tested granites.

KEYWORDS: Slake Durability, Acid, Decorating rock, Degradation

1. Introduction

A slake durability index test [1] has long been used to identify the durability and water sensitivity of rocks under engineering requirements. Several investigators have utilized this method with a common goal of correlating the rock durability, and sometimes strength, with the chemical or mineral compositions and the state of weathering [2-5]. Their findings suggest that factors affecting rock durability may include mineral compositions, microstructure (size, shape, and geometry of grains), degrees of alteration (bonding, density, and porosity) and texture [6-7]. Even though considerable amount of researches relevant to rock durability and weathering effects have been carried out, an attempt at investigating the long-term durability of rocks has rarely been made. The ASTM standard practice defines the rock durability by using only two test cycles under wet condition. This may not be sufficient to distinguish some rocks with similar strengths and compositions, and in particular for their long-term durability under different environmental conditions. The primary objective of this study is to investigate the long-term durability of some construction and decorating stones in Thailand. Up to 100 slake cycles are performed on 13 rock types. The effects of dry, wet and acidic conditions are determined. The results can be useful for the selection of appropriate rock type for various engineering and decorating applications

2. Sample Preparation

Rock samples used in this study are prepared from thirteen rock types, representing the most commonly used rocks in construction and decorating industry. They can be divided here into four groups: basalt, carbonate, sandstone and granite. The rocks in basalt group are obtained from Burirum province. The other three groups are from decorating stone suppliers in Pak Chong district, Nakhon Ratchasima province. Table 1 gives the rock names and types for each group. The main selection criteria are the availability, freshness and homogeneity, while aiming at the mineralogical diversity among different rock types. Some rocks also have significant impacts on long-term stability of many engineering structures in the north and northeast regions (e.g. embankments and foundations of highways, railways and reservoirs, dam abutments, and tunnels). The mineral compositions and mechanical properties of these rocks obtained from related studies are given in Tables 1 and 2. They can assist in explaining the discrepancies of rock durability under different test conditions.

Three separate sets of specimens for each rock type have been prepared for testing under dry, wet and acidic conditions. For each test condition, the specimens consist of ten representative, intact, roughly equidimensional fragments weighing 40 g to 60 g each. These fragments are produced by breaking with a hammer. The total specimen weigh is between 450 and 550 g.

Sulfuric acidic solution used here has pH of 5.6 which represents the annual mean pH from the monitoring sites in Thailand during 2010-2014 performed by EANET Acid Deposition Monitoring Network in East Asia [8]. The solution is prepared by pouring 20 cc of 1 M concentrated sulfuric acid solution into 1000 cc of distilled water. A pH meter is used to measure the hydrogen-ion activity in the water-based solution to confirm the precise pH value.

3. Test apparatus and method

Figure 1 shows the slake durability test apparatus used in this study. The electronic device can control constant rotation rate of the drum at 20 rpm for a period of 10 minutes. Three series of the slake durability index test are performed on three separate sets of rock specimens for each rock type. For the first series, the test procedure generally follows ASTM D4644 [1] standard practice, except that 100 cycles are undertaken rather than the two cycles as specified by the standard. This is primarily to establish a longer trend of weight loss as the rocks continue subjecting to more cycles of scrubbing in the drum. The temperature of the water in the trough is 25°C. The second test series is identical to the first one except that there is no water in the trough, i.e. slaking under dry condition. The third test series is carried out to assess the effect of sulphuric acid, which is the major constituent of acid rain, on the weathering process of rock under in-situ condition. For all test series, after removing the specimens from the drum, they are oven-dried for 12 hrs. These processes are repeated 100 times (100 days). The weight loss for each cycle is measured and used as an index of the durability of the test specimens. All calculations follow the ASTM D4644 [1] standard practice.

Table 1 Mineral compositions of rock specimens

Groups	Rock Types	Code	Rock Unit/Location	Mineral compositions	Sources
Basalt	Aphanitic Basalt	AB	Buriram Basalt Unit/ Buriram	50% Pyroxene and 50% Plagioclase (0.3-0.8 mm)	[14]
	Ferrous Oxide Basalt	FB		66% Pyroxene and 34% Plagioclase (0.3-0.5 mm)	This study
	Vesicular Basalt	VB		48% Plagioclase, 43% Pyroxene, and 9% other (0.1-0.3 mm)	This study
Carbonate	Limestone 1	SB 1	Saraburi Group/ Lopburi	98.4% Calcite, 0.3% Dolomite, 0.3% Quartz and 1.0% Other (1.0-5.0 mm)	[15]
	Limestone 2	SB 2		95.1% Calcite, 2.2% Dolomite, 1.3% Quartz and 1.5% Other (1.0-5.0 mm)	[15]
	Khao Khad Travertine	T	Saraburi Group/ Saraburi	98.7% Calcite, 0.1% Dolomite, 0.2% Quartz and 0.9% Other (1.0-2.0 mm)	[16]
	Khao Khad Marble	MB		100.0% Calcite (1.0-2.0 mm)	[17]
Sandstone	Calcareous Lithic Sandstone	GST	Phu Kradung Formation/ Nakhon Ratchasima	48.8% Quartz, 46.1% Albite and 5.1% Kaolinite (0.1-1.5 mm) (hematite cementation)	[18]
	Quartz Sandstone	YST	Phu Phan Formation/ Nakhon Ratchasima	72.0% Quartz, 20.0% Feldspar , 3.0% Mica, 3% Rock fragment and 2.0% Other (0.5-1 mm) (silica	[14]

				cementation)	
	Arkosic Feldspathic Sandstone	RST	Sao Khua Formation/ Nakhon Ratchasima	57.0% Quartz, 39.5% Albite, 2.9% Feldspar and 0.6% Mica (0.1-1.0 mm) (calcium carbonate cementation)	[19]
	White Quartz Sandstone	WST	Phra Wihan Formation/ Nakhon Ratchasima	75.0% Quartz, 15.0% Feldspar, 7.0% Mica, and 3.0% Other (1.0-1.5 mm) (calcium carbonate cementation)	[14]
Granite	Plagiogranite	GGR	Tak Batholith/ Tak	40% Plagioclase, 30% Quartz, 5% Orthoclase, and 5.0% Other (2.0-5.0 mm)	[17]
	Quartz Syenite	RGR		75% Orthoclase, 10.0% Quartz, 10.0% Plagioclase and 5.0% amphibole (1.0-5.0 mm)	[17]

Table 2 Mechanical properties of rock specimens

Groups	Code	Density (g/cm^3)	Color	σ_c (MPa)	σ_B (MPa)	E (GPa)	Sources
Basalt	AB	2.79	very dark grey to black	188.1± 26.3	14.4±0.8	33.2±3.4	[17]
	FB	2.71		170.2±68.8	13.7±1.7	-	This study
	VB	2.40		43.7±12.2	9.5±2.9	-	This study
Carbonate	SB 1	2.73	dark gray	78.7±14.6	13.19±1.7	21.3±4.4	[14, 15]
	SB 2	2.70	light gray	74.4±12.6	10.0±0.2	28.7±2.4	[14, 20]
	T	2.58	yellowish brown	41.7	7.9±0.7	8.1±0.1	[16, 21]
	MB	2.73	white	50.5±1.6	8.0±0.3	13.1±5.7	[15, 20]
Sandstone	GST	2.55	grayish green	84.1±12.7	9.7	10.1±1.3	[22, 23]
	YST	2.43	brownish yellow	86.3±11.1	10.7±0.7	11.1±0.9	[20, 22]
	RST	2.37	red	67.5±4.6	9.4±1.8	11.5±0.5	[14]
	WST	2.36	brownish white	66.8±13.9	6.7	11.2±3.3	[22, 23]
Granite	RGR	2.62	pink	138.1±18.9	15.0±3.6	34.5±4.3	[17]
	GGR	2.62	white with scattered	119.3±18.3	11.3±1.5	32.4±4.6	[17]

Figure 1 Slake durability test apparatus [1]

4. Test Results

The test results are plotted as a function of the number of cycles (N) for dry, wet and acidic conditions in Figure 2. Table 3 gives examples of some specimens before and after testing. The slake durability index (I_d) of the specimens decrease under different rates. The sandstone group tends to degrade much quicker than do other groups. This is probably because the sandstones contain some percentages of clay minerals (e.g. kaolinite) in the rock matrix. The most durable rocks seem to be the granite group. Under two test cycles all rocks are considered as very high durability based on Gamble's classification [9]. Testing up to 100 slake cycles can however distinguish the durability of these rocks. The igneous rocks (basalt and granite groups) can resist against wet and acidic environments while the carbonate and sandstone groups are sensitive to water and acid. The rock specimens with high strength can well sustain the wetting and drying effects, as shown in Table 2. This is probably due to their mineralogy and the bonding between rock particles, as also observed by Mohamad et al. [10].

The degradation of the rocks in basalt group tends to be the same under dry, wet and acid (Figure 2a). The vesicular basalt (VB), posing the lowest strength in the group (Table 2), degrades notably quicker than do the other two basalts for all test conditions. This is primarily due to the fact that the vesicles or pore spaces enhance more surface areas and allow more fluid to penetrate into the rock matrix. The aphanitic basalt (AB) tends to be the most durable in the group. The ferrous oxide basalt degrades slightly more than aphanitic basalt, particularly under wet and acid. This is probably because the metal atoms are replaced by hydrogen atoms in water and acid, and hence the network structures and fiber strengths are destroyed, as explained by Wang et al. [11].

The acid solution greatly accelerates the degradation of all rocks in the carbonate group. Travertine (T), representing the lowest strength in the group (Table 2), is highly sensitive to water and acid, compared to the marble and limestone (Figure 2b). Under dry condition, Khao Khad marble (MB) however degrades quicker than the other three carbonate rocks, but it is slightly more durable than travertine when both are under water and acid. The sensitivity of carbonate rocks to fluids has also been observed elsewhere, e.g. by Gupta and Ahmed [12] and Franzoni and Sassoni [13].

For rock specimens in the sandstone group, their degradations are varied under different test conditions. The Phu Kradung sandstone (GST), even though posing relatively high strength (Table 2), is highly sensitive to water and acid. It tends to be very durable under dry condition, but degrades quicker than other three sandstones under the fluids (Figure 2a). This is probably because it contains the highest percentage of kaolinite. The differences in durability of the tested sandstones for each condition are probably governed by the variations of cementing materials between quartz grains and the induced micro-cracks when they are subjected to cycles of heating and cooling during the test.

Both granites show very similar trends of degradation for dry, wet and acidic conditions (Figure 2d), suggesting that water and acid have insignificance impact on their durability. They are classified as very high strength rock (Table 2). The plagiogranite (GGR) is slightly more durable than the quartz syenite (RGR) for all test conditions.

5. Discussions and Conclusions

The effect of grain sizes of sandstones could not be studied here because all tested rocks are fine grained. As a result, mineral compositions and cohesive bonding of the cementing materials seem to be important factors controlling the durability of the sandstones tested here. The tested igneous rocks (basalt and granite groups) can well resist against dry, wet and acidic environments. Plagioclase content seems to be an important factor affecting the rate of granite degradation. Ferrous oxide contents and amount of vesicles clearly enhance the degradation of basaltic rocks.

It is recognized that the rock types used in this study represent only some decorating and construction stones produced in Thailand. The conclusions drawn here are therefore limited by the relatively small diversity of the tested specimens. Nevertheless, the findings can be useful for the selection of the appropriate decorating and construction rocks for site-specific applications. For example, the commercially available travertine and Phu Kradung sandstone should be applied under relatively dry condition. Phu Phan sandstone degrades slowly and equally under wet and acidic environments. Both Tak granites can be applied under all environmental conditions.

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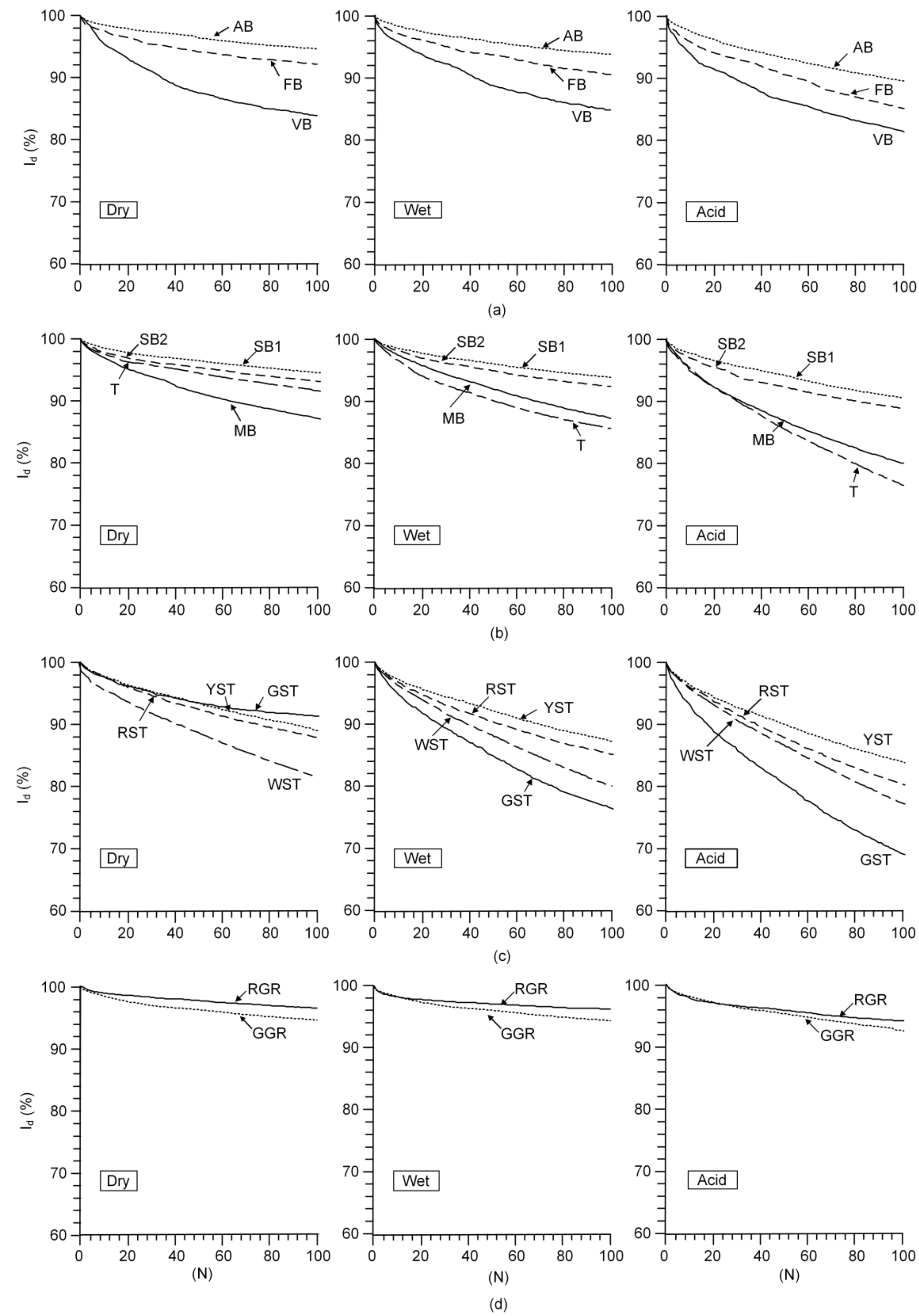
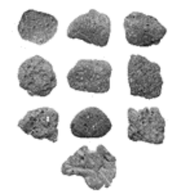
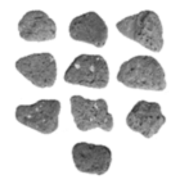
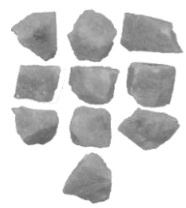
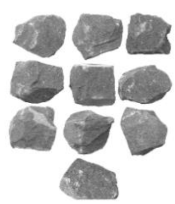
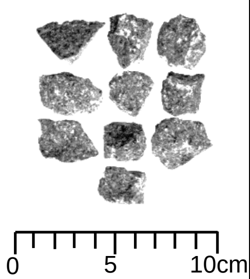


Figure 2 Slake durability index as a function of test cycle for basalt (a), carbonate (b), sandstone (c) and granite (d) groups

Table 3 Pictures of some specimens before and after 100 cycles of slake durability test

Rock Types	Initial	After 100 Cycles		
		Dry	Wet	Acid
Vesicular Basalt (VB)				
Khao Khad Marble (MB)				
Arkosic Feldspathic Sandstone (RST)				
Quartz Syenite (RGR)				

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