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The change of rock properties by artificial weathering tests and its implications for durability of building stones

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Abstract: Some well-known artificial weathering tests such as freezing-thawing, acid immersion, and salt crystallization are adopted to examine the change of rock properties during the processes of artificial weathering. Granites and other rock types of limestone, marble and basalt collected from different quarries in south Korea were sampled for this study. All tests were performed up to 30 cycles and physical properties were measured after experiencing every ten cycles of artificial weathering tests. During the tests, the variation trends of rock properties were too variable to draw generalized variation patterns but it can be concluded that weathering agents have different effect on rock properties depending on weathering circumstance and time. Even in short terms of salt crystallization tests, some rocks were severely deformed and then burst, and in the early stages of salt weathering, recrystallized salts filling pores and cracks in rocks could be a important factor affecting rock properties.

1. Introduction

Due to its superiority in strength, durability, aesthetic aspects and etc., stone has been used widely as building materials. The decay of stone in engineering structures and monuments is closely related to the geologic process of rock weathering influenced mostly by atmosphere, rainwater and rising ground moisture, with or without dissolved salts. A number of artificial weathering tests have been suggested to asses the durability of stone and to understand the effect of weathering process by individual agent (e.g. ASTM, 1997; Goudie, 1993; Kim and Park, 1999). In this study, some well-known methods of artificial weathering tests such as freezing-thawing, acid immersion, and saturated salt solution immersion were adopted to examine the change of rock properties during the processes of artificial weathering.

2. Specimen Preparation and Artificial Weathering Tests

The samples selected for this study were granites and other rock types of limestone, marble and basalt collected from different quarries in south Korea. The granite from Chuncheon (CG) is light grey biotite granite of medium- to coarse-grained equigranular texture with some feldspar phenocrysts and scattered mafic clots. The Wonju granite (WG) is medium- to coarse-grained granular biotite granite with some large phenocrysts of euhedral plagioclase and subhedral biotite. The Gapyeong granite (GG) is leucocratic granite of coarse grain with relatively small amounts of mafic minerals. The Okgye limestone sample (OL) is relatively low-grade limestone of light-grey color and the Jeongseon stone (JM) is a fine-grained marble showing a flow pattern along which fine-grained quartz and biotite are scattered. The basalt from Cheolwon (CB) is of massive texture with small vesicles smaller than 1mm in diameter. Rock cores of 54mm in diameter were drilled from the selected rock samples, and then cut to 107mm in length and polished to meet the ISRM suggested methods for the strength tests. Some physical properties such as apparent specific gravity, absorption, ultrasonic wave velocity and uniaxial compressive strength were measured before the artificial weathering tests (Table 1).

To observe the effect of temperature changes on rock properties, the prepared rock specimens were fully saturated with water and subjected in a freezer of 20℃ and successively in a water chamber of 20℃, maintaining constant temperature for three hours, respectively, which is called one cycle. The freezing-thawing temperature and the duration time were determined in consideration of really possible environment and stabilizing time of temperature at the inner part of the specimen. Stones exposed to atmosphere, rainfalls, stream waters and others can be weathered chemically mainly by reactions of hydrogen ions and rock-forming minerals. For the chemical reactions of rocks with hydrogen ions, one of the most powerful weathering agents, the rock specimens of OL and JM were immersed for 24 hours in daily refilled hydrosulfric acids of pH 4.5 but the others(CB, CG, WG, GG) in 1,000 times diluted H_2SO_4(98,08%), which is one cycle of acid-immersion test. Salts are the most powerful weathering agent and can act in several ways such as by crystallization, hydration, differential thermal expansion and osmosis. One cycle of artificial salt crystallization test was composed of immersion of rock specimens in oversaturated solutions of $CaCl_2$, KCl, NaCl and Na_2SO_4 for 15 hours and successive drying in an oven of 105℃ for 3 hours and cooling at room temperature. Six rock specimens were tested for each artificial test and for each location.

Table 1. Averaged physical properties and chemical composition (wt. %) of the studied rocks.

	limestone(OL)	marble(JM)	basalt(CB)	granite(CG)	granite(WG)	granite(GG)
apparent specific gravity	2.70	2.73	2.57	2.63	2.62	2.57
porosity (%)	0.24	0.27	4.43	1.20	0.62	0.73
absorption (%)	0.09	0.10	1.73	0.46	0.24	0.29
P-wave velocity (m/s)	4610	4680	4430	3200	3930	3590
compressive strength (MPa)	108.7	140.2	126.5	139.0	222.0	197.2
SiO_2	12.50	6.30	49.12	74.06	70.83	73.62
Al_2O_3	1.68	1.10	15.70	13.59	15.29	14.21
TiO_2	0.09	0.05	1.67	0.09	0.35	0.03
$Fe_2O_3^T$	0.55	1.81	11.02	2.09	1.84	1.30
MgO	1.11	11.49	9.08	0.06	0.45	
CaO	46.06	37.82	8.51	1.04	1.82	0.82
Na_2O	0.12	0.09	3.34	3.50	3.94	3.96
K_2O	0.71	0.17	1.54	4.29	4.36	4.91
MnO	0.03	0.46	0.16	0.07	0.03	0.04
P_2O_5	0.08	0.02	0.34	0.04	0.12	0.02
LOI(loss on ignition)	36.7	40.67		0.40	0.47	0.30

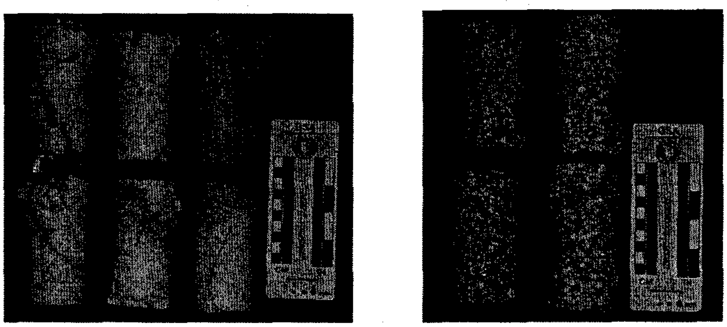
3. Results and Discussion

All tests were performed up to 30 cycles and specific gravity, porosity, absorption, and ultrasonic velocity were measured after experiencing every ten cycles of freezing-thawing test and acid-immersion test but porosity and absorption were not measured in the salt crystallization test because of soluble salts crystallized in pores. Uniaxial compressive strength was measured only after 30 cycles of each test.

During the process of freezing-thawing test, the changes of apparent specific gravity were negligible for all samples from six locations. Porosity and absorption increased and ultrasonic velocity decreased gradually in significant ratios for OL and JM samples but insignificantly for the other rock samples. Uniaxial compressive strength decreased after 30 cycles of freezing-thawing test for all rock specimens except for CG samples probably due to their inhomogeneity of freshness.

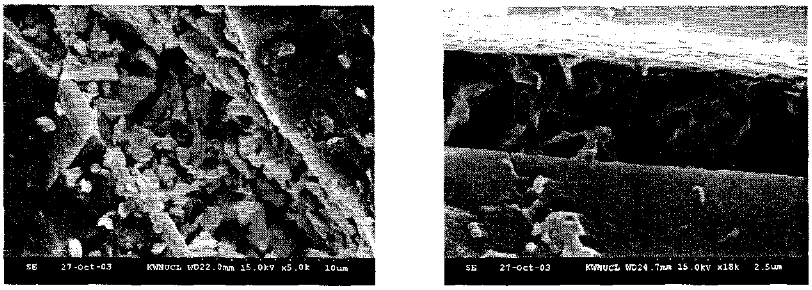
Among the tested rock samples, limestone and marble were affected mostly by repeated acid-immersion, especially in porosity and absorption. Contrary to expectation (Min et al., 2000, 2002), ultrasonic velocity increased gradually during the acid-immersion test for granite samples (CG, WG and GG), which should be re-tested and studied thoroughly. Uniaxial compressive strength decreased in a relatively low ratio after 30 cycles of acid-immersion test for all rock specimens.

The change patterns of physical properties during the salt crystallization tests are too variable to generalize the effect of salt crystallization tests on physical properties. During the repeated Na_2SO_4 salt crystallization, OL and CG samples were gradually deformed excessively and burst after 20 to 30 cycles of test (Fig. 1). The recrystallized salts were well observed in the cracks of rock samples through the scanning electron microscope (e.g. Fig. 2). In the all salt crystallization tests, apparent specific gravities for all tested samples increased generally but not so significantly due to recrystallization of salts.



- Okgye Limestone (OL) - **- Chuncheon Granite(CG) -**

Fig. 1. Photographs of the OL and the CG samples after 25 cycles of Na_2SO_4 salt crystallization test.



- Okgye Limestone(OL), Na_2SO_4 - - Chuncheon Granite(CG), $CaCl_2$ -

Fig. 2. SEM photographs of the $CaCl_2$ and Na_2SO_4 salt crystals filling the cracks in the OL and the CG samples

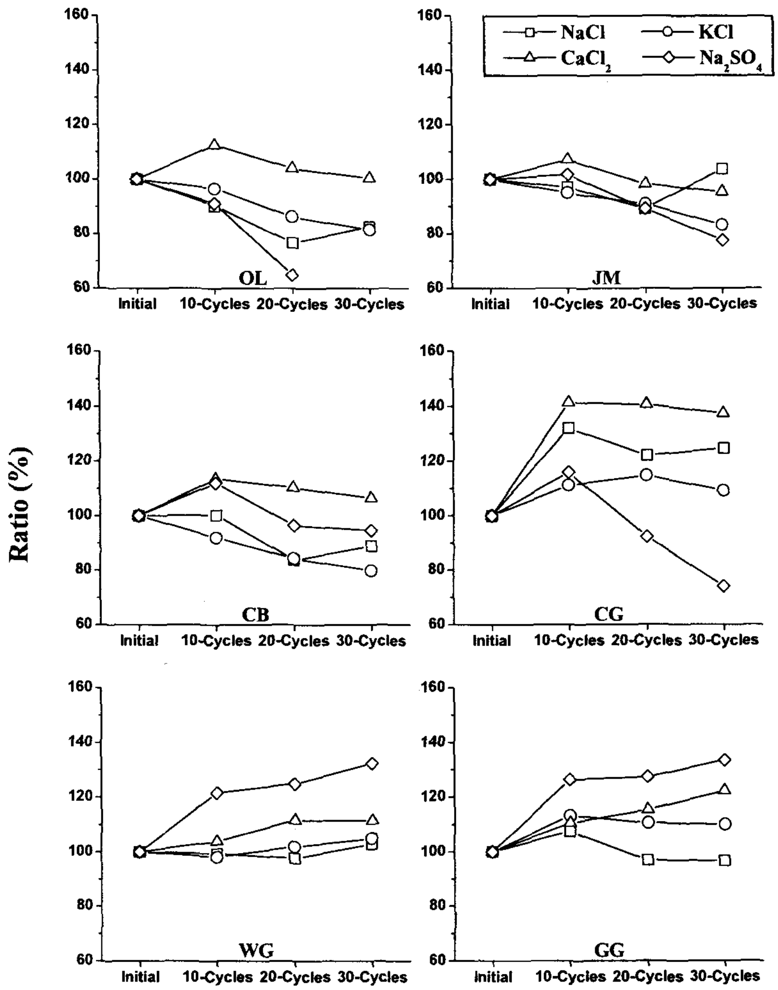


Fig. 3. Variation ratios of ultrasonic velocity in rock samples during salt crystallization tests.

As the cycles of salt crystallization tests increase, the variation patterns of ultrasonic velocity in the tested rock samples can be grouped into three types; steady decrease, increase and then decrease, steady increase. Generally OL, JM and CB samples show steady decrease patterns of ultrasonic velocity during salt crystallization tests except for $CaCl_2$ and Na_2SO_4 tests showing a slight increase during early stage of salt crystallization tests for some samples. For granite samples of WG and GG, during salt crystallization tests ultrasonic velocity increases with a trend of steady increase but increases and then decreases for CG samples. Those patterns can be related with the durability of tested rock samples against salt crystallization. During the early stage of salt crystallization for some rock samples, the salt crystals filling the pores in rock samples have an effect on the increase of ultrasonic velocity and then in later stages the repeated cycles of salt crystallization result in development of cracks leading decrease of ultrasonic velocity.

4. Conclusions

The change of rock properties during the processes of artificial weathering tests such as freezing-thawing, immersion and salt crystallization to assess its applicability for durability of rocks against natural agents of weathering. In the tests, the variation trend of rock properties was too variable to draw generalized conclusions but it can be concluded that weathering agents have different effect on rock properties depending on natural circumstance and time. Even in short terms of salt crystallization tests, some rocks were severely deformed and then burst, and in the early stages of salt weathering, recrystallized salts filling pores and cracks in rocks could be a important factor affecting rock properties. It is suggested that further more thorough weathering tests be necessary to understand the effect of various weathering agents on rock properties and the weathering processes of repeated salt crystallization.

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