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ROCK PROPERTIES OF AN ANDESITE AFTER FREEZING AND THAWING IN WATER

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Freezing and thawing damages of rock materials in many rock slopes have been well known to be severe under climatic cold region of Fukui Prefecture. Here, several weathering tests for hard rock material of andesite have been executed by freezing and thawing in water from -30°C to +50°C temperature. As the result, it is cleared that many rock properties tend to fall into decay gradually in linear relationship to the number of repeating cycles within 600 cycles.

1. Introduction

The change processes in quality of rock material due to weathering action are very complex to analyse, and these problems must be considered synthetically from both physical and chemical fields. In general, almost all weathering actions are divided into physical weathering due to freezing, insolation, swelling etc. and chemical weathering due to solution, oxidation and deoxidation, hydration etc .. Here, as one of the physical weathering actions, the degradation of rock properties after freezing and thawing in water has been considered experimentally. The volume of water expands about 9 % in the freezing time at 0°C. Such a large volume change of pore water will raise an enormous pressure among confined rock-forming minerals ,and the porosity of rock material increase gradually by means of heaving and wedging of ice. This weathering action of repeating freezing and thawing in water is one of the most severe physical weathering.[1]

In winter, Fukui prefecture has been often covered with snow and ice. Freezing and thawing action occurs easily in this cold region. And, many rock slope failures due to degradation of rock or rock mass have often occured at the thawing time. In this region, the

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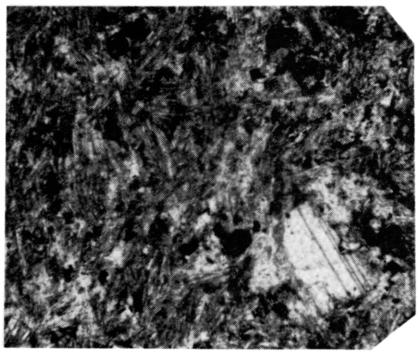
freezing and thawing action is considered to be one of the most important factors influencing on the weathering of rock mass or rock materials. And the rock properties, that is, density, absorption, porosity, longitudinal elastic wave velocity, compressive strength, Shore hardness, and so on are estimated to degrade gradually with repeating freezing and thawing, because the joints, cracks or pores of rock materials will expand and the rock-forming minerals are separated together due to expansive pressure of pore water at freezing time.

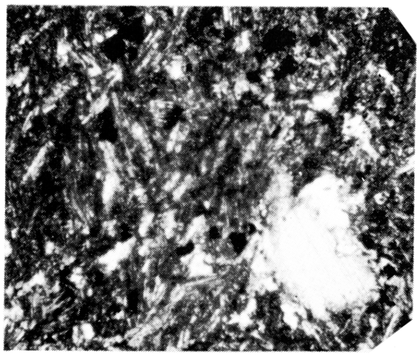
As laboratory tests, freezing and thawing tests in water against andesite have been executed under the condition of minimum freezing temperature -30°C and maximum thawing temperature +50°C. Then, the relations between several rock properties mentioned above and the number of repeating freezing and thawing cycle are analysed, and the effects of freezing and thawing action influenced on the engineering properties of rock materials are considered.

2. Preparation of Rock Samples and Rock Properties

As rock samples, hard rock materials of andesite have been selected, which are distributed for a wide range of Fukui prefecture.[2] And, two groups of fresh rock blocks of andesite have been sampled from construction site of new Takefu tunnel along National Road, route No.8. These rock blocks have been drilled perpendiculary to their sedimentary direction by use of core-cutter, and about one hundred of test pieces have been prepared as cylindrical pieces of diameter 50 mm and height 100 mm respectively. And these test pieces have been strictly selected ascertaining them to be sound without any crack or microfracture with the naked eye. Furthermore, the determination of required minimum number of test pieces has been done in the manner described in "Richt-



(a) Single Nikol (×87)



(b) Cross Nikol (×87)

Photo.1 Polarization microphotograph of Andesite linien für Festigkeitsuntersuchungen an Gesteinen --- Entwurf 1963 des Internationalen Büros für Gebirgsmechanik ---"[3]. The variation of rock properties is considered though all of the two groups of rock blocks were sampled from the same wall rocks respectively. That is, the necessary number of test pieces is determined to be more than 6 test pieces as an unit for each weathering test. The relative deviation of uniaxial compressive strength for each group of test specimens have been calculated to be about 23 % alike from the test results examined for arbitrarily selected 10 fresh test pieces. And the uniaxial compressive strength has been modified in the manner described in the same standard, considering the shape effect of test specimen.

The name of these rock samples is "Altered Andesite". Photo.1 shows the microphotograph of mineral composition of the altered andesite belonging to group X, as an example. And this polarization microphotograph is taken at the initial stage before the weathering test starts. The external appearance shows green and black fine uniform grained rock-forming minerals containing white fine stripes, but there are not any porphyritic crystals in the naked eye. Under the microscope, porphyritic texture is observed, the size of phenocryst is smaller than 1.0 mm diameter and there is a little amount of phenocrysts. All phenocrysts are perfectly substituted by some carbonate minerals "Calcite". And the groundmass has pilotaxitic texture which is constituted from columnar structure crystal "Plagioclase" of 0.1$\sim$0.2 mm length and chlorite minerals. The content of phenocrysts is only 1 %, and the other parts are constituted of groundmass. And the groundmass is divided into 44 % plagioclase, 36 % chlorite minerals, 8 % zeolite minerals, 7 % carbonate minerals and 4 % oxidized iron.

Table 1 shows the mean value and the standard deviation of initial rock properties for both X and Y group of rock samples. The number of test specimens measured and calculated here is 50 respectively for all rock properties except the uniaxial compressive strength. For X and Y group of rock samples, the density, specific gravity, uniaxial compressive strength and longitudinal elastic wave velocity have nearly almost the same value between X and Y group respectively, but the water content, absorption, porosity and Shore hardness have a different value between X and Y group respectively. The porosity of rock specimen n was calculated as $n = (G_s-G)/G_s$, G_s is specific gravity and G is apparent specific gravity, including the porosity of inner parts of rock which is entirely

Table 1 Initial Rock Properties

Rock sample		Group X	Group Y
Wet density	γ_t (g/cm^3)	2.637±0.007	2.637±0.028
Saturated density	γ_{sat} (g/cm^3)	2.638±0.007	2.644±0.027
Dry density	γ_d (g/cm^3)	2.632±0.007	2.600±0.038
Specific gravity	G_s	2.669±0.004	2.712±0.025
Natural water content	w (%)	0.207±0.058	1.477±0.565
Absorption	W (%)	0.267±0.082	1.711±0.580
Wet porosity	n_t (%)	1.208±0.343	2.444±0.664
Saturated porosity	n_{sat} (%)	1.151±0.333	2.238±0.637
Dry porosity	n_d (%)	1.411±0.341	3.575±0.815
Shore hardness	H_s	70.82±3.33	47.93±5.76
Uniaxial compressive strength	σ_D (kg/cm^2)	1523.7±223.5	1589.8±273.2
Longitudinal elastic wave velocity			
Wet	V_t (m/sec)	——	3473.8±222.6
Saturated	V_{sat} (m/sec)	3985.3±123.3	4059.8±294.8
Dry	V_d (m/sec)	3320.7±167.6	3020.5±154.4

isolated from the outside world.[4] And absorption W was calculated as (Saturated weight - Dry weight)/Dry weight. The modified uniaxial compressive strength σ_D was calculated by the equation $\sigma_D = 9\sigma_d/(7+2d/l)$, σ_d is a measured value, d and l is a diameter and length of cylindrical rock specimen.[3] And the longitudinal elastic wave velocity was measured under about 15 kg compressive force by use of an apparatus for measuring the velocities of ultrasonic waves in rocks [5].

To investigate the thermal properties of these rock samples, specific heat and thermal conductivity have been measured respectively. The average specific heat has been given as 0.338 cal/g·deg by use of water calorimeter, and the average thermal conductivity of saturated rock samples has been given as 1.13×10^{-2} cal/cm·deg·sec at normal room temperature. This thermal conductivity test has been executed in the manner described in LEE's Method.[6]

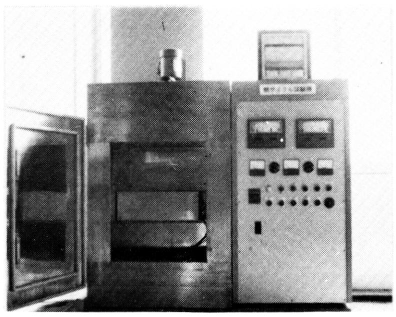


Photo.2 General view of thermal cycle test apparatus

3. Experimental method and apparatus

The weathering tests due to freezing

and thawing of rock materials in water have been executed by use of a thermal cycle test apparatus, of which general view is shown in Photo.2. This thermal cycle test apparatus consists of 47cm*50cm*60 cm test chamber and thermal exchange box which is drived by 2 P.S. electric refrigerator and 2 KW heater. The temperature of test chamber is able to decrease until the minimum value -30°C by use of freon gas as an unfrozen liquid, while the temperature is able to increase until the maximum value +100°C by the heater. The operation of this apparatus is automatically controlled by relay controlled system, and is able to continue systematically for a long time. Therefore, freezing and thawing action is able to repeat automatically for the rock test specimens, as both upper and lower limit of temperature are set for the test chamber and for a center core of rock sample respectively. Here, the temperature of center core of rock sample is set between -30°C and +50°C, while the temperature of the test chamber is set between -30°C and +80°C. During the freezing and thawing repeated tests, the temperatures of test chamber, center core of rock sample and water in vessel are continuously recorded on a thermal recorder. For an example, Fig.1 shows the one cycle record of their 3 thermal paths. In our freezing and thawing tests, 7.5 hours freezing process, 3 hours thawing process and 10.5 hours total process per one cycle are required. In this case, the temperature of center core of rock sample is lower than 0°C for 5 hours and higher than 0°C for 5.5 hours. And it is cleared that the temperature of water in vessel precedes slightly the temperature of center core of rock samples as shown in this figure.

All rock specimens are set and submerged into the vessel made of stainless steel having low specific heat and high thermal conductivity, of which capacity is 33cm*43cm*15cm, and thickness is 1.4mm. The freezing and thawing tests for group X and Y of rock samples

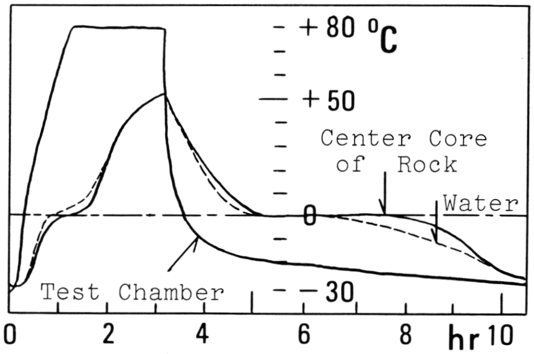


Fig.1 Example of Thermal Path Curves

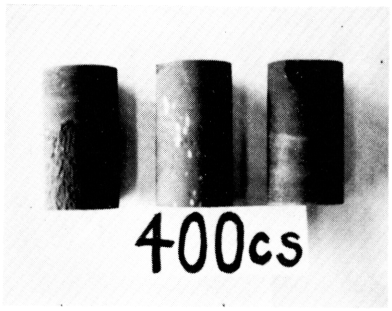


Photo.3 Example of Surface Exfoliation at 400 cycles

have been executed to 400 cycles and 600 cycles respectively, and the variations of several rock properties are investigated for every 50 cycles and 200 cycles respectively.

4. Experimental results and considerations

Table 2 shows the relations between several rock properties and number of repeated freezing and thawing cycles for rock group X and Y respectively. The mean values and the standard deviations of dry density γ_d, saturated density γ_{sat}, absorption W, saturated porosity n_{sat}, dry porosity n_d, Shore hardness H_s, longitudinal elastic wave velocity at saturated state V_{sat} and at dry state V_d are calculated from the whole data which have been measured for all rock specimens. But for uniaxial compressive strength σ_D, they are calculated from only 6 data for every time.

For rock group X, the correlations between rock properties and number of repeated freezing and thawing cycles n are summarized as follows ;

$$\gamma_d = -2.18 * 10^{-5}\ n + 2.633 \quad (r=-0.86) \tag{1}$$
$$\gamma_{sat} = -5.53 * 10^{-6}\ n + 2.640 \quad (r=-0.63) \tag{2}$$
$$W = 4.86 * 10^{-4}\ n + 0.286 \quad (r=0.62) \tag{3}$$
$$n_{sat} = 3.67 * 10^{-4}\ n + 0.996 \quad (r=0.27) \tag{4}$$
$$n_d = 8.52 * 10^{-4}\ n + 1.278 \quad (r=0.66) \tag{5}$$
$$H_s = -7.96 * 10^{-3}\ n + 71.40 \quad (r=-0.70) \tag{6}$$
$$\sigma_D = -3.49\ n + 3208 \quad (r=-0.70) \tag{7}$$

for Rock Type A

$$\sigma_D = -2.15\ n + 1435 \quad (r=-0.89) \tag{8}$$

for Rock Type B

$$V_{sat} = -1.15\ n + 3916 \quad (r=-0.93) \tag{9}$$
$$V_d = -0.348\ n + 3483.7 \quad (r=0.38) \tag{10}$$

Here, r is the coefficient of correlation. Both dry and saturated densities decrease gradually with cycle number as shown in Fig.2 and Fig.3. Especially, the relation for dry density has high coefficient of correlation. It means that the dry density expresses more delicately the expansion or microfracture of pore structure due to weathering of repeated freezing and thawing than the satulated density. Absorption increases considerably with cycle number as shown in Fig.4. And both saturated and dry porosities tend to increase gradually with cycle number as shown in Fig.5 and Fig.6. These rock properties mentioned above are degraded owing to the failure of frame structure of rock materials due to the freezing expansive

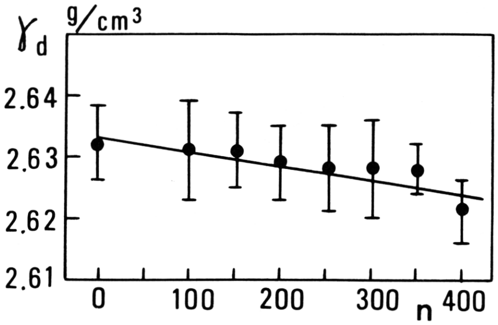


Fig.2 Variation of Dry density γ_d with cycle n

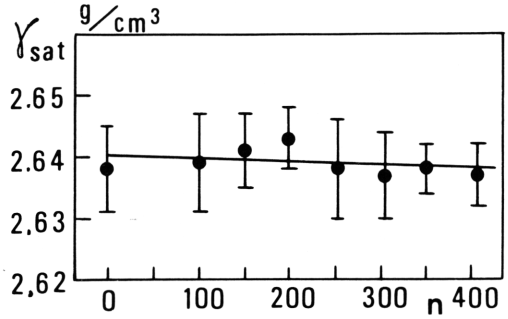


Fig.3 Variation of Saturated density γ_{sat} with cycle n

pressure of pore water, the difference of volume strain of each crystals or other factors. Shore hardness on the surface of rock specimen decreases gradually with cycle number as shown in Fig.7. As the weathering starts from the surface of rock specimen, the surface hardness drops down and surface exfoliation may be occured as shown in Photo.3. And, the uniaxial compressive strength decreases remarkably with cycle number as shown in Fig.8. In general, the compressive strength of weathered rock is controlled by the volume and shape of pores, and materials which occupy the space of pores.[7] The porosity n is divided generally into porosity of fissure n_f and the other parts of porosity n_p.[8] The larger the porosity of fissure n_f of rocks, the easier the structure tends to degrade due to freezing of pore water. In this figure, rock type A has a high uniaxial compressive strength, and there is not any hair-crack in the specimen. Almost all the porosities of rock specimen are constructed of porosity n_p, and the rock specimen has crushed into fragments at the uniaxial compression test as shown in Photo.4. On the other hand, rock type B has a comparatively low uniaxial compressive strength, and there is some porosity of fissure n_f which is very difficult to observe in the naked eye. The rock specimen has broken in two along some surface of crack as shown in Photo.5. Next, both longitudinal elastic wave velocity at saturated state V_{sat} and at dry state V_d decrease gradually with cycle number

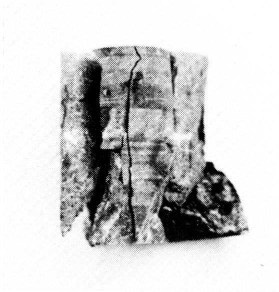


Photo.4 Break to pieces(Rock Type A)

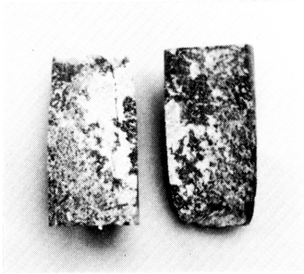


Photo.5 Break in Two (Rock Type B)

Table 2 Alteration of rock properties with cycle number of freezing and thawing for rock group X and Y

Rock sample		Group X						
Cycle Number		103	149	200	255	303	350	409
Dry density	γ_d (g/cm^3)	2.631±0.008	2.631±0.006	2.629±0.006	2.628±0.007	2.628±0.008	2.628±0.004	2.621±0.005
Saturated density	γ_{sat} (g/cm^3)	2.639±0.008	2.641±0.006	2.643±0.005	2.638±0.008	2.637±0.007	2.638±0.004	2.637±0.005
Absorption	W (%)	0.304±0.087	0.429±0.090	0.494±0.080	o.366±0.099	0.332±0.116	0.372±0.097	0.585±0.178
Saturated porosity	n_{sat} (%)	0.988±0.312	0.877±0.025	0.804±0.179	1.365±0.270	1.202±0.271	1.106±0.143	1.125±0.200
Dry porosity	n_d (%)	1.291±0.300	1.296±0.269	1.299±0.234	1.713±0.240	1.539±0.328	1.470±0.162	1.710±0.169
Shore hardness	H_s	-----	69.82±2.15	70.79±2.37	70.60±4.91	69.62±2.62	66.58±2.58	68.32±2.72
Uniaxial compressive strength	σ_D (kg/cm^2)	-----	A 2241±423 B 1123∓ 50	A 2985±617 B 1026∓126	----- B 646±152	A 2451±722 B 956∓ 82	A 1990±611 B 805∓ 12	A 1692±425 -----
Longitudinal elastic wave velocity	Saturated V_{sat} (m/sec)	3813.3±152.7	3647.5± 99.3	3596.5± 83.7	3670.7±115.2	3587.2± 71.7	3527.9± 77.1	3460.0± 66.9
	Dry V_d (m/sec)	3677.2±176.3	3402.4±177.8	3395.8±111.2	3491.2± 86.0	3345.2± 75.1	3305.4± 94.6	3316.0±130.8

Rock sample		Group Y			
Cycle Number		125	200	400	600
Dry density	γ_d (g/cm^3)	2.582±0.037	2.604±0.037	2.617±0.039	2.608±0.052
Saturated density	γ_{sat} (g/cm^3)	2.633±0.024	2.643±0.026	2.652±0.027	2.647±0.039
Absorption	W (%)	2.080±0.661	1.467±0.504	1.368±0.053	1.810±0.904
Saturated porosity	n_{sat} (%)	2.654±0.603	2.253±0.687	1.969±0.752	2.478±0.846
Dry porosity	n_d (%)	4.291±0.812	3.490±0.775	3.117±0.815	3.708±1.237
Shore hardness	H_s	-----	45.30±4.96	45.15±4.89	51.19±4.49
Uniaxial compressive strength	σ_D (kg/cm^2)	-----	1329.0±524.7	1125.5±108.8	1351.8±606.6
Longitudinal elastic wave velocity	Saturated V_{sat} (m/sec)	3913.0±203.8	4480.1±298.3	4268.3±367.0	4298.5±241.9
	Dry V_d (m/sec)	3537.3±268.2	3409.4±208.9	3146.2±241.3	3001.9±210.9

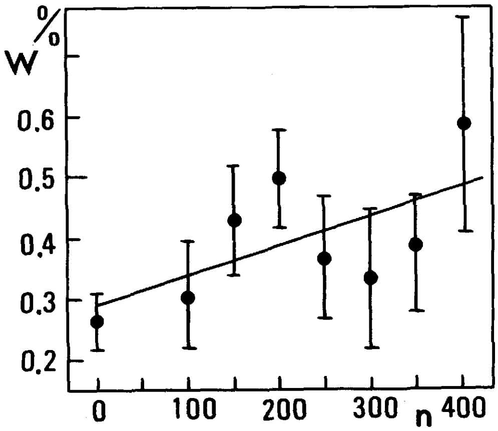


Fig.4 Variation of Absorption W with cycle n

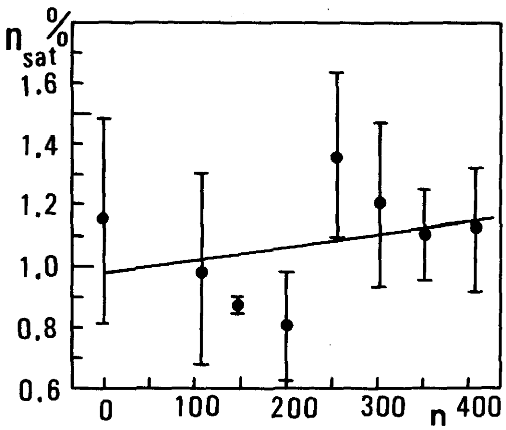


Fig.5 Variation of Saturated porosity n_{sat} with cycle n

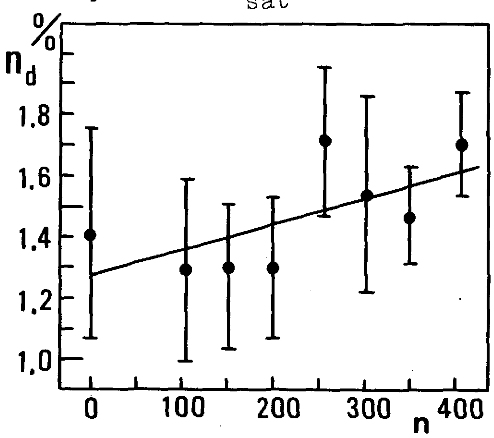


Fig.6 Variation of Dry porosity n_d with cycle n

as shown in Fig.9 and Fig.10 respectively. In this case, the longitudinal elastic wave velocity at saturated state V_{sat} should be more higher evaluated for these weathering tests than the other rock properties, because the relation between V_{sat} and number of cycle n has a very high coefficient of correlations.

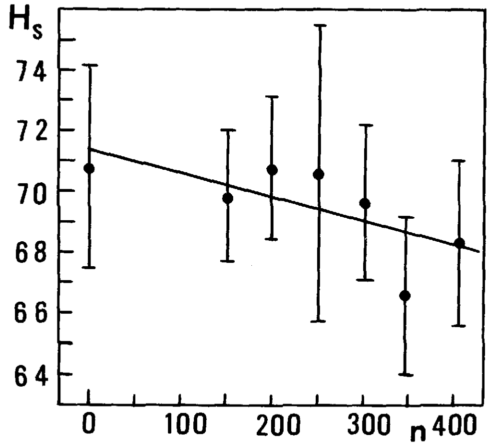


Fig.7 Variation of Shore hardness H_s with cycle n

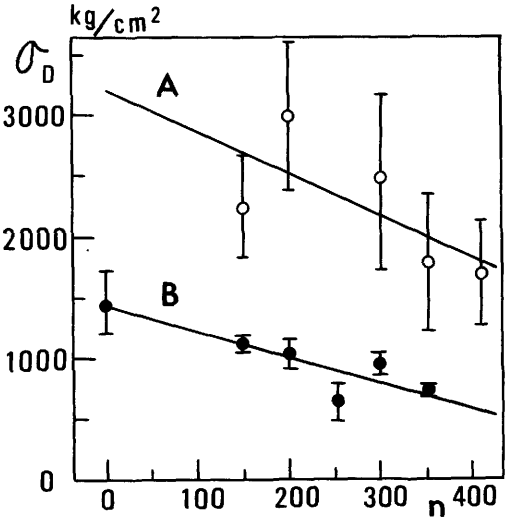


Fig.8 Variation of Uniaxial compressive strength σ_D with cycle n

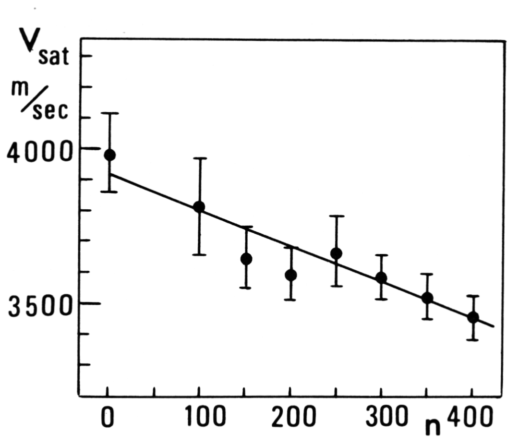


Fig.9 Variation of Saturated longitudinal elastic wave velocity V_{sat} with cycle n

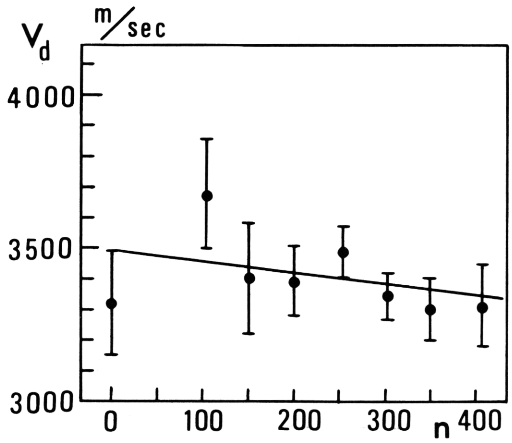


Fig.10 Variation of Dry longitudinal elastic wave velocity V_d with cycle n

For rock group Y, the correlations between rock properties and number of repeated freezing and thawing cycles n are summarized as follows ;

$$\gamma_d = 3.22 * 10^{-5}\ n + 2.594 \qquad (r = 0.55) \qquad (11)$$
$$\gamma_{sat} = 1.64 * 10^{-5}\ n + 2.639 \qquad (r = 0.54) \qquad (12)$$
$$W = - 2.18 * 10^{-4}\ n + 1.745 \qquad (r = -0.18) \qquad (13)$$
$$n_{sat} = - 6.73 * 10^{-5}\ n + 2.336 \qquad (r = -0.06) \qquad (14)$$
$$n_d = - 4.99 * 10^{-4}\ n + 3.768 \qquad (r = -0.28) \qquad (15)$$
$$H_s = 4.82 * 10^{-3}\ n + 45.95 \qquad (r = 0.44) \qquad (16)$$
$$\sigma_D = - 0.459\ n + 1486.7 \qquad (r = -0.62) \qquad (17)$$
$$V_{sat} = 0.451\ n + 4084.3 \qquad (r = 0.48) \qquad (18)$$
$$V_d = - 0.387\ n + 3325.4 \qquad (r = -0.38) \qquad (19)$$

Generally speaking, these rock properties of specimens belonging to this rock group have a comparatively large standard deviation. And, these relations between rock properties and cycle number have not any distinct tendency within 600 cycles. Photo.6 shows the state of surface exfoliation of this rock group after 600 cycles have passed. And, Photo.7 shows the general view of break in pieces after uniaxial compressive strength has executed at 600 cycles.

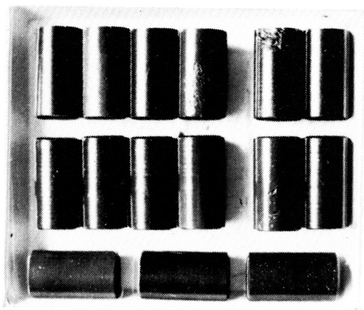


Photo.6 The state of surface exfoliation at 600 cycles

Now, the variations of 9 rock properties due to the repeated freezing and thawing in water have been investigated. For defining a degree of weathering, it is difficult to determine what kind of

Photo.7 Break in pieces at 600 cycles

property in many engineering properties of rocks is important. The degree of weathering for weak rocks, for example, for mud stone has already been defined by their grain-sizes [9]. For hard or middle hard rocks, the longitudinal elastic wave velocity is one of the most convenient properties to investigate in order to define the degree of weathering. The relations between elastic wave velocity, that is, "Rock Quality Index" and porosity have already studied by Fourmaintraux.D et al [8],[10]. And there are some examples which the elastic wave velocity has been utilized for evaluating the degree of weathering of cutting slopes [11], and weathered zone in soft rock [12]. In these cases, it is important to clear the correlations between the elastic wave velocity and the other engineering properties of rocks.[13]

5. Conclusions

Freezing and thawing tests in water have been executed for andesite by use of thermal cycle test apparatus. The temperature of center core of rock sample is controlled to repeat between -30°C and +50°C. The correlations between several rock properties and number of repeated freezing and thawing cycles are experimentally determined. As the results, both dry and saturated densities decrease gradually with cycle number. Especially, the relation for dry density has high coefficient of correlation. It means that the dry density expresses more delicately the expansion or microfracture of pore structure due to repeated freezing and thawing than the saturated density. And absorption, saturated and dry porosities increase gradually with cycle number. Shore hardness measured on the surface of rock specimen decreases gradually with cycle number due to surface exfoliation. And, the uniaxial compressive strength decreases remarkably with cycle number. Both longitudinal elastic wave velocity at saturated state and at dry state decrease gradually with cycle number. In these experiments, the longitudinal elastic wave velocity at saturated state should be more higher evaluated for these weathering tests than the other rock properties, because the relation between the velocity and number of cycle has a very high coefficient of correlations.

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