Resistance of Aggregate to Freezing and Thawing

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(Received July 15, 1976)

Abstract

Freezing and thawing test of water saturated samples of crushed stone was performed, and weight loss was determined screening the samples after the freezing and thawing test by diminution of grain size. It was recognized that there were correlationships between the weight loss by the freezing and thawing and soundness, specific gravity or absorption. Consequently it could be reasoned that the soundness test of crushed stone is an effective measure for estimation of resistance to freezing and thawing. Effects of grain size on the weight loss, elongation and variation of ultrasonic wave velocity of rock specimens due to repetition of freezing and thawing were also examined.

Introduction

In recent years demand for crushed stones has been markedly growing, and they are utilized as material for road pavement, coarse aggregate for concrete or ballast for railroad in large quantities. It appears therefore that among the properties of the crushed stones strength and durability as rock are most important. Since the crushed stones used as the road pavement or railroad ballst are liable to be subject to weathering action, it is not seldom that their unit weight changes by decrease of grain size as the result of repetition of freezing and thawing in water-bearing condition.

As for concrete, though its resistance to freezing and thawing can be improved by entrained air, it is considered that fracture of coarse aggregate causes desintegration of the concrete.

Accordingly it is improtant to make clear the resistance of the crushed stones to freezing and thawing for quality controll of the crushed stones. Although several workers have hitherto studied about the freeze-thaw resistivity of concrete[1)~6)] few studies have been performed on the resistance of aggregate to freezing and thawing[7),8)]. The author then performed experimental study in order to obtain the resistance of crushed stones to the freezing and thawing using several types of rock samples, and examined the results comparing with specific gravity and absorption as well as results of soundness tests which have hitherto been performed for the purpose of estimating the resistivity of aggregates to the weathering action. Elongation and variation of ultrasonic wave velocity by the freezing and thawing were also investigated.

Experimental

As the sample of this experiment besides several types of rocks which are utilized

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as crushed stone at present, a few types of weak rocks were used for the purpose of comparison. Nine types of rocks shown in Table 1 were used as samples for this experiment. Specific gravity, absorption, abrasion, compressive strength and tensile strength are shown in this table.

Table 1. Sources and physical properties of the crushed stones used as samples.

Sample no.	Rock type	Sources	Specific gravity	Absorption (%)	Abrasion (%)	Compressive strength (kg/cm²)	Tensile strength (kg/cm²)
1	Limestone	Mine-shi, Yamaguchi-ken	2.68	0.26	28.5	992	88
2	Chert	〃	2.58	1.20	29.6	—	—
3	Serpentine	Ube-shi, Yamaguchi-ken	2.55	2.05	22.3	1340	139
4	Augite-andesite	Ito-shi, Shizuoka-ken	2.62	1.99	26.7	—	—
5	〃	Aira-gun, Kagoshima-ken	2.52	2.29	11.3	1920	161
6	〃	Kumamoto-shi	2.66	1.65	16.7	—	—
7	Fine-grained sandstone	Awa-gun, Chiba-ken	2.15	14.11	27.5	864	82
8	Rhyolite	Shibata-shi, Niigata-ken	2.38	5.24	18.7	932	115
9	Biotite-granite	Ube-shi, Yamaguchi-ken	2.54	1.40	—	—	—

The resistance of crushed stones to the freezing and thawing was obtained determining reduction of grain size by screening of grains of the samples, after the freezing and thawing test of the samples having uniform grain size.

The freezing and thawing apparatus is composed of a freezing isotherm circulator Type CML–1 of Taiyo-Kagakukogyo, a freezing and thawing chamber, two mercury thermostats and a multi contact points time switch. Since the control circuit of the circulator is opened and closed at constant interval by the time switch, thermal reciprocating liquid in the circulator is repeatedly freezed and heated intermitently and is pumped up into the freezing and thawing chamber. Air temperature in the chamber changes cyclically in accordance with the cyclic change of temperature of the thermal reciprocating liquid.

The freezing and thawing chamber is made of polyvinyl resin surrounded by heat insulating material as shown in Fig. 1. Methanol (melting point −94°C and boiling point 64.5°C) was used as the thermal reciprocating liquid. The upper and lower limit temperature of the liquid were set up by the two mercury thermostats.

The sample of the crushed stone was put in a cylindrical vessel made of thin copper plate, and the lower half of the vessel was soaked in the liquid. A 400 W refrigerator

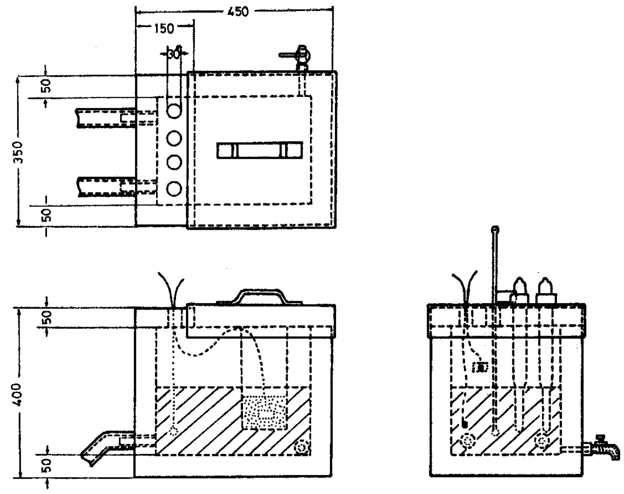

Fig. 1 Freezing and thawing chamber.

and a 1500 W electric heater, the imput voltage of which is adjustable, are assembled in the freezing isotherm circulator. The refrigerator are driven continuously while the electric heater works when the control circuit is closed. The time switch were adjusted so that it repeats on and off at an interval of 1 hour. The upper and lower limit temperature were set at 14°C and −21°C respectively.

When the circulator is driven under the condition described above, it takes about 50 minutes for liquid temperature to descend from 14°C to −21°C in freezing process, and then the temperature is kept constant at -21 ± 0.2°C for about 10 minutes. In heating process, the liquid temperature rises from -21 ± 0.2°C to 14°C in about 20 minutes, and then the temperature is kept constant at 14°C for about 40 minutes, hence it takes 2 hours for the temperature change of one cycle.

Liquid temperature and air temperature in the freezing and thawing chamber were measured by the mercury thermometer. The liquid temperature were recorded using thermistor as well. Since the temperature in a grain of crushed stone used as sample and that of grain surface may not be equal, temperature at center of rock core was recorded using a thermistor buried at center of a core, 24.7 mm in diameter and 24.7 mm in length. This core was put in the central portion of the sample grains.

Fig. 2 shows the temperature change of reciprocating liquid, air temperature in the freezing and thawing chamber and central portion of the sample measured by thermometers. It can be seen that there are time lags between the temperature change of liquid and air. The temperature at the central portion of the sample still more lags behind the temperature change of the air. Lag time of temperature at the central portion of the sample behind the temperature of the liquid was about 20 minutes at the lower limit, and about 30 minutes at the upper limit. The temperature change at the central portion of the sample gives approximately a sine curve. Fig. 3 indicates the recorded temperature changes of the liquid and the sample.

The sample of crushed stones, which had been screened so that its grain size becomes uniform and the specific gravity and absorption of which had been measured was

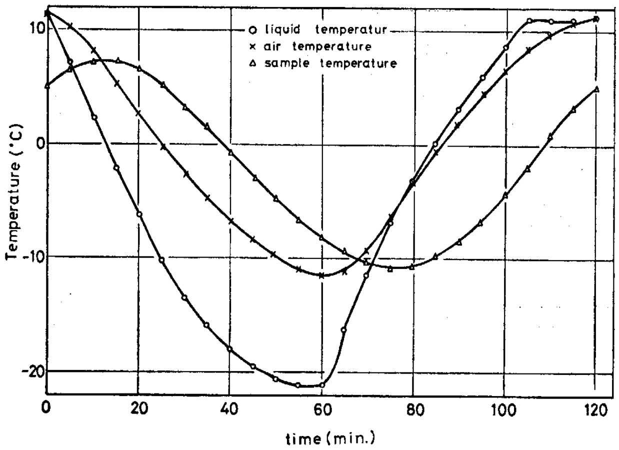

Fig. 2 Temperature change of liquid, air and sample.

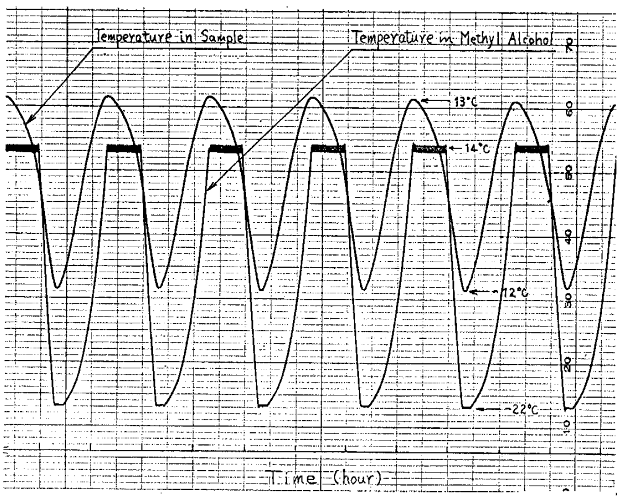

Fig. 3 Recorded temperature change of the liquid and the sample.

subject to freezing and thawing test in water saturated condition after being soaked in water for more than 48 hours. The sample about 1 kg in weight was tested by freezing and thawing up to 60 cycles.

In order to avoid desiccation in the process of freezing, the sample was packed by a vinyl sheet. The sample was taken out of the chamber when the temperature at the central portion of the sample was higher than 5°C at intervals of 12 cycles. Then this sample was screened by a screen used for preparation of the sample, and the resistance to freezing and thawing which corresponds to weight percentage of sample passing the screen to the original sample was determined.

The soundness of crushed stone samples was measured by the method which has been prescribed by JIS A1122. Samples 1 kg in weight were immersed in saturated solution of sodium sulfate for 16 hours, and then dried in a drying oven for 8 hours. Soundness was determined by weight loss after repeating the procedure described above five times.

Expansion of rock specimen may occur when the coherence of grains composing rock is loosened by the repetition of the freezing and thawing. In order to investigate such expansion, elongation of prismatic test pieces, 20 mm square in cross section and 100 mm in length was measured by length comparator at the end of each freezing and thawing cycle. Moreover, ultrasonic wave velocity of cylindrical specimen made from original rock of the crushed stone was measured at the end of each 12 cycles.

Results and Discussion

In the freezing and thawing tests of crushed stones, range of temperature measured by the thermistor buried in the core showed a little fluctuation owing to conditions such as grain size of the sample. The upper limit temperature was 10～13°C and the lower limit temperature was −11～13°C. Though the upper and the lower limit temperature were not constant as mentioned above, it could be reasoned that freezing and thawing would occur sufficiently even at the central portion of the sample grains.

Relationship between freezing and thawing cycles and weight loss of the sample, the grain size of which lies between 20 to 10 mm, is plotted in Fig. 4. In the test of samples 7–1 and 7–2, weak fine-grained sandstone, almost all grains were fractured by 60 cycles of freezing and thawing. In the test of other samples, weight losses at 60 cycles were mostly less than 15 percent. It can be seen that for every sample weight loss increases at a decreasing rate as frequency of freezing and thawing cycle increases. This phenomena may be explained as follows. Fracture of each grain of crushed stone

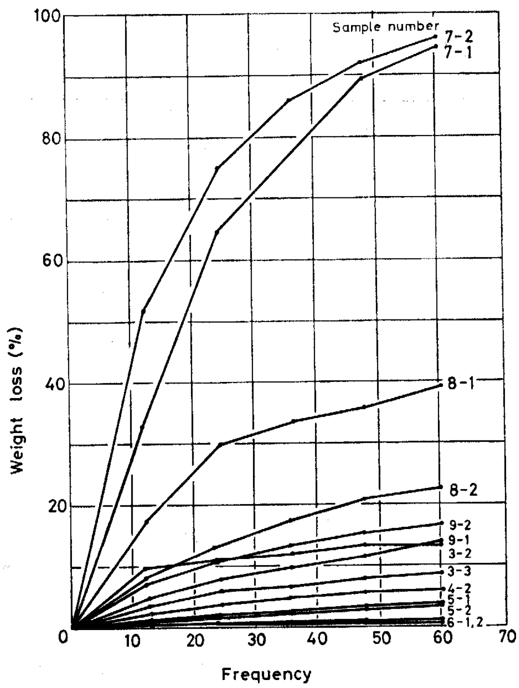

Fig. 4 Weight loss vs. frequency of freezing and thawing cycles.

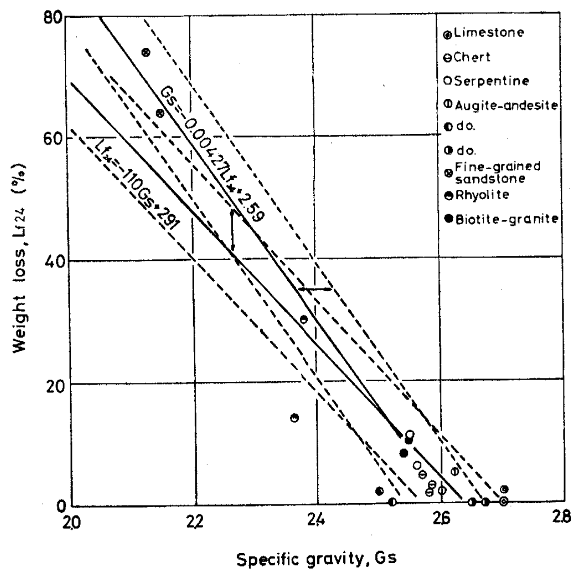

Fig. 5 Weight loss after 24 cycles of freezing and thawing vs. specfic gravity.

by volume increase of water, embraced in pores or minute cracks in the grain, occurs at the portion where the resistance to fracture is feeble at early stage, and gradually moves into portion where the resistance to fracture is larger.

Relation between the specific gravity and the weight loss after 24 cycles of freezing and thawing is shown in Fig. 5. From this figure it could be recognized that the crushed stones having large specific gravity tend to exhibit large resistance to freezing and thawing. The dotted lines about regression lines indicates range of standard deviations. Correlation coefficient between the specific gravity and the weight loss was -0.928.

Relation between the specific gravity and the weight loss after 60 cycles of freezing and thawing is shown in Fig. 6. The weight loss of samples the specific gravity of which is higher than 2.5 was approximately lower than 18%. Weight loss of samples having low specific gravity showed high value. Correlation coefficient obtained in this case was -0.927.

Relation between absorption and weight loss after 24 cycles of freezing and thawing of samples having grain size between 20 and 10 mm is shown in Fig. 7. From this

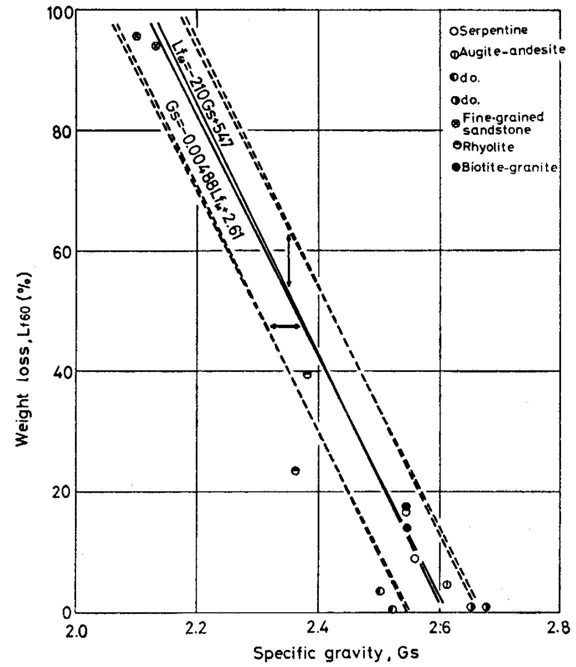

Fig. 6 Weight loss after 60 cycles of freezing and thawing vs. specific gravity.

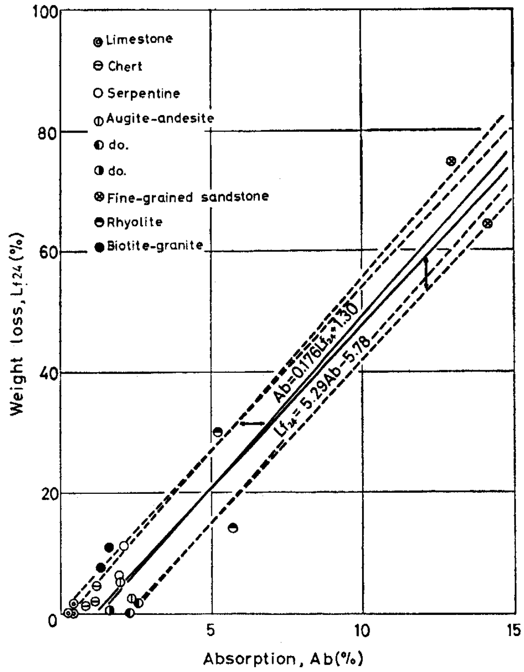

Fig. 7 Weight loss after 24 cycles of freezing and thawing vs. absorption.

figure it could be seen that the larger the absorption of a sample is, the higher the weight loss becomes. Correlation coefficient in this case was 0.966. Relationship between absorption and weight loss after 60 cycles of freezing and thawing is shown in Fig. 8. Weight loss of samples having absorption less than 3% shows approximately 18% of weight loss, while samples having high absorption show large weight loss.

In order to investigate the influence of grain size on the resistance to freezing and thawing, tests were performed by samples having four kinds of grain size. Fig. 9 shows results of this tests, in which samples of biotite granite having grain size of 30~20 mm, 20~15 mm, 15~10 mm and 10~5 mm were tested. Since the weight of the sample was 1 kg, number of grains for the samples of large grain sizes was so small that fluctuation of the results was very large. It could be recognized that the larger the grain size is, the higher the weight loss becomes.

Fig. 10 indicates the transition of the ultrasonic wave velocity measured by a specimen of fine-grained sandstone, with the progress of freezing and thawing cycles. The results obtained by four specimens indicate considerable fluctuation. The largest diminution of the velocity ratio after 120 cycles of freezing and thawing was about 23%. The fine-grained sandstone used in this test was comparatively weak. Almost no diminution in ultrasonic wave velocity was obtained by the other hard rocks.

Relation between specific gravity and weight loss by the soundness tests is plotted in Fig. 11. It could be reasoned from this figure that the larger the specific gravity of the sample is, the lower its weight loss by the soundness tests becomes. Equations for regression lines are shown in this figure. The correlation coefficient between the specific gravity and the weight loss by soundness tests was −0.913.

Relation between the absorption and the weight loss by soundness tests is plotted in Fig. 12. From this figure it could be seen that the weight loss by the soundness test increases as absorption increases. Correlation coefficient in this case was 0.982.

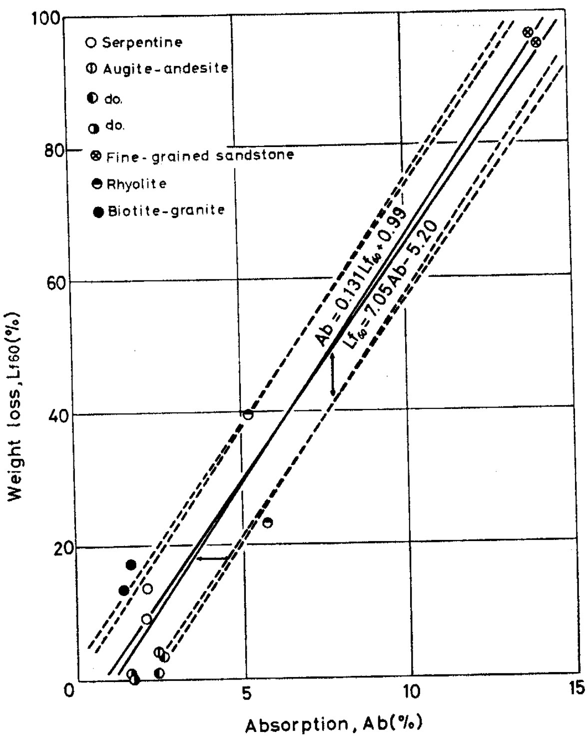

Fig. 8 Weight loss after 60 cycles of freezing and thawing vs. absorption.

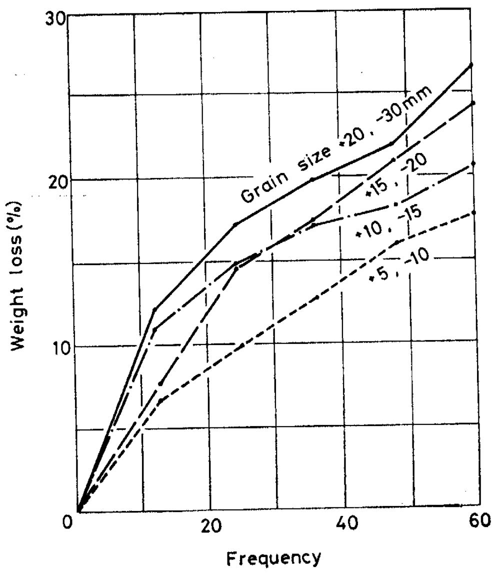

Fig. 9 Influence of grain size on the weight loss by freezing and thawing (biotite-granite).

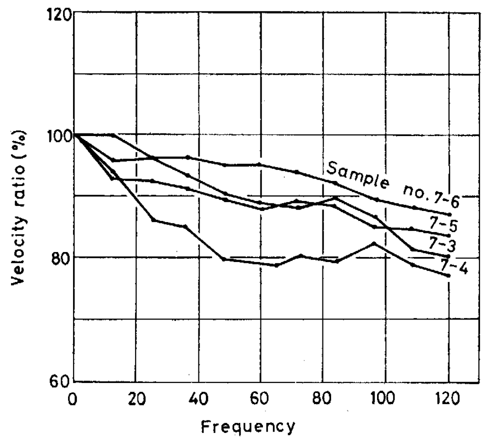

Fig. 10 Velocity of ultrasonic wave velocity vs. frequency of freezing and thawing cycles (fine grained sandstone).

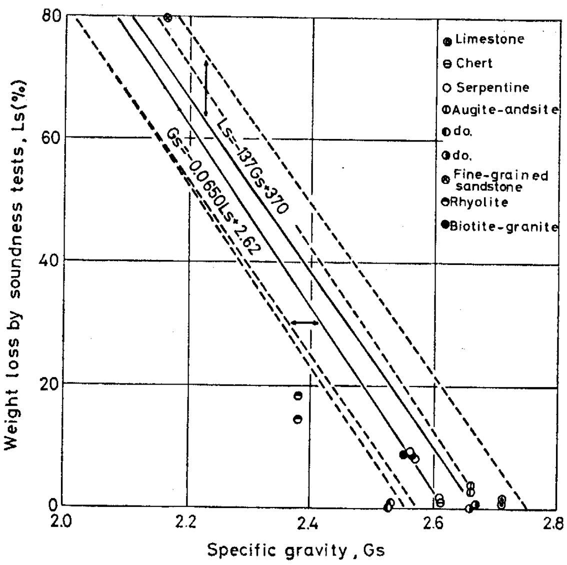

Fig. 11 Weight loss by soundness tests vs. specific gravity.

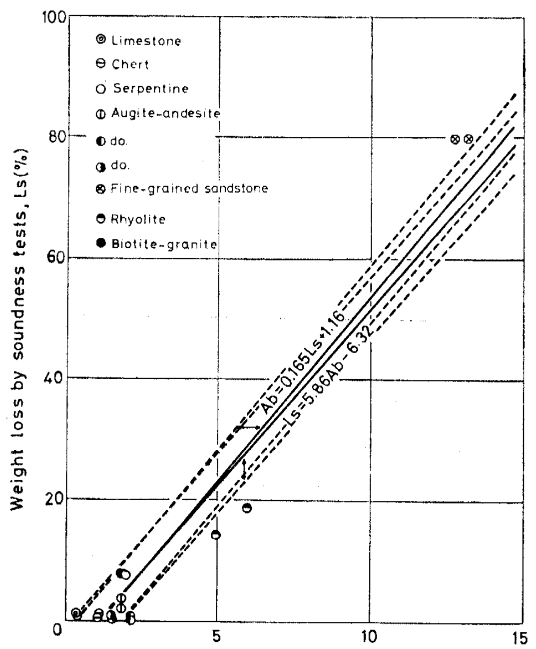

Fig. 12 Weight loss by soundness tests vs. absorption.

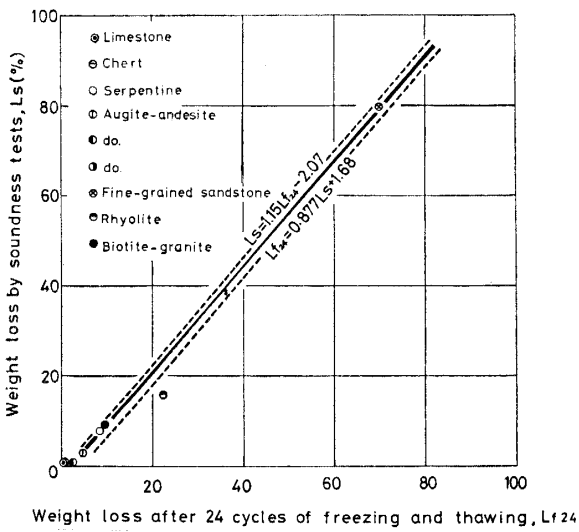

Fig. 13 Weight loss by soundness tests vs. weight loss after 24 cycles of freezing and thawing.

Relation between the weight loss after 24 cycles of freezing and thawing and the weight loss by soundness tests is plotted in Fig. 13. It could be recognized that the weight loss by freezing and thawing tests is approximately in proportion to the weight loss by soundness tests. Correlation coefficient in this case was 0.995. It could be reasoned from this result that crystal growth of sodium sulfate in the pores or minute cracks of sample grains for the soundness test exhibits similar effect as the growth of ice crystals by freezing of water absorbed in the grains. It may be reasonable therefore to estimate the resistance to freezing and thawing from the results of soundness test.

Fig. 14 indicates the relation between the weight loss after 60 cycles of freezing and thawing and the weight loss by soundness tests. It could be reasoned that there is proportional relationship between both weight losses. Correlation coefficient for the both weight losses was 0.990.

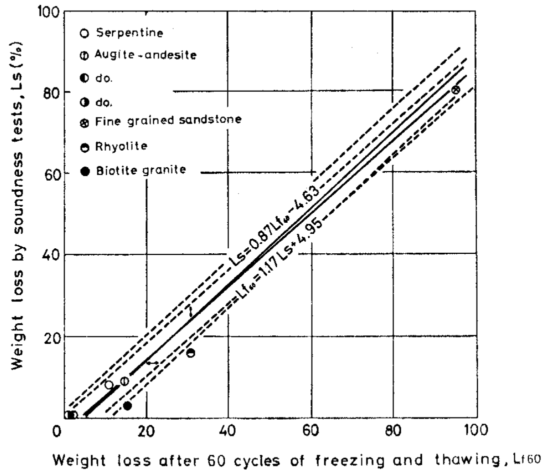

Fig. 14 Weight loss by soundness tests vs. weight loss after 60 cycles of freezing and thawing.

Elongation due to repetition of freezing and thawing was not observed by specimens of hard rocks, though specimen of weak soundstone exhibited elongation ratio 2.7×10^{-3} after 15 cycles of freezing and thawing and then fractured soon after.

Conclusions

As the result of freezing and thawing tests of crushed stone samples in water saturated condition, in which reduction in grain size was determined, it was recognized that there are fairly strong correlationship between the weight loss by freezing and thawing and specific gravity, absorption as well as soundness. In particular, the soundness test is considered to be effective measure for estimation of resistance of crushed stone to freezing and thawing.

Acknowledgement

The author wishes to thank to Messrs. Yoshiaki Kajitani and Eikichi Kikyo, graduates of our department, for their aid in present study.

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