Utilization of a rubber mat for the concrete caisson structures as a friction-increasing material

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ABSTRACT

Several engineers laid an asphalt mat between gravity-type concrete caisson and rock mound in breakwaters and offshore in cold seawater region to increase the sliding resistance of the concrete caisson and succeeded in contributing to the decrease of construction cost for the gravity-type concrete caissons. The asphalt mat has kept comparatively stable performance in cold seawater region, while execution and delivery workings of the asphalt mat were comparatively difficult. Authors' group tried to replace asphalt mat with rubber mat made of crushed pieces of waste tyre and binders for caisson structure from environmental grounds as well as economic ones. This paper describes the change of the mechanical properties of five kinds of rubber mats for last three years as a function of temperature. The results may be summarized as follows: 1) The natural rubber mat showed higher tensile strength, tensile elongation at break and tear resistance than those of recycled-rubber mats, independent of temperature and submerged years. 2) All rubber mats showed approximate values of hardness, independent of temperature and submerged years. 3) Temperature susceptibility of tensile strength, tensile elongation at break, tear resistance and hardness for all rubber mats were comparatively small. 4) The four kinds of recycled-rubber mat specimens didn't show significant changes in tensile strength and tear resistance for two years, while natural rubber specimen decreased those properties for two years.

1. INTRODUCTION

Increasing cost of stock maintenance for the infrastructures and limitation of a mass consumption of natural resources used for construction work are serious problem in Japan, with civil engineers being required to minimise any construction cost of infrastructure and destruction of environment. At the same time, sustainable construction of the lifeline is a very important to establish a safe and peaceful life for people, with a multitude of new concepts and terminology. Some researchers in civil engineering field proposed to lay a new composite material, known as asphalt mat, between concrete caisson and rock mound to increase the coefficient of friction of them and resulted in increasing the sliding resistance of the gravity-type concrete caisson. This technology contributed to the decrease of construction cost for the gravity-type concrete caissons for breakwaters and offshore [1, 2, 3, 4].

The asphalt mat used as a friction-increasing material has kept comparatively stable mechanical property and coefficient of static friction over a long period of time in the both of Mashike Harbour and Ochiishi Fishing Harbour in Hokkaido Prefecture in Japan [5, 6], while asphalt mixture had low stiffness at warm temperature in the field [7, 8, 9].

On the other hand, disposing of scrap tyre is a serious problem in Japan and engineers are required to convert waste tires to beneficial use. Following on from the success of asphalt mat technology in the concrete caisson structure, a new series of research on the topic of recycled composite material in concrete caisson construction has been planed. Authors' group launched a study on replacing asphalt mat with rubber mat for caisson structure in cold seawater region from environmental grounds as well as economic ones three years ago. To put it correctly, waste tyre crumb was used as a filler mixed with virgin natural rubber and/or synthetic rubber, or mixed with some binders, and hardened rubber was pressed to a required pattern of rubber mat.

This paper describes the outline of rubber mat technology in the gravity-type concrete caisson structure and the change of the mechanical properties of five kinds of rubber mats submerged in seawater for two years.

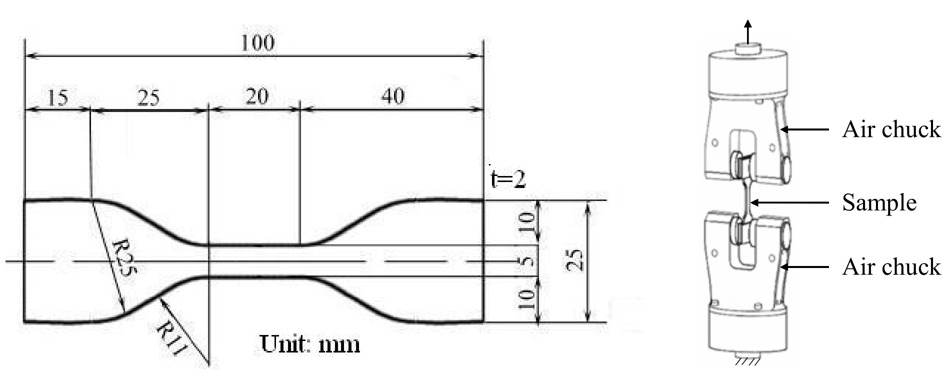
2. EXPERIMENTAL MATERIALS AND METHOD

2.1 Experimental material and method

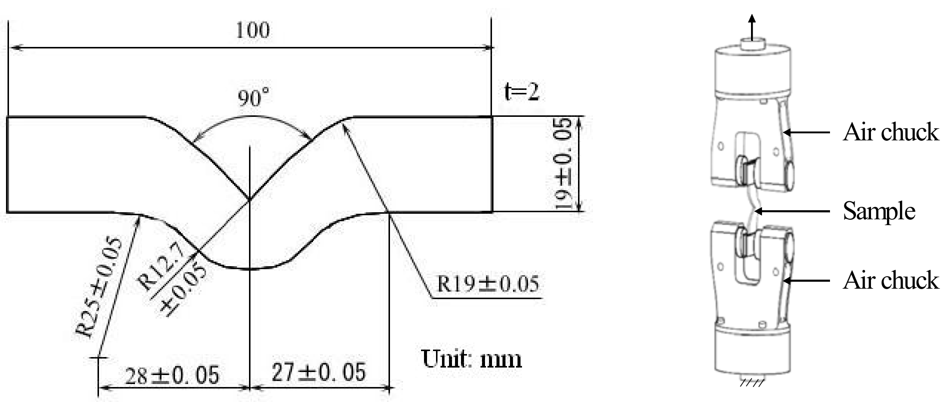
Five kinds of rubber mats, NR1, RR1, RR2, RR3 and RR4, were used in this study. NR1 was made of virgin natural rubber and others were made of waste tyre crumb mixed with virgin natural rubber and/or synthetic rubber, or mixed with some binders. Rubber mat blocks with 100 x 150 x 30 mm dimensions both for tensile and tear tests have and the one for hardness test has 50 x 50 x 30 mm dimensions.

Rubber mat blocks have been put into 1.9 x 1.9 x 2.0 m concrete box with drilled holes on the ceiling and bottom, and submerged in seawater at Abashiri Harbour in Hokkaido Prefecture in Japan. After pulling up from the sea at fixed day, rubber mat blocks for tensile and tear tests were cut into designated specimen shapes and tested for both tests, and rubber mat blocks for hardness test were used for testing without cutting. Tensile specimen was a dumbbell type test piece, with 100 mm long, 2 mm thick and 5 mm wide in the waist section, as shown in Fig. 1. The test pieces of tear specimens were ‘angle’ type designed to produce weak points where a tear was initiated, with 100 mm long and 2 mm thick dimension, as shown in Fig. 2.

A testing machine with digital dual servo control system is employed to ensure the constant rate of tensile deformation to the specimen in the tensile test and tear test. For example, constant rate of tensile deformation, 500 mm/min, was applied to a dumbbell type specimen gripped by air chuck of a jig for tensile test as shown in Fig. 1 and tensile stress was measured. Similarly, constant rate of tensile deformation, 500 mm/min, was applied to an angle type specimen gripped by air chuck of a jig for tear test as shown in Fig. 2 and tear stress was measured. A constant pressure pneumatic, wedged type grips, so called air chuck, was used to tighten specimens automatically and exert a uniform pressure across the grips surfaces, increasing as the tension increases in order to prevent slippage. Three samples were tested for



“**Fig. 1.** Shape of sample and jig for tensile test.”



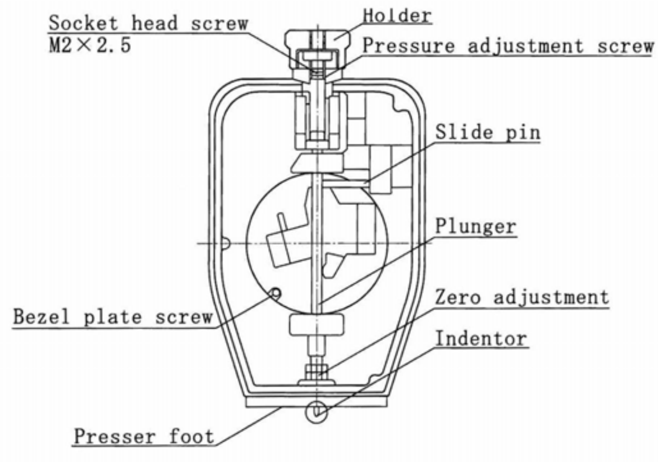
“**Fig. 2.** Shape of sample and jig for tear test.”

"**Table 1.** Experimental conditions."

Test method	JIS*	Shape of specimen	Loading speed mm/min	Test temp. ^{o}C
Tension	K 6251-1993	Dumbbell type	500	0, 20
Tear	K 6252-1993	Angle type	500	0, 20
Hardness	K 6253-1997	50x50x30 mm	Surcharge:1kg	0, 20

*Japan Industrial Standard

each property listed in the Table 1 which showed experimental conditions used in this study. Hardness measurement is one of the most commonly used methods in product testing and quality control for rubber, and hardness of rubber can be determined using either the IRHD (International Rubber Hardness Degree) or the Shore Scale [10] . In this study, the basic measurement of the hardness of the rubber specimen was carried out using a "Type A Durometer" as shown in Fig. 3. The method is based on the penetration of a specified indentor forced into the rubber specimens with 50 x 50 x 30 mm dimensions under 1 kg surcharge. Hardness, H_D of the rubber specimen tested was read directly from the indicator shown on window of the "Durometer".



"**Fig. 3.** Durometer for hardness test."

In this study, the specimen was set in a thermostatically controlled air-chamber for about half an hour and the surface temperature of a dummy sample placed next to the sample being tested was recorded using a thermocouple. Five minutes later the dummy sample reached the set temperature, the specimen was placed into a testing device for loading.

2.2 Analytical method

Tensile strength and elongation at break were calculated as follows:

$$T_B = F_B / A \tag{1}$$

$$E_B = (L_1 - L_0) / L_0 \times 100 \tag{2}$$

Where

T_B : tensile strength, N/m^2,
E_B : elongation at break,
F_B : maximum tensile load,
A : cross-sectional area of the unstretched specimen,
L_0 : original distance between the bench marks, and
L_1 : observed distance between the bench marks on the stretched specimen.

Tear resistance was calculated as follows:

$$TR = F / t \tag{3}$$

Where
TR : tear resistance, N/m
F : force, and
t : specimen thickness.

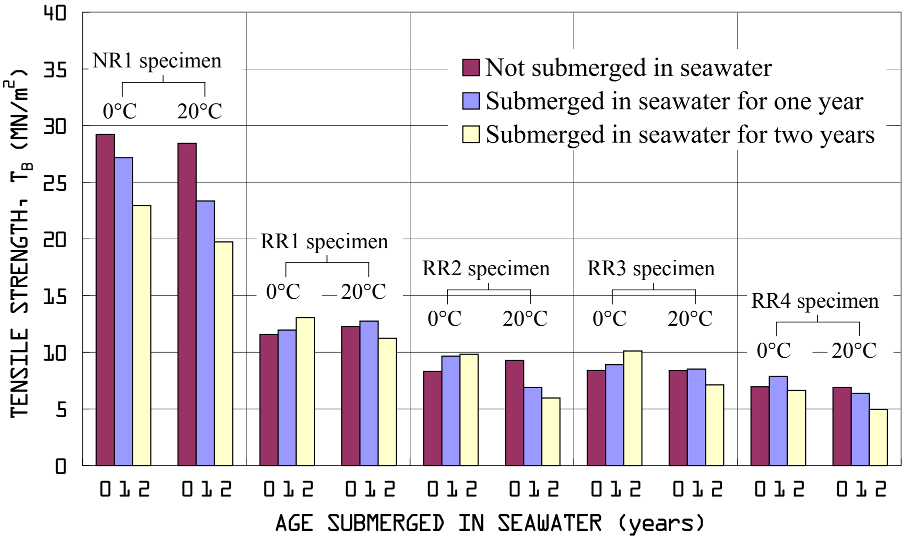
The median of the test measurement values for three specimens was taken as a result for the rubber mat tested in the tensile test and tear test respectively. Moreover, a test result for hardness was the median of five individual hardness readings.

3. EXPERIMENTAL RESULTS

3.1 Relation between tensile strength of rubber mats and age

Fig. 4 shows the relation between tensile strength, T_B and age at 0 ^oC and 20 ^oC for five kinds of rubber mats submerged in seawater at Abashiri Harbour in Hokkaido Prefecture in Japan. Tensile strength of natural rubber mat specimen named NR1 was higher than those of recycled-rubber mat specimens, that is, RR1, RR2, RR3 and RR4, independent of temperature and submerged years.

On the other hand, tensile strength was highest in the RR1 specimen and then decreasing order, in the RR2 specimen, RR3 specimen and RR4 specimen amongst the four kinds of recycled-rubbers mat specimens, and however, differences in them were small.



"**Fig. 4.** Relation between tensile strength and age for various rubber mats submerged in Abashiri Harbour."

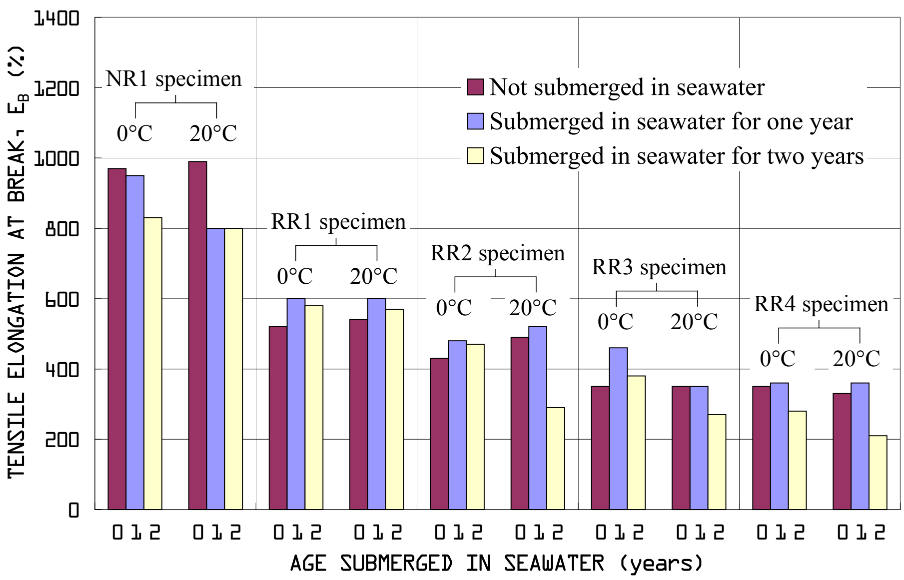
Temperature dependent nature of tensile strength for all rubber mat specimens was comparatively small, independent of years submerged in seawater. This fact means that tensile strengths of all rubber mats tested in this study did not change, even though temperature of seawater varied by 20 ^{o}C which were comparatively large temperature change in the cold seawater region in Hokkaido Prefecture in Japan.

The four kinds of recycled-rubber mat specimens showed comparatively small changes in tensile strength for two years, while natural rubber specimen,NR1, decreased its tensile strength for two years. For example, the tensile strengths at 0 ^{o}C for the NR1 were about 29.2 MN/m^{2} for not submerged in seawater, about 27.2 MN/m^{2} for submerged for one year and about 22.9 MN/m^{2} submerged for two years respectively. That is, the values of tensile strength at 0 ^{o}C for the NR1 mats not submerged in seawater were about 1.1 times and about 1.3 times those of the NR1 mats submerged for one year and two years respectively. Similarly, tensile strength of the not submerged NR1 at 20 ^{o}C was about 1.2 times and 1.4 times those of the NR1 submerged for one year and two years.

3.2 Relation between elongation at break of rubber mats and age

Fig. 5 shows the relation between tensile elongation at break, E_B and age at 0 ^{o}C and 20 ^{o}C for five kinds of rubber mats submerged in seawater at Abashiri Harbour in Japan. Tensile elongation at break of natural rubber mat specimen,NR1, was higher than those of recycled-rubber mat specimens, that is, RR1, RR2, RR3 and RR4, independent of temperature. Tensile elongation at break was highest in the RR1 specimen and then decreasing order, in the RR2 specimen, RR3 specimen and RR4 specimen amongst the four kinds of recycled-rubber mat specimens.

Tensile elongations at break of almost all rubber mat specimens also hardly showed temperature susceptibility for temperature differences of 20 ^{o}C. For example, the values of elongation at break at 0 ^{o}C and 20 ^{o}C for the RR1 rubber mat were about 520 and about 540 for specimens not submerged in seawater, about 600 and about 600 for specimens submerged for one year and about 580 and about 570 for specimens submerged for two years. Considering that the temperature range of 0 ^{o}C to 20 ^{o}C fully covers seawater temperatures in cold seawater region where rubber mats tested in this study are utilized as a friction-increasing materials, it is important that almost all rubber mat specimens showed similar elongation at break at these temperature ranges.



“**Fig. 5.** Relation between tensile elongation at break and age for various rubber mats submerged in Abashiri Harbour.”

Almost all rubber mat specimens decreased tensile elongations at break for two years submerged in the seawater regardless of temperature, and however, the rates of decrease of those were small. Considering that elongation at break is a measure of deformation characteristics, it is clear for the rubber mat used as increasing-friction material to have a comparatively high deformation resistance to loading in comparison with that of asphalt mat used as a friction-increasing materials in concrete caisson structures [5, 6].

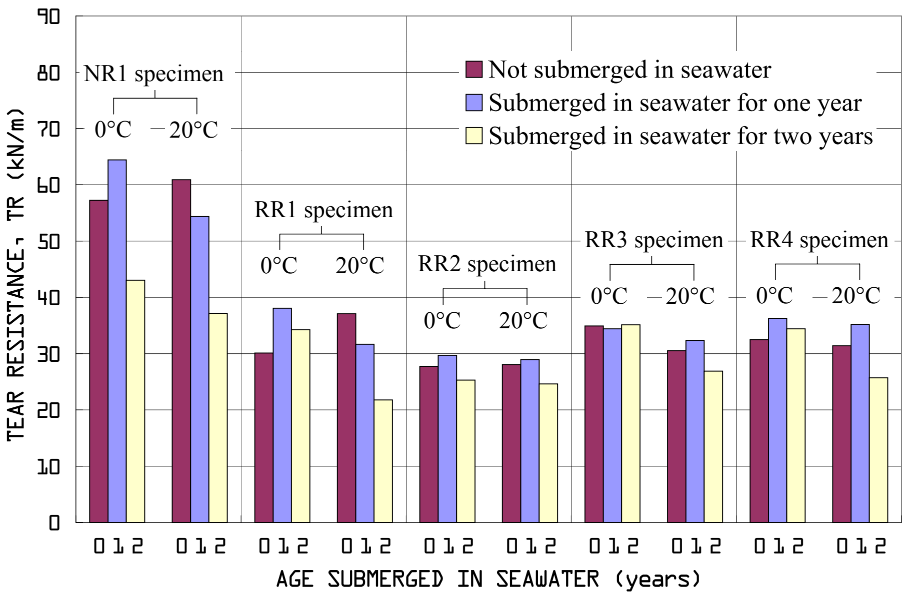
3.3 Relation between tear resistance of rubber mats and age

Fig. 6 shows the relation between tear resistance, TR and age at 0 °C and 20 °C for five kinds of rubber mats submerged in seawater at Abashiri Harbour in Japan. Tear resistance of natural rubber mat specimen,NR1, was higher than those of recycled-rubber mat specimens, that is, RR1, RR2, RR3 and RR4, independent of temperature and submerged years.

On the other hand, tear resistance was lowest in the RR2 specimen amongst the four kinds of recycled-rubbers mat specimens, and however, differences of tear resistance values in those rubber mat specimens, that is, RR1 specimen, RR3 specimen and RR4 specimen were very small. For example, the values of tear resistance of RR1 specimen, RR3 specimen and RR4 specimen at 0 °C were about 38, about 34, and about 36, in case of one year submerging in seawater.

In general terms, the temperature dependent nature of tear resistance for rubber mat specimens was comparatively small at first year (not submerged in seawater) and at submerged for one year, while the temperature dependent nature at submerged for two years was comparatively large, that is, tear resistances at 0 °C for rubber mat specimens were higher than those at 20 °C. Especially, this temperature susceptibility nature was observed for natural rubber mat specimen.

The four kinds of recycled-rubber mat specimens didn't show significant changes in tear resistance for two years, while natural rubber specimens decreased their tear resistances for two years.

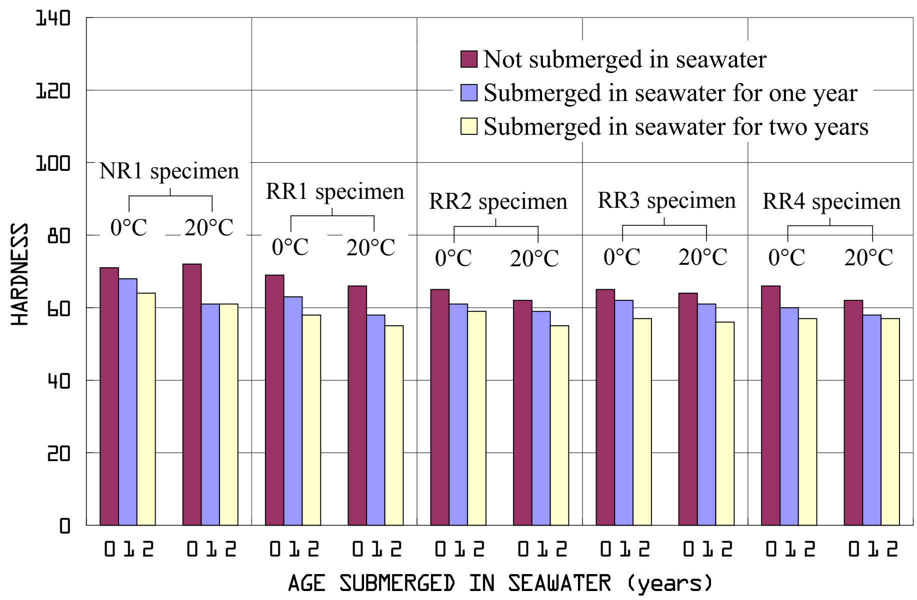


"**Fig. 6.** Relation between tear resistance and age for various rubber mats submerged in Abashiri Harbour."

3.4 Relation between hardness of rubber mats and age

Fig. 7 shows the relation between hardness, H_D and age at 0 °C and 20 °C for five kinds of rubber mats submerged in seawater at Abashiri Harbour in Japan. All rubber mat specimens

showed almost approximate values of hardness in comparison with other mechanical properties, that is, tensile strength, tensile elongation at break and tear resistance of them. For example, hardness of NR1, RR1, RR2, RR3 and RR4 specimens at 0 °C were about 71, about 69, about 65, about 65 and about 66 at first year (not submerged in seawater), about 68, about 63, about 61, about 62 and about 60 for one year submerged specimens, and about 64, about 58, about 59, about 57 and about 57 for two years submerged specimens. Taking into account the above-mentioned tendency on hardness, one can solve the difficult problem of connecting rubber mat with concrete caisson and with rock mound using steel bars in the execution of gravity-type concrete caisson, because similar hardness properties of rubber mats do not specific requirements to the divers working in the execution field of the ocean floor and result in making routine working possible for divers in the seawater.
Temperature dependent nature of hardness for all rubber mat specimens were small, independent of years of submerged in seawater. Moreover, changes in hardness of rubber mat specimens for submerged year were also small and consequently, performance from a viewpoint of hardness of rubber mats was stable over two years.



"**Fig. 7.** Relation between hardness and age for various rubber mats submerged in Abashiri Harbour."

4. CONCLUSIONS

The following conclusions were obtained.

1)The tensile strength, tensile elongation at break and tear resistance of natural rubber mat were higher than those of four kinds of recycled-rubber mats, independent of temperature and submerged years.

2)The RR1 rubber mats showed highest tensile strength and tensile elongation at break amongst the four kinds of recycled-rubber mats.

3)All rubber mats showed approximate values of hardness, independent of temperature and submerged years.

4)All rubber mats showed comparatively small temperature dependency of tensile strength, tensile elongation at break, tear resistance and hardness.

5) The four kinds of recycled-rubber mats didn't show significant changes in tensile strength and tear resistance for two years, while natural rubber mats decreased those properties for two years.

6)Almost all rubber mats decreased tensile elongations at break for two years submerged in the seawater regardless of temperature, and however, the rates of decrease of those were small.

ADDITIONAL WORK IN FUTURE

Generally speaking, materials characteristics exert an influence on the performance of the structures in the civil engineering field and result in affecting on a safe and peaceful life for people. Therefore, sustainable evaluation on the various rubber mats submerged in the seawater is a very important to establish a rubber mat technology, with a multitude of new concepts and terminology.

We had prepared enough rubber mats in the seawater at Abashiri Harbour in Hokkaido Prefecture in Japan to carry out tensile test, tear test and hardness test 50 years hence, and would continue needed additional works to evaluate the durability of rubber mats.

ACKNOWLEDGEMENTS

The authors wish to thank research staffs in Civil Engineering Research Institute of Hokkaido and Mayama Research Laboratory in Hokkaido Institute of Technology, for valuable comments on the manuscript.

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