PRESENT STATUS AND EVALUATION OF ANTI-ICING PAVEMENTS IN JAPAN

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1. Abstract

The technology for developing anti-icing pavements has been developed in Japan since it was introduced from abroad in the 1970s and 1980s. The pavements have contributed widely to the management of road surface in winter, and have so far prevailed with coverage of about five million square meters. Since the anti-icing pavements can control both the icing of road surface and the freezing of packed snow, they are expected to ensure the safety of road traffic in winter and to increase the efficiency of snow removal.

The anti-icing pavements used in Japan are classified, based on the anti-icing mechanism, into two types: namely chemical and physical ones. The former lowers the freezing point by releasing the chemicals added to the pavements. About four representative methods are available based on the type of chemical used. The latter works as follows: ice layers formed on the road surface are destroyed and removed when elastic materials placed in or on the surface of the pavements are deformed under traffic loads. There are about 10 representative methods classified according to the type of elastic materials or the method of placement. Although several methods have been proposed for the evaluation of the effects of such anti-icing pavements, no quantitative evaluation method has yet been established.

Under the circumstances, the Research Group of Anti-icing Pavement tried to make a simple, quantitative evaluation method of anti-icing effects using an improved hydraulic adhesion test apparatus to measure adhesive strength of the ice. The findings of the attempt are described below.

(i) Various types of anti-icing pavements can be evaluated by the same method either in a laboratory or in the field.

(ii) Evaluation can be carried out not only in the winter but also through the year.

(iii) The evaluation method can be used for the selection of a construction method appropriate for a designated site.

This paper introduces the present status of anti-icing pavements in Japan, the results of a case study in the applicability and evaluation methods as well.

2. Introduction

The Japanese islands extend in north-south direction narrowly, with a band of 2,000 m high mountain chains running through the center of the archipelago. The cold, snowy areas in Japan extend from Hokkaido to the Chugoku district. The division of Japan is shown in Figure 1. The cold, snowy zone occupies about 60% of the total Japanese landmass, where about 30% of the total population live in. This topography provides great differences in climatic conditions, with a variety of road conditions in winter depending on the area.

Road managers take a number of measures to ensure road traffic safety, including efficient removal of snow, application of anti-icing agents, and installation and operation of information systems to provide data on road and climatic conditions. Several types of anti-icing pavement have been developed and constructed as one of these measures. These anti-icing pavements are qualitatively proven to be effective, but no quantitative evaluation methods have been established yet. Even front line people can evaluate the performance of these pavements only in wintertime.

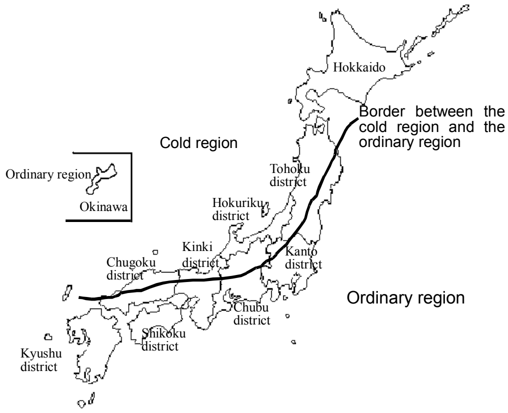


Fig. 1 Distribution of cold, snowy areas in Japan [1)]

Given these circumstances, the Research Group for Anti-icing Pavements, in an attempt to establish a simple and quantitative method to evaluate the anti-icing effect of the anti-icing pavement, developed an anti-freezing strength test, an improved version of the adhesive strength measuring method based on the use of a hydraulic tensile test machine, so as to evaluate the anti-icing pavement regardless of the season.

This paper reports the present status of anti-icing pavements in Japan and summarizes the results of the studies made so far on anti-icing pavements, including the applicability and evaluation methods for such pavements.

3. Japanese Climate

The average temperatures and accumulated snow depths in wintertime in Japan are shown in Fig. 2. For winter climatic conditions, temperatures and cumulative snow depths in Japan are from -4 °C to + 7°C and from 0.5 m to 8 m respectively, showing

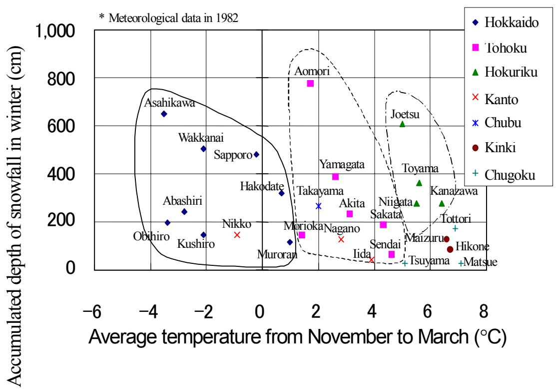


Fig. 2 Winter climatic conditions in major cities in Japan

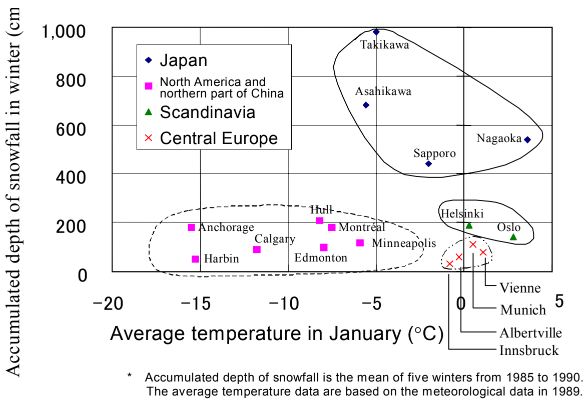


Fig. 3 Winter climatic conditions in major cities in the world

great variation depending on the area. Fig. 3 shows the relationship between the average temperature in January and the accumulated depth of snowfall in winter in cities of the world. It is indicated that Japan has more snowfall than the cities of the world for its relatively high temperature, which is a Japanese special climatic trait.

Appropriate response to these varying climatic conditions in Japan requires appropriate de- and anti-icing measures optimally tuned to the needs of each area.

4. State-of-art of Anti-Icing Pavements

4.1 Types of anti-icing pavements

Anti-icing pavements used in Japan are classified as chemical-type and physical-type pavements. Either of these types is allowed to exhibit its effective anti-icing performance in the temperature range down to around – 5℃. [2)]

• The chemical-type

The chemical-type promotes the peeling of ice sheets as chlorides exuded from the pavements reduce the freezing point and consequently promote melting of ice. There are two types of the chemical-type pavements depending on how the chlorides are added, see Fig. 4. Powdered chlorides are used as aggregate and added during mixing at an asphalt plant for aggregate replacement type, whereas chlorides are filled into voids of open graded asphalt concrete after the pavements are constructed for void fill type.

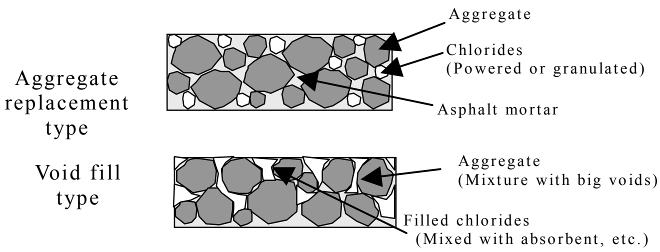


Fig. 4 Conceptual diagram of a typical chemical anti-icing pavement

• The physical-type

In the physical-type, elastic substances, such as rubber or urethane, are placed in the pavement flex. As passing vehicles impose loads on the pavement, the resultant flexure of the pavement breaks ice sheets and thus makes it easy to remove the sheets. Some pavements have elastic substances, such as rubber particles, mixed during the preparation process at an asphalt plant. Others have elastic substances filled into the surface of the pavement or placed in grooves cut on the surface or have elastic substances filled into voids of open graded asphalt concrete. Fig. 5

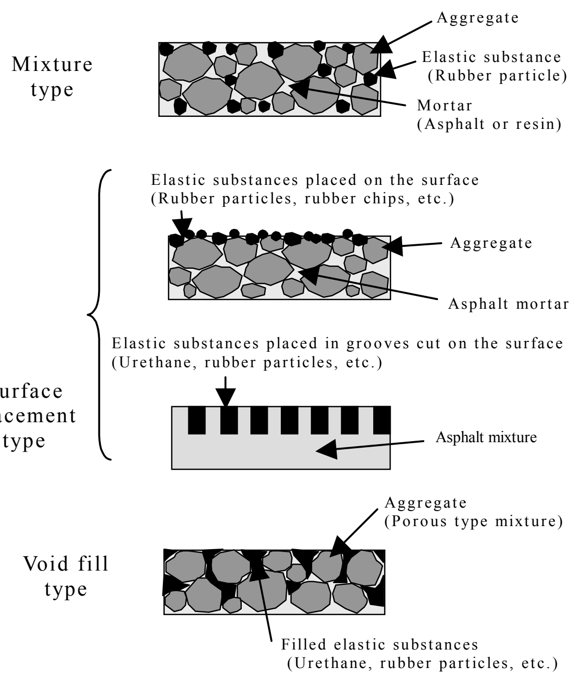


Fig. 5 Conceptual diagram of a typical physical anti-icing pavement

is the conceptual diagram of a typical physical anti-icing pavement.

4.2 Places of application

Anti-icing pavements are not designed to directly control the exposed surface condition of the roads, but they are to support road management in winter for snow removal and scattering of anti-freezing agents. Although it has not clearly identified how to select the type for different conditions, it is often assumed that physical ones are more often used for roads with relatively heavy traffic and chemical ones suitable for roads with relatively light traffic considering the mechanism of anti-icing effect.

Special cases of the application include roads with slopes downward; roads near intersections where vehicles are required to decelerate or stop; roads near entrances or exits of tunnels where the road condition considerably changes; roads the surfaces of which particularly prone to freezing such as those in shadow or bridge deck surfaces; places where using smaller amounts of anti-icing agents is desirable, such as near agricultural fields; and roads subject to chronicle delay in removal work, such as in mountains as well[3)].

4.3 The achievement of the application

The cumulative road surface area using anti-icing pavements is shown in Fig. 6. The anti-icing pavement was put into use around 1985. When manufacturing of studded tires was banned in 1991, the anti-icing paving area appeared a rapid rise, the total paving area in 1999 amounted to about 5 million m^2.

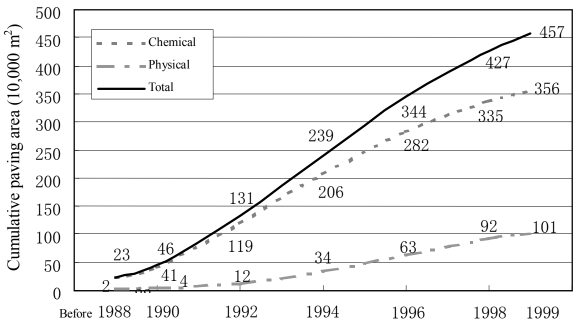


Fig. 6. Cumulative paving area with anti-icing pavements

In general, the road areas covered by chemical pavements are greater than those by physical ones. Since a series of trial experiments of anti-icing pavements in Sapporo, Hokkaido, and other cities, was conducted from 1993 to 1994, physical-type has been began to draw more attention. Thus, roads surfaced by physical-type have been increasing since around 1994. After 1997, about 30 to 40% of the annually paved areas are covered by the physical type.

For cumulative paving areas up to 1999, Tohoku and Chubu are the largest users of anti-icing pavements, totaling over 1 million m^2 for each. The runners-up are Hokkaido, Kanto, Hokuriku, Kinki, and Chugoku in this order.

Although in Kyushu and Shikoku districts, anti-icing pavements have not paved so many, local road managers are considering use of these pavements and the areas covered by such pavements should be increasing.

5. Evaluation of Anti-icing Pavements

5.1 General evaluation method

5.1.1 Laboratory evaluation and problems

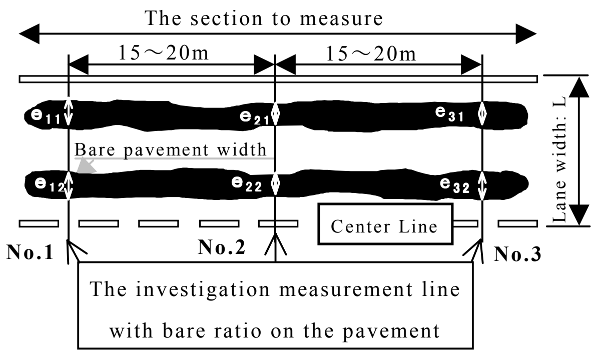
A representative evaluation method adopted in laboratory for the chemical-type one is to measure the saline content released from the pavement. Other methods include the measurement of the ice adhesion strength between the pavement surface and the iced snow layer, and the measurement of skid resistance of the pavement at low temperatures.

The physical-type one is often evaluated by measuring the condition of the pavement under static or dynamic loads, with deformation of the elastic substance taken into consideration. Another method is the measurement of tire torque at low temperatures with a rotational labeling test machine.

There has been much discussion over laboratory evaluation methods without any unified method yet established. There is no quantitative evaluation for anti-icing pavements. One of obstacles to establish a standard method is the unqualified relationship between the actual roads and anti-freezing performance provided by anti-icing pavements.

5.1.2 Field evaluation and problems

The most widely accepted method for field evaluation of anti-icing pavements in Japan is the measurement of the exposed road surface area ratio during the cold, snowy period. An overview of this method is illustrated in Fig. 7.



Bare ratio on the measurement line

$e_1=(e_{11}+e_{12})/L$ $e_2=(e_{21}+e_{22})/L$ $e_3=(e_{31}+e_{32})/L$

The bare ratio on the pavement = $(e_1 + e_2 + e_3) / 3$

Fig. 7 Overview of measurement of exposed road surface ratio [5)]

The procedure for this method is as follows: the target road section is divided at some given intervals for the placement of a measuring point per division; the length of each exposed area is measured during the predetermined length of time for determination of the exposure ratio to the road width; and the total exposure ratio is calculated by averaging the values over all the measuring points. This approach, however, is still based on judgment through a relative comparison and does not produce accurate results in certain conditions, such as the presence of black ice, which defies clear distinction from the exposed surface.

Field evaluation, by nature, has to be made during the cold, snowy period and its results are thus subject to geographical and meteorological conditions. There is no recognition yet among road managers and traffic engineers that this method is capable of providing standardized quantitative results.

5.2 Study of new evaluation methods

Knowing this situation, our group has been engaged in the development of a quantitative evaluation of the performance of anti-icing pavements around the year, both at laboratory and field settings, with a special focus on adhesion between the road surface and iced snow as a key measurement element.

The ice adhesive strength test is intended to provide a measure for adhesion of the ice. The following paragraphs present the study results for identification of test requirements, a preliminary laboratory evaluation in case the test is applied to anti-icing pavements, and cases of field evaluation.

5.2.1 Ice adhesive strength test

One of potential effects of the anti-icing pavement is the ease with which ice comes off the road surface. In the ice adhesive strength test, a jig is frozen fixed to the pavement specimen and the strength of the ice adhesion to the pavement surface is measured as ice adhesive strength. We speculated that measurement of adhesive strength of the ice would lead to quantitative evaluation of anti-icing performance.

Fig. 8 shows how to place the hydraulic tensile test machine and the special jig. For the procedure, unwoven cloth glued to the steel jig should be moistened to saturation and placed on the road surface and frozen at a predetermined temperature.

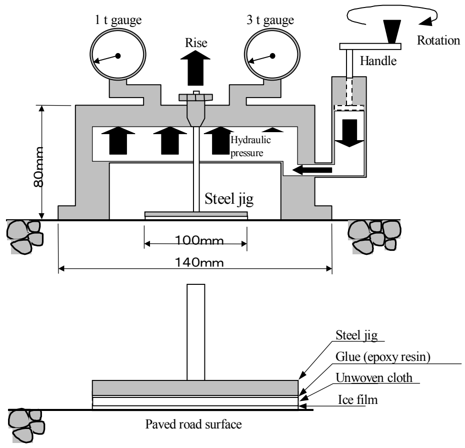


Fig. 8 Overview of ice adhesive strength test [6)]

5.2.2 Fundamental experiment

A fundamental experiment in laboratory was conducted in order to establish an appropriate ice adhesive strength test that can evaluate the performance of anti-icing pavements in the field setting. It is described as follows.

(1) Relationship between temperature and adhesive strength

The purpose of this experiment was to understand the relationship between the test temperature and the adhesive strength of the ice so as to set an appropriate test temperature. The desired test temperature is in the range in which the anti-icing performance is accurately identified.

The test procedure is as follows: to place a specimen of wheel tracking test prepared by using dense grade asphalt mixture 13 mm TOP (herein referred to as "dense grade pavement") in a room with a set, constant temperature; to attach the jig, covered by water-saturated cloth to the specimen for four hours after ensuring the entire specimen has the predetermined temperature; and to set the hydraulic tensile test machine and to measure the adhesive strength. Measurement results at a test temperature of -3°C, - 6°C, and -10°C are for an example shown in Fig. 9.

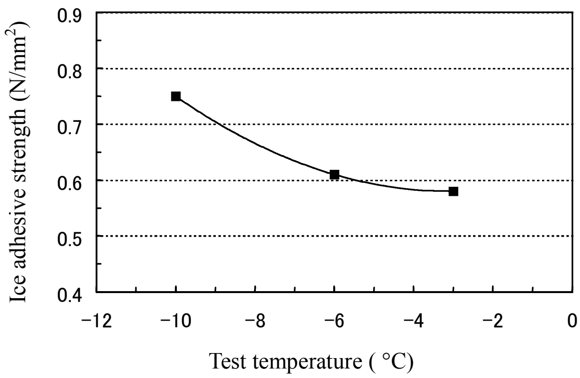


Fig.9 Relationship between test temperature and adhesive strength of ice

As shown by the figure, the adhesive strength increased with the reduction of the temperature. The difference in adhesive strength between -3°C and -6°C is larger than that between -6°C and -10°C. If the difference in adhesive strength in a certain temperature range is taken as temperature susceptibility, then the temperature susceptibility for -3°C to -6°C is smaller than that for -6°C to -10°C. In other words, if the test temperature range for an ice adhesive strength test is set to -3°C to -6°C, it is considered possible to reduce reading errors and lax test requirements.

It should also be noted that the range of test temperature corresponds to what is generally considered to be where the best benefits of the anti-icing pavement are achieved. For the coefficient of variation for adhesive strength at each test temperature, it is 8% for -3°C, 6% for -5°C, and 11% for -10°C. It then follows that variability of test values may be reduced by setting the range at -3°C to -6°C. Based on these results, the test temperature for the ice adhesive strength test was set at the range from -3°C to -6°C.

(2) Effect of cooling time on adhesive strength of ice

In order to check how the cooling time would affect the adhesive strength of the ice after the placing of the measuring jig, the jig was placed on the specimen and the adhesive strength of the ice was measured with changing the length of cooling time. The test procedure used is the same as what was mentioned in the above section, except that the test temperature was set at -3°C and the cooling time at 120 min, 180 min, 240 min, and 300 min. The test results are showed in Fig. 10.

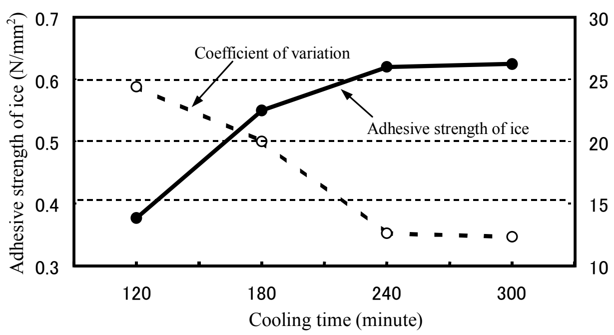


Fig. 10 Relationship between cooling time and adhesive strength of ice

It is indicated in Figure 10 that the adhesive strength tends to increase with the extension of the cooling time and that the increase is insignificant after the cooling time exceeds 240 min. The coefficient of the strength variation decreases with the extension of the cooling time. It is thus determined from the result that the cooling time for adhesive strength of the ice in laboratory testing was set at 240 minutes (4 hours).

(3) Preliminary evaluation of anti-icing pavements

Taking the results of the study above into consideration, it was determined that the test cooling temperature is -3°C, the cooling time 240 minutes, and the handle rotation speed 60 rpm. This setting, which is referred to as "standard test method," was applied to a preliminary evaluation of anti-icing pavements, with its results

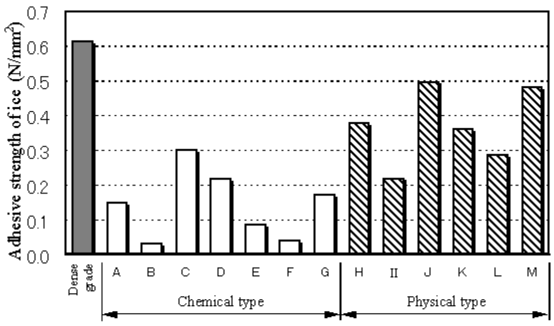


Fig. 11 Adhesive strengths of ice for anti-icing pavements

summarized in Fig. 11.

The adhesive strength of the ice is 0.03 to 0.30 N/mm^2 for chemical type pavements, 0.22 to 0.50 N/mm^2 for physical type pavements and 0.6 N/mm^2 for the dense grade pavement, see Figure 11. These results provide an evaluation of anti-icing performance quantitatively. In general, values of the strengths for physical type pavements are greater than those for chemical ones. It should be noted that when considering how the anti-icing effect works under traffic loads, it was considered necessary to apply loads to the measuring jig in case the test is given to physical type pavements.

(4) Results of fundamental experiment and setting of test requirements

Our group set test requirements for the adhesive strength test through fundamental experiments and conducted a preliminary evaluation of anti-icing pavements in the laboratory setting. As the results indicate, the adhesive strength test is found to be capable of quantitatively indicating the effects of anti-icing pavements. Table 1 shows the test requirements for the adhesive strength test as well as the results of other studies. The cooling time here was set at 4 hours, but when one wants to shorten the cooling time for easier application to actual roads, the suggested practical method for cooling time reduction is to set the cooling temperature to around -10°C first, cure the pavement at a temperature lower than the test temperature, cause the temperature to return to the test temperature, and perform the test. It is also confirmed that this method can ensure the ice adhesive strength of about 0.6 N/mm^2, equivalent to the test value 4 hours later.

Table. 1 Ice adhesive strength test requirements

Items	Requirements
Thickness and material of unwoven cloth	5 mm thick polystyrene span bond unwoven cloth
Load imposed on the jig frozen to the road	Total weight of jig: 1.6 kg (2 kPa)
Water for freezing	Potable water
Test temperature (temperature inside unwoven cloth)	- 3°C to - 6°C
Jig	ϕ 10 cm steel jig with 5 mm thick unwoven cloth glued to it
Handle rotation speed	60 rpm (tension speed 13 mm/min.)
Temperature of cooling room	- 3°C to - 6°C (laboratory test)
Curing time	4 hours

5.2.3 Field evaluation

Reflecting the results of the fundamental laboratory experiment, applicability of the ice adhesive strength test to actual roads was examined. The outline of the test and the evaluation results are summarized below:

(1) Outline of test

A total of six types of pavements were tested for ice adhesive strength. The pavements include two chemical types (C#1 and C#2), two physical types (P#3 and P#4), a water permeable pavement, and a dense grade pavement as a control pavement as well. The test was conducted in the time until the outside temperature was at its lowest, or from the evening to the early morning of the next day. Since the purpose of field test was to check the applicability of the test to actual roads, the test conditions used were equal to those in Table 5.1, which was determined based on the results of the fundamental laboratory test.

The tested roads were constructed in October 1999. Large-scale test vehicles ran on the roads for about three months for the purpose of fundamental investigation into anti-icing pavements. The road surfaces, therefore, were deprived of surface asphalt films, unlike the surfaces of the laboratory test specimens.

(2) Evaluation of the results and discussion

In the ice adhesive strength test, thermocouples were attached inside the unwoven cloth, which formed an ice film, to check the temperature of the ice, or the temperature inside the unwoven cloth, reached - 3°C to - 6°C before commencing the test. Outside air temperature was also measured at the same time.

In this test, even though the outside air temperature dropped to - 4°C, the temperature of the ice in the unwoven cloth did not go below - 3°C. When the outside air temperature went below - 5°C, the ice temperature in the unwoven clothe suddenly decreased to reach the test target temperature of - 3°C to - 6°C. The test continued for about one hour, during which the ice temperature inside the unwoven cloth was kept at - 3°C to - 6°C.

The jig was placed in two ways in order to verify the relationship between the difference in ice formation time and ice adhesive strength, or in the evening of the day before the test and about three hours prior to commencement of the test.

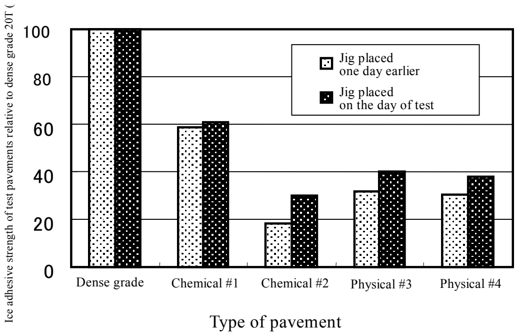


Fig. 12 Ice adhesive strength of test pavements relative to dense grade pavement

Ice adhesive strength of the dense grade pavement was 0.8 to 1.0 (N/mm^2), the value of which is taken as 100. A comparison of the adhesive strength with those of other pavements is shown in Fig. 12. The adhesive strength of anti-icing pavements is all smaller than that of the dense grade pavement, or about 20 to 60% of the latter. As with the fundamental test in laboratory, anti-freezing performance is considered to be sufficiently evaluated. Unlike the laboratory test, the ice adhesive strength of the dense grade pavement is slightly larger, which is presumed to be due to the difference in asphalt films.

It is therefore concluded that the ice adhesive strength as measured by the ice adhesive strength test is capable of evaluating the anti-freezing performance of anti-icing pavements.

For the relationship between the difference in ice formation time and the ice adhesive strength, the strength transpired to be greater in the case of jig placement about three hours earlier than in the case of jig placement one day earlier for extension of ice formation time. As a result of observation of the post-test condition of ice formed in the unwoven cloth, the surface of the ice formed since a day earlier was apparently rougher than that of the ice formed on the day of the test. This is probably because of evaporation of water during the extended process of ice formation. Therefore, in cases where it is known to take a long time to form ice, measures should be taken to refill water or prevent water evaporation.

6. Conclusions

Conclusions of this report are as follows:

(1) Japan has climatic conditions unique to its own: it has more snowfall with relatively higher temperatures than major cities overseas.

(2) Anti-icing pavements used in Japan are categorized into chemical type and physical type. At the end of 1999, anti-icing pavements have been constructed 4,570,000 m^2 in the road area, 80% of which are chemical type pavements.

(3) When anti-icing pavements applied to roads are evaluated, it has to be carried out mainly in the cold, snowy period. Evaluation results are therefore often greatly influenced by geographic or meteorological conditions. There has not been any quantitatively unified evaluation established so far.

(4) Test requirements for laboratory were determined, as shown in Table 5.1.

(5) The adhesive strengths of the ice on actual roads are almost equal to those obtained in laboratory.

(6) Test of ice adhesive strength is capable of evaluating quantitatively anti-icing pavements.

It is necessary to examine further by gathering more data that whether it is possible to evaluate anti-icing performance equally in laboratory and in the field in the future. The authors are currently developing a device capable of performing through the year ice adhesive strength tests regardless of outside air temperatures by cooling the road surface. The performance of an anti-icing pavement immediately after its construction is evaluated by the proposed test. The authors hope to develop a fully established method to conduct a quantitative evaluation of the performance of anti-icing pavements through the improvement of the test device.

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