Towards Sustainable Winter Road Maintenance: Development of Ice-breaking Pavement

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ABSTRACT

In recent years, the effects of climate change have become more pronounced worldwide, even in winter. Severe snowfall afflicts northern Europe; the coldest winter in thirty years was recorded in eastern Asia. As regards roads, conventional anti-icing measures using chemicals such as salt tend to exhibit declining performance over time. Therefore, winter road maintenance is an important challenge, in terms of both sustainability and road safety. In order to tackle this problem from a paving perspective, ice-breaking pavement technology has been developed to achieve the following benefits: prevention of ice build-up on roads, mitigation of environmental impact, and reduction in traffic accidents. This paper describes the practical and environmental effects of ice-breaking pavement technology through its development and application, with the following conclusions being drawn from this study. With regard to serviceability, laboratory and field tests show that any ice forming on the road surface is effectively crushed due to the flexing of rolled rubber aggregate chips at the surface. In terms of practical considerations, a computer simulation using Finite Element analysis explains the mechanism for the ice-layer breakage and the design details, such as the appropriate amount of rubber aggregate to use. Finally, field monitoring reveals that the ice-breaking pavement retains good surface condition and performance even after three years, and it is likely to be useful in mitigating environmental damage, as no chemicals are applied to the road surface.

KEYWORDS

CLIMATE CHANGE; ROAD MAINTENANCE; ICE-BREAKING; SUSTAINABILITY

1. INTRODUCTION

In order to prevent health hazards from particles caused by studded tires wearing out the pavement, the use of studded tires on vehicles has been restricted from 1992 in Japan. Since then, the studless tire has replaced the studded tire. However, to assure traffic safety, lower road maintenance costs, and preserve the roadside environment (i.e. reduce the usage of salt), etc., anti-freezing pavements have been developed in Japan [1, 2].

From the mid 1970s, anti-freezing pavement with physically flexible materials, meaning composite pavement including rubber particles, have been introduced. Anti-freezing pavement with rubber particles is pavement using hot asphalt mixture with rubber particles added. The anti-freezing function works by transforming the overall thickness of the surface course through the stress induced by the traffic load, which increases stress in the ice on the pavement surface, so that cracks develop in the ice. Once cracked, the ice on the pavement surface where the rubber particles are exposed will be exfoliated from the surface, because the adherent strength of rubber and ice is less than that of the asphalt and ice. Increasing the amount of rubber particles mixed into the asphalt enhances the deflection of the surface course, thus promoting the anti-freezing effect [3]. However, if too many rubber particles are mixed in, it becomes difficult to compact the hot asphalt mixture, and the strength and durability of the pavement is significantly compromised.

Ice-breaking Pavement has been developed to solve this problem. In this pavement, rubber aggregate chips of approximately 20-mm diameter are used. This pavement is constructed by rolling the rubber aggregate chips on the spread hot asphalt mixture, to create a surface with exposed rubber aggregate. This pavement does not use rubber particles, but instead rubber aggregate chips, and does not mix the rubber aggregate into the asphalt mixture, but exposes them to the surface of the pavement.

Details of the design and the introduction of some features on a recent application are shown in Figure 1.

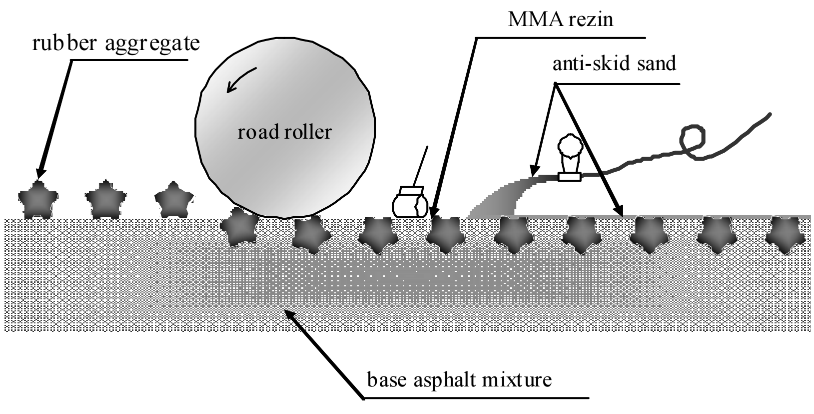


Figure 1 – Conceptual diagram of Ice-breaking Pavement

2. DESIGN

2.1 Base Asphalt Mixture

The Ice-breaking Pavement uses the surface course of the asphalt pavement as its base. It has the same standard 5 cm thickness as the typical surface course in Japan. In terms of binder, usually, a polymer-modified asphalt is used for greater durability. However, in the case of lower traffic volume roads, straight asphalt 40/60 is also used. In addition, the aggregate and filler should meet the quality standard listed in the pavement construction manual (see Table 1).

Table 1 – Quality standard of materials

Material	Quality standard
Polymer-modified asphalt Type II Petroleum asphalt for roads 40~60	Standard properties or quality standard described in Pavement construction manual
Course aggregate • Fine Aggregate • filler	

Table 2 shows an example of a base asphalt mixture. Table 3 indicates the properties of the mixture using polymer-modified asphalt.

Table 2 – Mixing example of base asphalt mixture

Materials	Design Ratio (%)
Single-sized crushed Stone S-20 (Grade 6)	20
Single-sized crushed Stone S-13 (Grade 5)	20
Fine sand	50
Mineral filler	10
Asphalt	7.0 – 9.0

Table 3 – Example of properties of Marshall test

Density (g/cm^3)	Air Void (%)	Degree of saturation (%)	Marshall stability (kN)	Flow value (1/100 cm)
2.320	3.7 (3 – 7)	82.0 (70 – 85)	9.73 (More than 4.9)	47 (20 – 50)

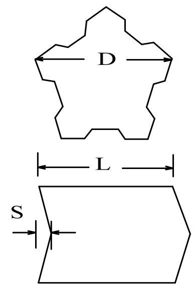
( ): Target Value

2.2 Rubber Aggregate

2.2.1 Specifications

Table 4 shows the specifications of the rubber aggregate used in Ice-breaking Pavement. The rubber aggregate is coated with asphalt to ensure good adhesion with the base asphalt mixture.

Table 4 – Specifications of rubber aggregate

Item	Specification	Remarks
Shape	Special pentagonal prism	
Diagonal length D (mm)	20.0±2.0	
Length L (mm)	22.0±5.0	
Ruggedness Length S (mm)	2.0±1.0	
Material	SBR special rubber Recycled rubber powder is partly used.	
Hardness of rubber	70-90 JIS K 6301(A Sclerometer)	

Note: The rubber aggregate is pre-coated with straight asphalt or modified asphalt emulsion.

2.2.2 Shape

The rubber aggregate is shaped in the form of a pentagonal prism. In the early development of Ice-breaking Pavement, the adhesion of the rubber to the asphalt was insufficient and there were concerns that the rubber aggregate would be exfoliated and be scattered when subjected to repeated traffic loads. Various shapes were used in testing the fretting resistance and area of exposure of each shape. After a comprehensive evaluation, the shape adopted was one that approximates that of a pentagonal prism (Figures 2 and 3).

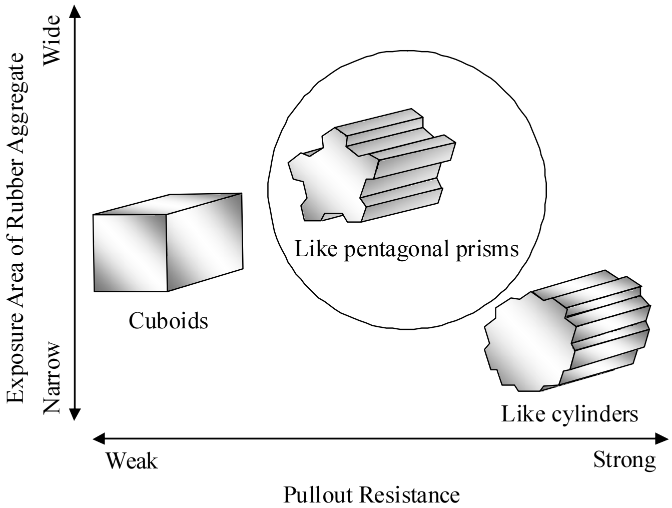


Figure 2 – Relationship between pullout resistance and area of exposed rubber aggregate

Figure 3 – Pentagonal rubber aggregate

2.2.3 Material

In the development stage, the chosen rubber material was made of ethylene propylene rubber (EPDM) in consideration of its weatherproofing qualities. However, as there was a problem with the rubber hardness and anti-wearing qualities of EPDM, styrene-butadiene rubber (SBR) was instead chosen for usage. Table 5 shows a comparison between the two types of material. Since it is acknowledged that SBR can be improved to be approximately three times harder and more flexible than EPDM, which therefore has greater workability in a test construction, SBR (consisting of partially recycled rubber) is mainly used in practice.

Table 5 – Comparison table of rubber materials

Main raw material		EPDM	SBR	Test Methods
Specific gravity		1.30	1.35	JIS K6301
Hardness		84 – 88	80 – 86	JIS Hardness (A) JIS Hardness Meter
Modulus of Elasticity (Theoretical value)		About 5 MPa	About 4 MPa	Calculated from Hardness
Embedded performance		Good	Good	Practice
Remarks	Wear resistance	Better	Good	JIS K6264
	Weather Proofing	Good	Better	JIS K6266

2.3 Amount of Rubber Aggregate Chipping

The amount of rubber aggregate chipping has been set from 1.6 – 2.0 kg/m^2. However, the amount used was mostly around 2.0 kg/m^2 in practice.

2.3.1. Anti-Freezing Mechanism of Ice-breaking Pavement

The assumed anti-freezing mechanism of Ice-breaking Pavement is shown in Figure 4. Due to the weight load of passing vehicles, bending failure of the ice between the rubber aggregate chips occurs. The ice is crushed and scattered by repeated loads, which partially exposes the road surface. The remaining ice is likewise compressed, impacted and broken up by friction gradually exposing the road surface.

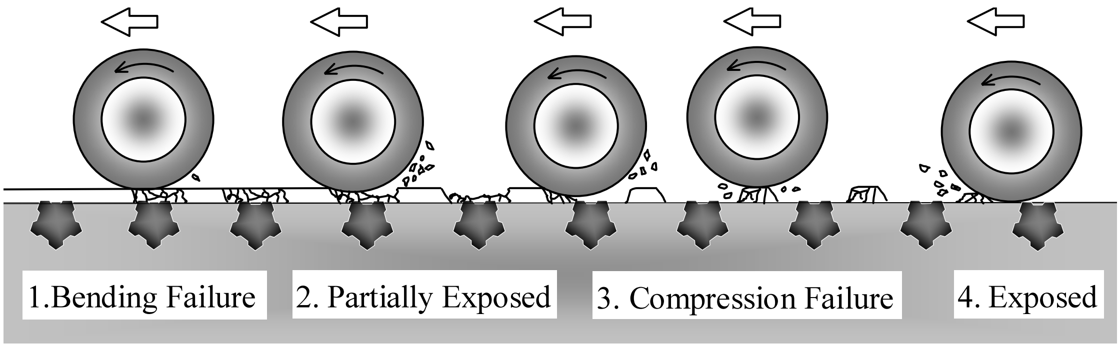


Figure 4 – Assumed Mechanism of Anti-freezing

2.3.2. Range of Bending Failure using Finite Element Analysis

Figure 5 shows the supposition of a FEM model [4]. Using the wheel load of a large commercial truck, a stress analysis on the analysis range (half the width from the centre of the rubber aggregate) of the ice surface was conducted. The load range for the position of the passing tires was considered to be random, and the area of the rubber aggregate was half. Although with actual traffic, there would be different multiple repeated loads, this analysis presents the results of a single load.

Figure 6 shows the distance between the rubber aggregate chips and the tensile failure stress of ice at 1.0 MPa [5]. As can be seen from the result, the rubber aggregate exhibited the failure point at the centre. According to Figure 6, if the distance between the rubber aggregate chips laid on the road surface is within 65 mm, it was determined that the tensile strength would cause a general breaking up of the ice. If the distance between the rubber aggregate chips were 85 mm, a 33 mm distance between the centres of the adjoining rubber aggregates would result in a bending failure leaving an 85 – 33 × 2 = 20 mm lump of ice in the centre.

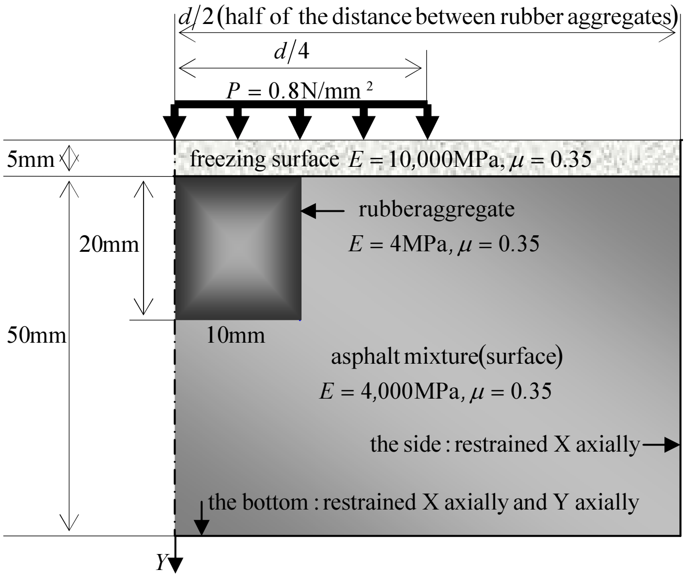


Figure 5 – Analytical FEM model

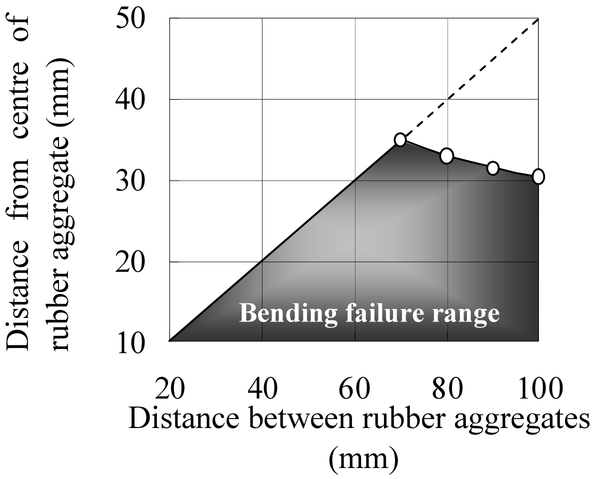


Figure 6 – Range of freezing bending failure

2.3.3. Compression Failure

The impact of a passing tire over a lump of ice on the road surface is also considered. However, a study to calculate the area of the ice broken up was conducted using working compression only. Based on an area of ice lump A, with a wheel load of a passenger car at 2.500 kN and compression failure stress of 6,000 kN/m^2, our equation is:

$$A = 2.5\text{kN} \div 6{,}000\text{kN/m}^2 = 0.00042\text{m}^2$$

If the ice lump is circular, the diameter would be 23 millimetres.
In the case of bending failure, Figure 6 assumes the wheel load of a large truck. A certain amount of wheel load is needed; however compression failure of a lump of ice depends on the size of the lump and will occur even with a passenger car.

2.3.4. Practical considerations

Based on the area of bending failure and compression failure as stated in the above paragraphs, it was decided that the appropriate distance between the rubber aggregate chips should be 85 mm. (The bending failure distance with a large vehicle at 33 mm × 2 and compression failure with a passenger car at 22 mm.) The distance of such rubber aggregate chips is shown at 1.6 kg/m^2. 1.8 – 2.0 kg/m^2 as the chipping amount was adopted for the design value. This chipping amount is calculated based on the bending failure caused by a large vehicle. The construction experience of a route with a lower traffic volume uses a chipping amount of approximately 2.5 kg/m^2.

3. CHARACTERISTICS OF ICE-BREAKING PAVEMENT

The Ice-breaking Pavement characteristics are shown below [6].

(1) Anti-freezing surface

The size of the rubber aggregate chips is large, and their shape greatly deforms with the passing traffic. Moreover, a wide area is affected which makes it easy to fracture the freezing layer. Therefore, it is difficult for any snow to freeze as ice and any freezing layer is easily exfoliated on the exposed area of a large surface course on a pavement consisting of rubber aggregate chips with low bond strength (see Figure 7).

Figure 7 – Comparison between Ice-breaking Pavement and normal pavement with snow

(2) Continued effectiveness

In the case of anti-freezing pavement dependant on chemicals, the anti-freezing effect diminishes with the elution of salt in the pavement. However, since Ice-breaking Pavement is physically flexible, the anti-freezing effect continues throughout the pavement's life.

(3) High durability

Due to the structure of the rubber aggregate scattered close to the surface, compared with the type that uses rubber particles in the mixture, there is no difficulty with rolling, and enough compaction for the asphalt mixture can be obtained.

(4) Protecting the environment

Ice-breaking Pavement eliminates the need to scatter salt in winter. This better preserves any bridge deck structures as well as the roadside environment.

4. CASE STUDY

4.1 Construction site

Ice-breaking Pavement is applied on an expressway where the designed speed is 80 km/h. The area is the Shitosaka Toge Road in the mountainous region of Tottori Prefecture (which traverses 86.5 km of the central section of the Chugoku Transversal Expressway as shown in Figure 8). Annual cumulative snowfall is forecast at more than three meters. The standard measure for removing snow and ice on the expressway is to spray a snow-melting agent and the use of snow removal equipment. However, in order to avoid the use of salt which pollutes the roadside environment and to lower maintenance costs, Ice-breaking Pavement was applied at this site [7].

4.2 Construction overview

As shown in the construction overview table below, Ice-breaking Pavement was applied to 1,147 m of the main line ramp and 2,094 m of the access road.

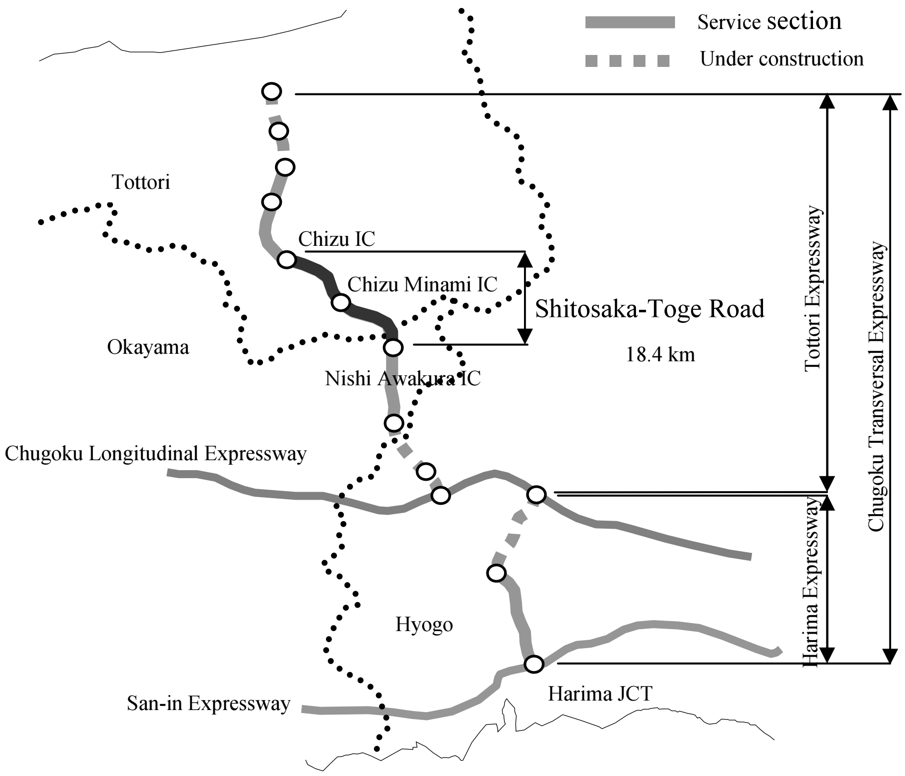


Figure 8 – Location map

Table 6 - Construction overview

Name of Works		Shitosaka Toge Road Chizu Pavement Works	Shitosaka Toge Road Chizu 2 Pavement Works
Construction Period		March 16 ~ December 22, 2007	June 26, 2007 ~ March 13, 2008
Ice-breaking Pavement Area	Total	12,410 m^2	9,820 m^2
	Earthwork	Main line & ramp: 9,320 m^2	Main line & access: 5,480 m^2
	Bridge	Main line: 3,090 m^2	Main line & access: 4,340 m^2
Width		Pavement width = 7 m (3.5 m $\times$ 2)	

4.3 Construction process

The construction process for the Ice-breaking Pavement is the same as that to construct rolled asphalt pavement. The base asphalt mixture is spread using an asphalt paver. The rubber aggregate chips are spread over the asphalt surface mainly using a vibrating roller with the chipping device in front of it. As the rubber aggregate is chipped and spread over the hot asphalt mixture, it is simultaneously rolled into the asphalt by a road roller. Finally, intermediate rolling of the pavement is conducted with a pneumatic tire roller.

Figure 9 shows the construction of a bridge section. In the case of an earthwork section, normal sized rubber aggregate is used. However, in the case of laying on a bridge surface, as the asphalt mixture is designed to be laid at a thickness of 4 cm, a special sized rubber aggregate (L=18 mm, D=16 mm) is used. The chipping amount for the special rubber aggregate is set to provide the same exposure area as that of standard rubber aggregate.

Because such construction tends to be in autumn, a measure to account for the temperature drop in the hot asphalt mixture is to add an additive for warm mix asphalt at 3 kg/ton. This assures easy rolling of the rubber aggregate chips.

Spreading | Chipping and breakdown rolling | Intermediate rolling

Figure 9 – Paving of Ice-breaking Pavement

The surface is dressed with Methacrylic Resin (MMA) to suppress any scattering of the rubber aggregate chips by the action of the snow removal equipment in winter. In this construction, the undercoating is done by a rubber rake and brush rollers, and a spray gun is used for the top coating. It was determined by pre-construction testing to use an undercoating of 0.3 kg/m^2 of MMA resin and a top coating of 0.2 kg/m^2 of MMA resin and a dispersion amount of 0.6 kg/m^2 of anti-skid fine aggregate.

Undercoat Spraying anti-skid sand Top coating

Figure 10 – Surface dressing using MMA resin

4.4 State of usage

Figure 11 (a) shows a road during winter. As can be seen from the figure, traffic disperses the snow. Figure 11 (b) presents an enlargement of the surface of Ice-breaking Pavement. Figure 11 (c) was taken at the same time as Figure 11 (b) showing the condition of dense-graded asphalt concrete. The snow in Figure 11 (b) has turned to slush, but in Figure 11 (c) it has frozen solid on the pavement. One winter has passed since the opening of the road, but the scattering of rubber aggregate chips on a curve in the road is minimal, and the overall road condition is satisfactory. Moreover, as there have been no traffic accidents caused by frozen conditions since the road opened, the anti-freezing effect is considered effective.

(a) Surface after snowing (b) Ice-breaking Pavement (c) Normal Pavement

Figure 11 – Snow on pavement

5. Driving Comfort

Skid resistance and roughness are important factors affecting driving comfort, especially on winter roads. In addition, these two factors are closely related to traffic safety, as well as drivability. Therefore, it is vital to ensure good skid resistance and roughness after laying the Ice-breaking pavement. In order to confirm these factors, follow-up surveys were conducted to examine these two factors.

5.1 Skid resistance

Figures 12 and 13 show the skid resistance value measured, using a British Pendulum Tester and Dynamic Friction tester (DF tester) at a jobsite [8]. The tests were conducted in accordance with Japanese pavement standard S021-2 and ASTM E1911, respectively [9, 10]. As can be seen from the Figures, the Ice-breaking Pavement recorded a British Pendulum Number (BPN) score of more than 60, with coefficient of Dynamic Friction above 0.40. This trend remains consistent even after a year from the construction. Therefore, it can be said that driving on the Ice-breaking Pavement is safe.

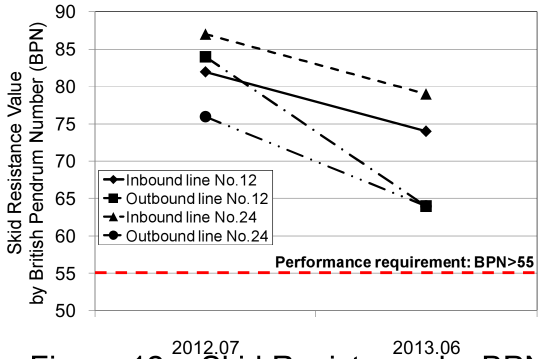


Figure 12 – Skid Resistance by BPN

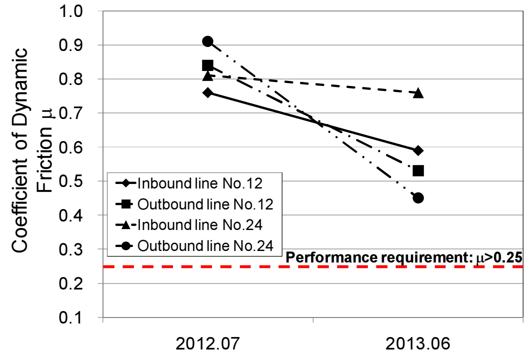


Figure 13 – Skid Resistance by DF tester

5.2 Roughness

When laying the Ice-breaking Pavement, there are some concerns about the rubber aggregate, because it may diminish the roughness of the surface. In order to understand the surface profile, the roughness was measured using a three-meter profile meter [11].

Figure 14 presents the roughness of the Ice-breaking Pavement at four sites. From the results, it was found that the four sites meet the standard requirement which is below 2.4 mm in standard deviation. Accordingly, it can be said that the surface of the Ice-breaking Pavement is almost identical to that of conventional pavement, in terms of roughness.

Table 7 – Roughness of the Ice-breaking Pavement

Jobsite	Roughness σ (mm)	Performance requirement
Site A	1.60 - 1.90	Less than 2.40
Site B	1.72	
Site C	1.50	
Site D	1.40 - 1.60	

6. TRAFFIC ACCIDENTS

According to a survey by a local government, the application of Ice-breaking Pavement appears to contribute to a reduction in traffic accidents. Comparing before and after the application, the number of traffic accidents on the Ice-breaking Pavement was less than on conventional pavement. Considering that traffic accidents in winter are mainly caused by icy conditions, this technology may be an effective means of reducing such statistics.

7. COST EFFECTIVENESS

In Japan, the total area of Ice-breaking Pavement constructed now exceeds 180,000 m^2. Also, its application in cold regions has been increasing not only for trunk roads, but also on bridge decks. Although Ice-breaking Pavement has been widely constructed, the drawback of this technology is the cost. The construction costs for the surface are almost the same or slightly more than dense-graded pavement. Some clients apply this technology in the hope of mitigating the effects of climate change; others are deferring its application due to the cost. Indeed, some cannot afford to treat existing surfaces at all because of the recent financial climate.

However, if we consider its advantages, the reduction in snow accumulation may prove to be a highly effective means of reducing the total life cycle costs of asphalt pavement, compared to applying chemicals. As described above, it can reduce ice formation as well as snow accumulation; the resin coating can also serve as surface reinforcement; and avoiding the use of chemicals may also contribute to delaying the aging of asphalt binder. If its effectiveness both environmentally and in terms of life cycle costs is proved, it may lead to more use of the technology, which may contribute to further cost reductions. Therefore, further investigations targeting both the environmental effect and life cycle costs need to be conducted for the future.

8. CONCLUSIONS

This paper presents the development and application of Ice-breaking Pavement. Based on results in the field, the following conclusions can be drawn:

- With regard to serviceability, laboratory and field tests show that any ice forming on the road surface is effectively crushed due to the flexing of rolled rubber aggregate chips at the surface.
- In terms of practical considerations, a computer simulation using Finite Element analysis explains the mechanism for fracturing the ice layer and the design details, such as the appropriate amount of rubber aggregate to use.
- With respect to the application, field monitoring reveals that the ice-breaking pavement retains good surface condition and performance even after three years; and it is likely to be useful in mitigating environmental damage, as no chemicals are applied to the road surface.
- This technology may be effective in minimising traffic accidents during winter, as the number of traffic accidents was reduced, when compared to conventional asphalt pavement in the local region.

REFERENCES

1. Inaba, N. (2006) About the consideration and the countermeasure of Gum-Rolled. proceedings of the 10th Hokuriku Road Conference (in Japanese).
2. Ando, M. (2009) Application example to expressway in anti-freezing pavement. Proceedings of the 11th Hokuriku Road Conference (in Japanese).
3. Kasahara, A., Uchida, S., Matsuo, H., Ichihara, T. (1997) Development of Gum-rolled Asphalt and Application Example, Journal of Pavement, Vol. 32-9, pp. 15-21 (in Japanese).
4. Yoshi, H. (1997). Anti Freezing Effect of Rubber-mixed Low Noise Pavement, Vol. 32-9, pp. 29-33 (in Japanese).
5. Nishizawa, T., Kameda, K., Fujita, Y., Murai, S. (1995) Anti Freezing Effect of Rubber-mixed Asphalt Pavement, 50th Annual Conference of Japan Society of Civil Engineers (in Japanese).
6. Ohashi, N., Hamaguchi, M., Taniguchi, T. (1993) On the Anti Freezing Mechanism of Lubit Pavement, 20th Japan Road Conference, Pavement section, pp. 754-755 (in Japanese).
7. Maeno, N., Kuroda, T. (1986) The Structure and Physical Properties of Snow and Ice, Kokon Shoin (in Japanese).
8. Matsumoto, M., Ishida, M., Sanpei, T. (2013) Report on Long-term Performance of Anti-freezing Pavement with Physically Flexible Materials, 30th Japan Road Conference, 2031 (in Japanese).
9. Japan Road Association (2007) Method of Measuring Surface Frictional Properties Using the British Pendulum Tester, Reference Book for Pavement Testing and Investigation, pp.92-97 (in Japanese).
10. ASTM E1911-98 (2002) Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester.
11. Japan Road Association (2007) Method for Measuring Roughness of Pavement Surface, Reference Book for Pavement Testing and Investigation, pp.147-156 (in Japanese).