Anti-Freezing Pavement Using Hot Rolled Asphalt Technology

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ABSTRACT: Anti-freezing pavements with rubber particles and those with chemical materials were introduced from Europe and have been widely constructed in Japan since the 1980's. However, the anti-freezing pavements with rubber particles have less durability because they incorporate soft materials in their whole surface course layer. The anti-freezing pavements with chemical materials will lose their effect in process of time. To solve these problems, we developed a new type of anti-freezing pavement with physically flexible materials, the Gum Rolled Asphalt. It is a kind of hot rolled asphalt pavement in which special synthetic rubber aggregates are used for chipping. As the synthetic rubber aggregates cannot adhere to ice easily, the anti-freezing function of the Gum Rolled Asphalt can be achieved through promoting the flaking off of the ice layer on the aggregates which have been crushed by passing vehicles. In the paper, we describe the details of the pavement, including anti-freezing details of design and a recent application to national highway.

KEY WORDS: Rubber aggregate, design, development, construction

1. INTRODUCTION

In Japan from 1992, in order to prevent health hazards from dust caused by studded tires wearing out the pavement, the use of studded tires on vehicles has been restricted. Since that time, the studless tire has replaced the studded tire. However, in order to assure traffic safety, lower road maintenance cost, and preserve the roadside environment (i.e. reduce the usage of chloride), etc., anti-freezing pavements have been utilized.

From the latter half of the 1970s, anti-freezing pavement with physically flexible materials, meaning pavement composite with 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 is to transform the overall thickness of the surface course by the stress caused by the traffic load, which increases stress in the ice on the pavement, eventually forming cracks in the ice. After the cracks form, the ice on the pavement surface where 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 in the asphalt mixture enlarges the deflection amount of the surface course and the anti freezing effect becomes greater. However, if too much rubber particles are mixed, it becomes difficult to compact the hot asphalt mixture, and the strength and durability of the pavement is significantly lowered.

Anti-freezing pavement with rubber aggregate was developed in 1994 for the purpose of increasing the anti-freezing effect and insuring the stability of the asphalt mixture for anti-freezing pavement. In the pavement, rubber aggregates of the equivalent size of 20 mm

are used. This pavement is constructed with rolling chipping rubber aggregates on the spread hot asphalt mixture, to construct the surface where rubber aggregates are exposed. This pavement does not use rubber particles but uses rubber aggregates, and does not distribute the rubber aggregates into the asphalt mixture but exposes them to the surface of the pavement. (See Figure 1)

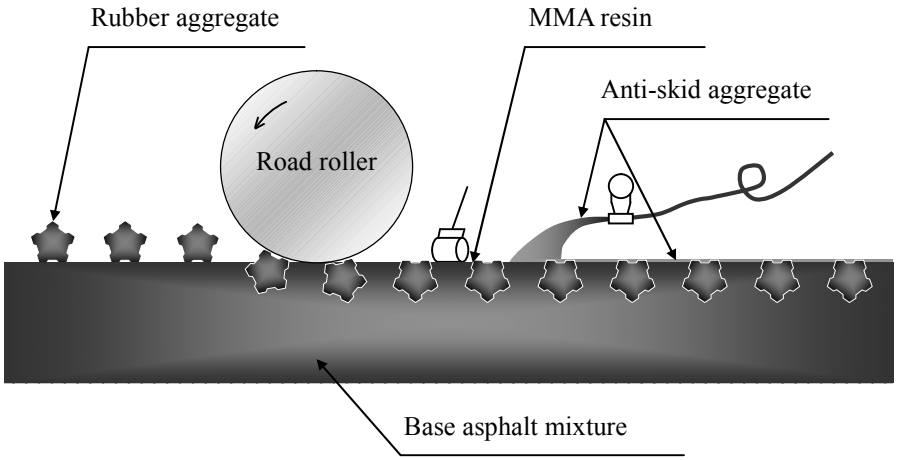


Figure 1: Conceptual diagram of Gum-Rolled asphalt

The English word “rubber” is pronounced [gɔmu] in Japanese. Therefore, we are calling the construction of anti-freezing pavements with rubber aggregates, “Gum-Rolled asphalt.”

Details of design and the introduction of some features and a recent application are shown as follows.

2. DESIGN

2.1 Base Asphalt Mixture

The Gum-Rolled method uses the surface course of the asphalt pavement. It has the same standard 5 cm thickness of the typical surface course in Japan. The binder using of the base asphalt mixture is made of a large proportion of polymer-modified asphalt type II in consideration of its fluidity resistance and its aggregate grip strength. However in the case of a relatively lower traffic volume, the use of petroleum asphalt penetration 40-60 is also used. Moreover, the aggregate and filler meet the quality standard listed in the Handbook of Pavement Construction (Table 1).

Table 1: Quality standard of materials

Material	Quality standard
Polymer-modified asphalt Type II Petroleum asphalt for road 40～60	Standard properties or quality standard described in the Handbook of Pavement Construction (the Japan Road Association)
Course aggregate・Fine Aggregate・filler	

Table 2 shows an example of a base asphalt mixture. Table 3 shows the properties of the mixture in which a binder uses polymer-modified asphalt type II.

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 (1/100cm)
2.320	3.7 （3～7）	82.0 （70～85）	9.73 （4.9以上）	47 (20～50)

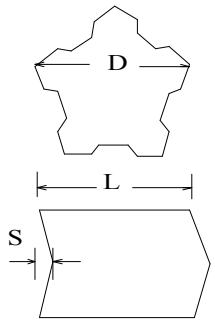
（）:Target Value

3.2 Rubber Aggregate

1) Specification

Table 4 shows the specifications of the rubber aggregate used in the Gum-Rolled asphalt.

Table 4: Specification 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 The recycled rubber powder is used for part.	
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) Shape

The rubber aggregate is shaped in the form of a pentagonal prism. In the early development of Gum-Rolled asphalt, the adhesion of the rubber with asphalt was not sufficient and there was concern that the rubber aggregate would exfoliate and be scattered when subjected to the force of passing vehicles. Various shapes were used 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 (Kasahara, 1997). (See Figure 2)

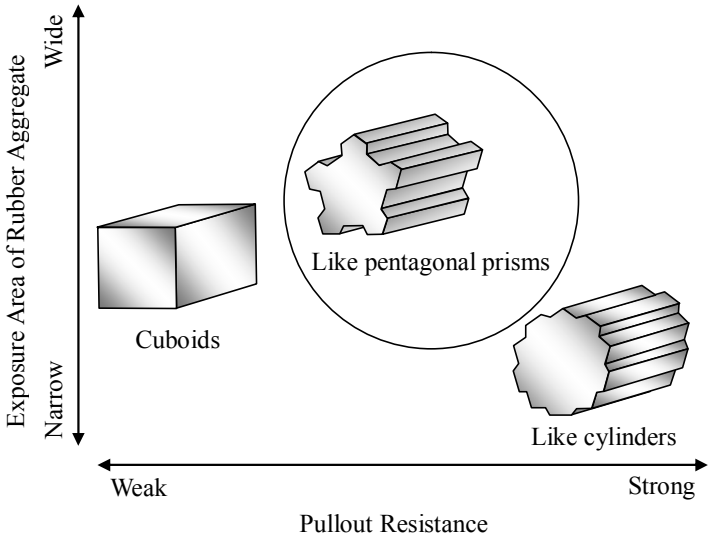


Figure 2: Relation between pullout resistance and exposure area of rubber aggregate

3) Material

In the development stage the chosen rubber material consisted of EPDM (ethylene propylene rubber) in consideration of its weather proofing qualities. However, because there was a problem with the rubber hardness and anti-wearing qualities of EPDM, SBR (styrene-butadiene rubber) was instead chosen for usage. Table 5 shows a comparison table of the two types of material. Because it has been acknowledged that SBR can be improved to be approximately 3 times harder and flexible than EPDM which therefore has greater workability in a test construction, SBR (consisting of partially recycled rubber) is used.

Table 5: Comparison table of rubber material

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 (Theory value)		About 5MPa	About 4MPa	Calculated from Hardness
Performance embedded		Good	Good	Practice
Remarks	Wear resistance	Better	good	JIS K6264
	Weather proofing	Good	Better	JIS K6266

3.3 Chipping Amount of Rubber Aggregates

The chipping amount of rubber aggregates have been set from 1.6～2.0kg/m2, however they are mostly around 2.0kg/m2. We shall present the examination used in order to determine the volume of the chipping rubber aggregate (Inaba, 2006).

1) Anti-Freezing Mechanism of Gum Rolled Asphalt

The supposition of anti-freezing mechanism of Gum Rolled is shown in figure 3. Due to the weight load of passing vehicles, bending failure of the ice between the rubber aggregates occurs. The ice is crushed by repeated load and scattered which partially exposes the road

surface. Remaining ice is likewise compressed, impacted and broken up by friction gradually exposing the road surface.

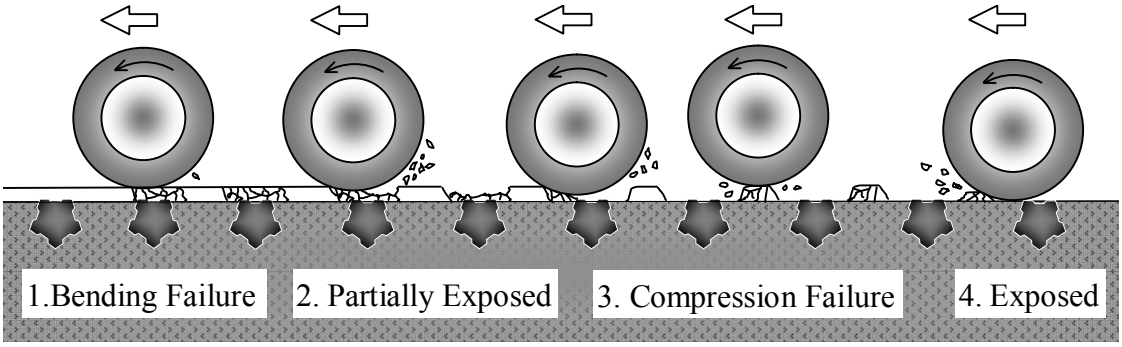


Figure 3 Assumption Mechanism of Anti-freezing

2) Range of Bending Failure

Figure 4 shows a supposition of the FEM model. Using the wheel load of a large commercial truck, a stress analysis on the analysis range (½ the width from the center of a rubber aggregate), of the ice surface was conducted. The load range of the position of passing tires was considered to be random, and the area of the rubber aggregates was ½. In an actual traffic there would be different multiple repeated loads but this analysis presents the results of a single load.

In figure 5, the distance between the rubber aggregates and the tensile failure stress of ice at 1.0MPa (Maeno, 1986) at the center of the rubber aggregates is plotted showing as the failure point. According to figure 5, if the distance between the rubber aggregates laid on the road surface is within 65mm, it was determined that the tensile strength would cause an overall breaking up of the ice. If the distance between the rubber aggregates is 85mm, a 32.5 mm distance between the centers of the adjoining rubber aggregates would result in a bending failure leaving an 85-32.5×2≒20mm size chip of ice in the center.

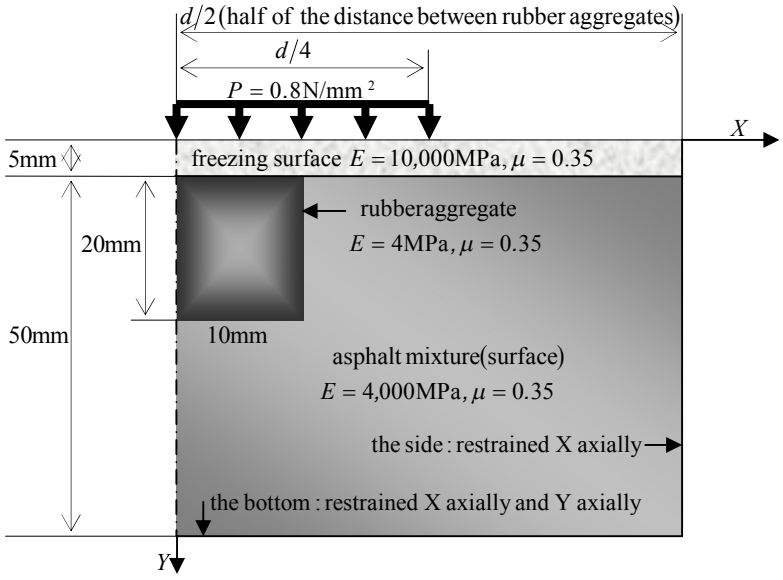


Figure 4 Analytical FEM model

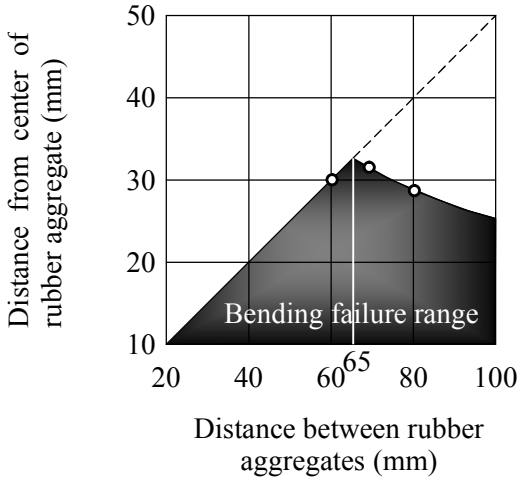


Figure 5: Range of freezing bending failure

3) Compression Failure

The impact of a passing tire over a chip 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. The area of ice lump (A), with a wheel load of a passenger car at 2.500kN and the compression failure stress of 6,000kN/m2 (Maeno, 1986), our equation is:

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

If the ice chip is a circle, the diameter would be 23 millimeters.

In the case of bending failure, figure 5 assumes the wheel load of a large truck. A certain amount of wheel load is needed; however the compression failure of a chip of ice is according to the size of the chip and will occur even with a passenger car.

4) Conclusion of Consideration

According to the area of bending failure and compression failure as stated in the above paragraphs, it was decided that the appropriate distance of the rubber aggregates should be 85mm. (The bending failure distance with a large vehicle at 32.5mm×2 and the compression failure of a passenger car at 23mm.) The distance of such rubber aggregates shown at 1.6kg/m^2. 1.8～2.0kg/m^2 of the chipping amount was adopted for the design value. This chipping amount is calculated with the consideration of 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 2.5kg/m^2.

3. ADVANTAGE

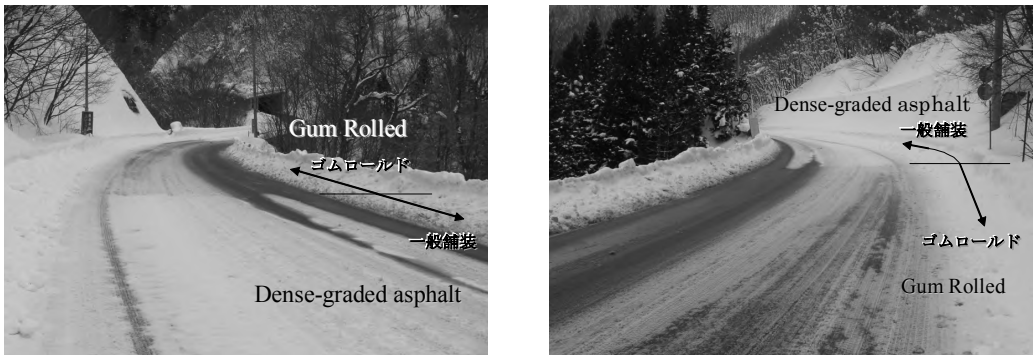
The characteristics of the Gum Rolled method are shown below.

1) A frozen surface is hard to occur. (Photograph 1)

The size of the rubber aggregate is large, and the shape of the rubber aggregates greatly deform with the passing traffic, moreover, the area affected is wide which makes it easy to

break apart the freezing layer.

It is difficult for snow to freeze and the freezing layer is easily exfoliated on the exposure area of a large surface course of a pavement consisting of rubber aggregates of low bond strength.



Photograph 1: Comparison between Gum-Rolled and normal pavement with snow

2) The continuation of the Effect

In the case of anti-freezing pavement made with chemical materials, the anti-freezing effect is lowered with the elution of chloride in the pavement. However, because Gum-Rolled asphalt pavements use anti-freezing pavement with physically flexible material, 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 course, compared with the type that uses a mixture of rubber particles, difficulty of rolling does not occur, and enough degree of compaction required for the asphalt mixture can be obtained.

4) Protecting the Environment

Gum Rolled asphalt does not require chloride spraying in the winter. This preserves the roadside environment.

4. A RECENT CONSTRUCTION EXAMPLE

4.1 The Construction Site

Here is an introduction of the application on an expressway where the design speed is 80 km/h. The area is the Shitosake Toge Road in the mountainous region of Tottori Prefecture (which crosses 86.5 km of the central section of the Chugoku Transversal Expressway as shown in Figure 6.) The yearly cumulative snowfall is forecast at more than 3 meters. The common measure of removing snow and ice on the expressway is to employ the spraying of a snow melting agent and the use of snow removal equipment. However, in order to avoid the use of chloride which pollutes the roadside environment and to lower maintenance costs, the application of Gum-Rolled asphalt with anti-freezing pavement with physically flexible materials was employed.

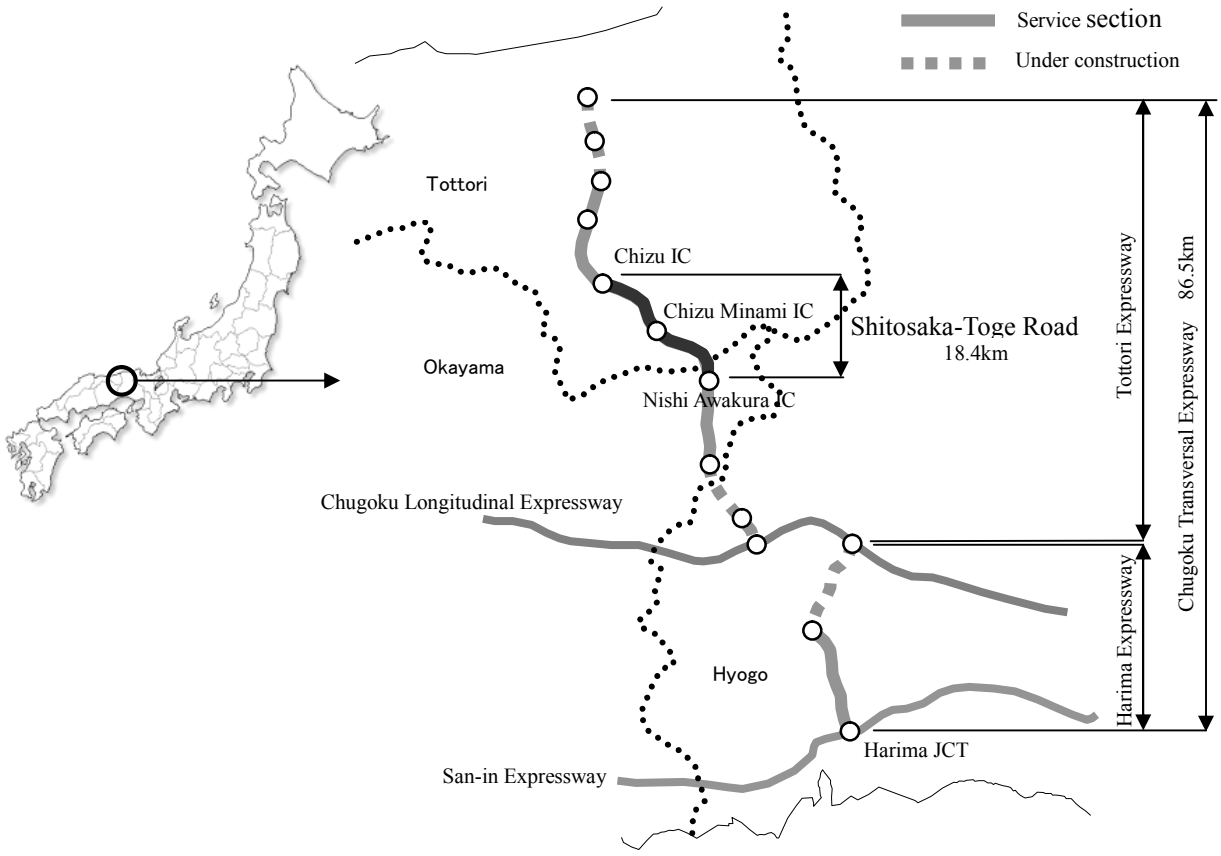


Figure 6: Location map

4.2 Construction Overview

As shown in the construction overview table below, Gum Rolled asphalt was applied to 1,147m of the main line ramp and 2,094m of the access road.

Table 6: Construction overview

Name of Works		Shitosaka Toge Road Chizu Pavement Works	Shitosaka Toge Road Chizu 2 Pavement Works
Construction Period		16.3.2007 -22.12.2007	26.6.2007.6.26-13.3.2008
Gum-Rolled Area	Total	12,410m^2	9,820m^2
	Earthwork	Main line & ramp: 9,320m^2	Main line &acces:5,480m^2
	Bridge	Main line:3,090m^2	Main line &acces:4,340m^2
width		pavement width =7m(3.5m×2)	

4.3 Construction Process

The construction process using Gum Rolled asphalt is the same method as that of constructing rolled asphalt pavement. The base asphalt mixture is spread with the use of an asphalt paver. The rubber aggregates are chipped and spread over the asphalt surface mainly using a vibrating roller with the chipping device in front of it. As the rubber aggregates are chipped

and spread over the hot asphalt mixture, they are simultaneously rolled into the asphalt by steel wheels of a vibrating roller. Finally, intermediate rolling of the pavement is conducted with a pneumatic tire roller.

Photograph 2 shows the construction status of a bridge section. In the case of an earthwork section, normal size rubber aggregate is used. But on a bridge surface because the asphalt mixture is designed to be laid at a thickness of 4cm, a special size rubber aggregate (L=18mm, D=16mm） is used. The chipping amount of the special rubber aggregate is set to be the same exposure area as that of a standard rubber aggregate.

Because the season of the construction site is autumn, the measure to account for a temperature drop of the hot asphalt mixture is to add an additive for warm mix asphalt at 3kg/ton. This assures the easy rolling of the rubber aggregates.

Spreading　　Chipping and breakdown rolling　　Intermediate rolling

Photograph 2: Paving of Gum Rolled asphalt

Surface dressing using MMA (Methacrylic) resin is implemented to suppress scattering the rubber aggregates by the action of 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 0.3kg/m^2 of MMA resin and a top coating of 0.2kg/m^2 of MMA resin and a dispersion amount of 0.6kg/m^2 of anti-skid fine aggregate.

Undercoat　　Spraying anti-skid aggregate　　Top coating

Photograph 3: Surface dressing using MMA resin

4.4 State of Usage

The photograph 4(a) shows a road during snow season. You can see that the passage of vehicles melt the snow. Photo (b) is an enlargement of the surface of Gum-rolled asphalt. Photo (c) was taken during the same time slot as photo (b) showing the condition of dense-graded asphalt concrete. The snow in photo (b) has become slush but in photo (c) it has frozen solid on the pavement. One winter has passed since the opening of the road but the

scatteration of the rubber aggregates seen on a curve of the road is minimal, and the overall road condition is satisfactory. Moreover, because there have been no traffic accidents caused by freezing since the road opening, the anti-freezing effect is considered to be demonstrated (Ando, 2009).

(a) Surface after snow (Gum-Rolled) (b) Gum-Rolled (c) Dense-graded asphalt

Photograph 4: Snow on the pavement

5. IN CONCLUSION

The difficult task of the full fledged application of the Gum-rolled construction process, firstly to an expressway and then to a normal road, has been solved by implementation of a single improvement of the process.

We strive for ever better quality to improve the durability and performance of road pavement as well as effectively lowering the winter road maintenance costs by the Gum-rolled construction method.

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