DEVELOPMENT OF ANTI-ICING ASPHALT PAVEMENTS USING RUBBER PARTICLES

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1. Abstract

After the use of stud tires was prohibited in 1991 in Japan, various types of frozen control pavement have been studied and developed to ensure traffic safety in winter.

We have developed three types of asphalt surface course containing rubber particles which have an anti-icing function:
(1) Gap-graded mixture with rubber particles
(2) Ultra-thin surfacing of asphalt mastic with rubber particles (RA mastic)
(3) Open-graded mixture with rubber particles

The ice debonding mechanism of asphalt mixtures containing rubber particles was examined by means of model experiments, photoelastic experiments, and finite element model analysis. The ice breaking effect of rubber particles was clarified from the results of these examinations.

Through laboratory tests, plant production tests and small field tests, rational mixture components, plant production methods and paving construction methods were considered and determined for the developed asphalt mixtures.

The determined gap-graded mixture usually consists of gap-graded aggregates, rubber particles (about 2~4% mass), filler and polymer modified asphalt. RA mastic is an asphalt mastic which consists of a large amount of rubber particles (20~30% mass), filler and polymer modified asphalt. The open-graded mixture is a porous asphalt having an elastic property due to the rubber particles contained in it. This mixture consists of open-graded aggregates, rubber particles (about 1% mass), filler and polymer modified asphalt. In this open-graded mixture case, some rubber particles are sometimes spread and adhered to the surface course in addition to the inside rubber particles.

These three methods were tested on some actual roads and the ice debonding effect was observed during winter. It was confirmed that the developed methods using rubber particles in surface mixtures have excellent ice breaking effect. Based on the results of the field trials, these three methods are now in practical use.

In this paper, we describe the concepts of the methods and the ice debonding mechanism of asphalt mixtures with rubber particles, and discuss the results of laboratory tests, plant production tests and small field tests, and the performance of the three developed methods when tested on actual roads. Finally, we outline the possibility of the developed methods for anti-icing pavements.

2. Introduction

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3. Ice Debonding Effects of Asphalt Mixtures with Rubber Particles

It was assumed that ice or compacted snow on the road surface of asphalt mixtures with rubber particles (AMRP) could be easily debonded and removed by the application of traffic load because of the deformation of rubber particles by traffic load.

The mechanism of ice debonding effects and the influence of various factors on them were investigated by model experiments, photoelastic experiments and finite element model (FEM) analysis [1), 2)]. It is believed that the protruding rubber particles on the pavement surface greatly contribute to the ice debonding effect.

Model specimens as shown in Figure 3.1 were made to simplify the above-mentioned pavement surface condition, and loading tests were carried out on the specimens using a steel cylinder of diameter 4 cm. Figure 3.2 shows the

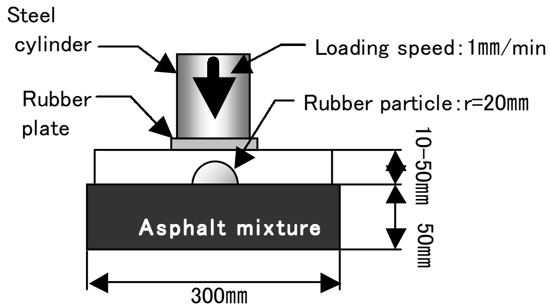


Figure 3.1 Specimen for the Model Experiment

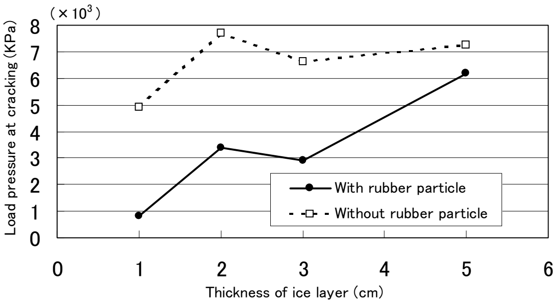


Figure 3.2 Relationship between the Thickness of Ice Layer and the Load Pressure at Cracking

relationship between the load required to initiate cracks in the ice layer and the thickness of the ice layer. It is obvious that a smaller load is required to initiate cracks in the ice layer of the model with rubber particles compared with the model without rubber particles. The thicker ice layer requires a larger load to initiate cracks in the ice layer of the models both with or without a rubber particle. When the thickness of the ice layer is considerably large, the ice debonding effect of rubber particles is not remarkable.

The results of the model experiments showed that the existence of rubber particles accelerates the induction of cracks in an ice layer on the surface of asphalt pavements. Therefore, photoelastic experiments and FEM analysis were conducted to examine the stress state in the ice layer around the rubber particles and the ice debonding mechanism of asphalt mixtures with rubber particles.

Figure 3.3 shows the model used for the photoelastic experiment. Figure 3.4 shows isochromatic lines under loading in the models with and without rubber particles. It is clear that larger stresses occur in the ice layer around the rubber particles compared with those in the model without rubber particles by a factor of about 2.5 times.

The stress condition in the ice layer was analyzed in an axisymmetric finite element model as shown in Figure 3.5. Figure 3.6 shows the relationship between the radial stress near the top of the rubber particle, σ_r, and the thickness of the ice layer, h. When h is small, the stresses are generally compressive, and when h becomes larger, the stress becomes tensile and reaches a maximum value at h = 15-30 mm. These large tensile stresses around the rubber particle might initiate cracks and cause breakdown of the ice. The results of FEM analysis on the effects of shape and stiffness of rubber particles show that the shape and

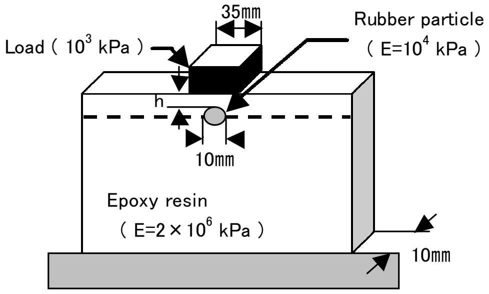
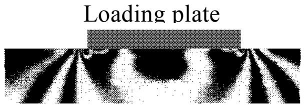
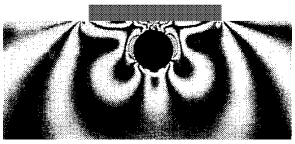


Figure 3.3 Model for the Photoelastic Experiment



No rubber particle



Rubber particle

Figure 3.4 Isochromatic Lines in the Photoelastic Experiment

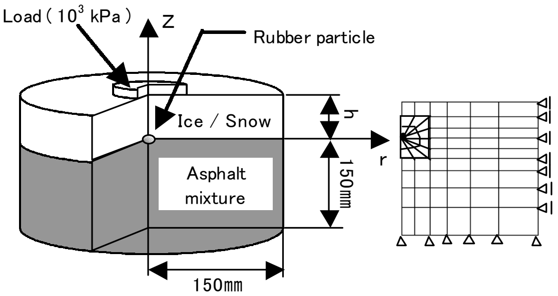


Figure 3.5 Axisymmetric Finite Element Model

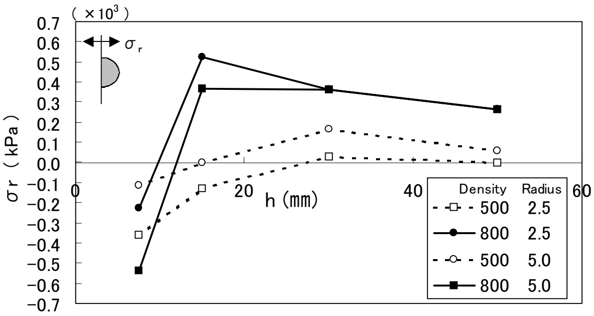


Figure 3.6 Relationship between σ_r and the Thickness of Ice Layer

stiffness have little effect.

Judging from the results of model experiments, photoelastic experiments and FEM analysis, the ice debonding effect of AMRP is due to the stress concentration in the ice layer around the rubber particles on the pavement surface under traffic loading.

4. Rubber Particles for Asphalt Mixtures

Rubber particles made by crushing remnants of scrapped rubber tires have been used for AMRP. But in case of open-graded mixtures with rubber particles (OMRP), the kind of rubber may influence the properties of the mixtures since the rubber particles may change the characteristics of the asphalt mortar. For this reason, two typical rubber particles were selected and tested: rubber particles from scrapped rubber tires (RP-A), and rubber particles from scrapped rubber packing (RP-B). Using these two kinds of rubber particles, some experiments were conducted to clarify the properties of the mixtures.

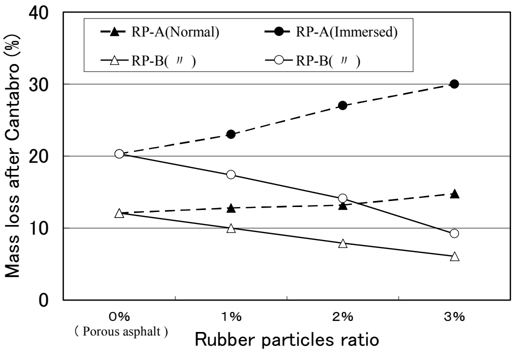


Figure 4.1 Cantabro Test Results

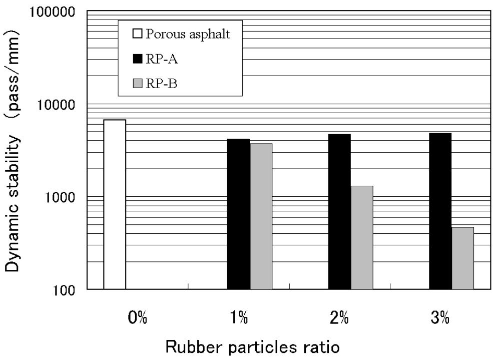


Figure 4.2 Wheel Tracking Test Results

Figure 4.1 shows the Cantabro test results. Normal Cantabro tests were conducted at the test temperature of 20℃. Immersed Cantabro tests were conducted at the test temperature of 20℃ as the normal Cantabro test after the specimens had been immersed in 60℃ water for 48 hours and cured in 20℃ for 6 hours. The composition of OMRP was decided using the same method as porous asphalt mixture design. In case of RP-A, the mass loss increases as the rubber particle ratio increases. This tendency is more remarkable in the immersed condition. Contrarily, the mass loss in case of RP-B decreases as the rubber particle ratio increases. Thus, from the durability point of view, rubber particles made from RP-B are better than those from RP-A.

Figure 4.2 shows the dynamic stability (DS) results from the wheel tracking tests. The DS values in case of RP-A are similar to those in porous asphalt, but the DS values in case of RP-B decrease as the rubber particle ratio increases

Based on these results, it was concluded that the rubber particles for open-graded mixtures should be RP-B from the waterproofing point of view and the ratio of RP-B should be less than 1% from the stability point of view.

It was considered that rubber particles might be more effective for anti-icing when they are present on the pavement surface. However, in case of open-graded mixtures, since the surface is porous and few rubber particles in the mixture appear on the surface, some rubber particles should be adhered to the surface.

Two methods of adhering rubber particles to the surface were examined: adhering RP-A to the surface using particular epoxy resin for adhesive, and adhering particular rubber particles containing epoxy resin (RP-C) to the surface by the following procedure. OMRP is placed in the form and RP-C is spread on it, then they are compacted at the same time. The temperature during compaction must be more than 140℃. The RP-C tightly adheres to the surface of OMRP.

The degree of exfoliation and scattering of rubber particles by traffic was investigated by a kind of raveling test. Rubber particles were adhered to the surface of a normal raveling specimen by each adhering method. In this raveling test the chain was covered with a rubber hose so as not to wear OMRP by itself. The test temperature was 20℃. The mass of the specimen was measured before and after the raveling, and the mass loss of rubber particles was calculated.

Figure 4.3 shows the results of mass loss of rubber particles. Since the mass loss of OMRP was less than 5% of the total mass of rubber particles, it was not considered in the calculation of mass loss of rubber particles. The mass loss of RP-C is smaller than that of RP-A using epoxy resin for adhesive.

Based on these results, it was concluded that RP-C is better for adhering rubber particles to the asphalt surface because of the better resistance to exfoliation and scattering and the shorter time required for adhering rubber particles.

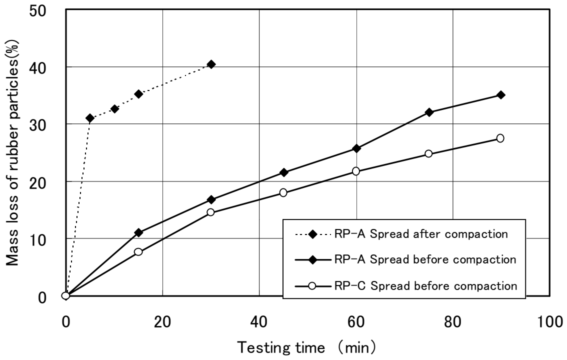


Figure 4.3 Mass Loss of Rubber Particles

5. Gap-graded Asphalt Mixture with Rubber Particles

Gap-graded asphalt mixture with rubber particles (GAMRP) consists of aggregates, rubber particles, filler and asphalt. Figure 5.1 shows a schematic illustration of GAMRP. The rubber particles at the surface of the pavement with GAMRP demonstrate ice debonding effects as explained in section 3. Figure 5.2 shows the winter condition of the road with the surface course of GAMRP. It is apparent that the surface of GAMRP has less snow and ice compared with the surface of normal asphalt mixtures. Table 5.1 lists the record of applications of GAMRP over 20 years. The method has been widely applied as an anti-icing pavement in cold areas of Japan.

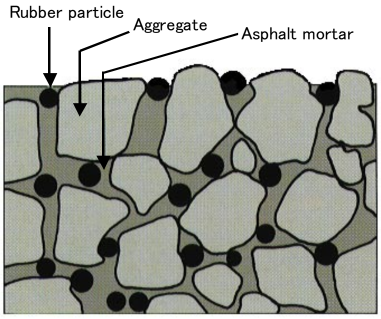


Figure 5.1 Gap-graded Asphalt Mixture with Rubber Particles

Figure 5.2 Pavement Surface Condition of GAMRP

A typical composition of GAMRP is presented in Table 5.2. Since GAMRP contains rubber particles made by crushing remnants of scrapped rubber tires, it should have more binder than normal mixtures and the binder should be modified binder with resistance to plastic deformation.

Table 5.1 The Record of Applications of GAMRP

Year	Applied area (㎡)
1981～1994	438,899
1995	78,414
1996	69,799
1997	52,919
1998	42,391
1999	18,634

Table 5.2 Typical Composition of GAMRP

Materials	SFB3	Coarse aggregate	Fine aggregate	Filler	Rubber particle	Total
Mass %	7.3	59.1	19.6	11.0	3.0	100.0
Volume %	16.5	51.4	16.9	9.1	6.1	100.0

GAMRP is manufactured in a conventional asphalt plant. When this mixture is paved by a conventional paver, the minimum compacted layer thickness is 4 cm. However, if a so-called multi-asphalt paver (MAP) (Figure 5.3) is used, and GAMRP and the layer immediately beneath it are simultaneously spread and compacted, the thickness of GAMRP could be reduced to 2-3 cm. An oscillatory roller should be used for intermediate compaction to fill the asphalt mortar into the voids in the coarse aggregates.

GAMRP has applicability as an anti-icing pavement and if MAP is used as a paver, the layer thickness could be reduced and therefore the construction cost decreased. This would encourage the application of such pavement in the future.

Figure 5.3 Multi-asphalt Paver (MAP)

6. Porous Asphalt Pavement with Rubber Particles Adhered to the Surface

In order to investigate the ice debonding effects of porous asphalt with rubber particles adhered to the surface (PARP), loading tests on the same model specimens as those in section 3 were conducted. The thickness of the ice layer on the specimen was 3 mm, and the temperature of the ice layer was –3℃. Figure 6.1 shows the load required to initiate cracks in the ice layer.

The load to initiate cracks in case of OMRP and PARP was less than half of that in the case of porous asphalt. It seems that the ice layer on the surface of OMRP and PARP could be easily debonded and removed by traffic load. Additionally, since the load on PARP was smaller than that on OMRP, the rubber particles adhered to the surface had a greater ice debonding effect.

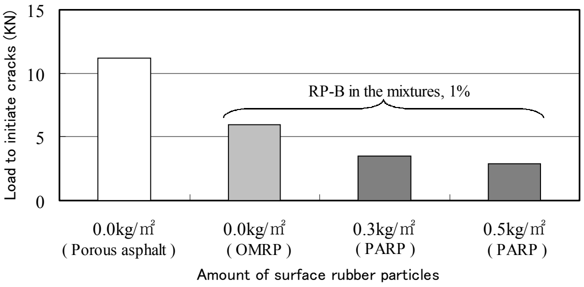


Figure 6.1 Load to Initiate Cracks

These results are similar to those described in section 3.

Figure 6.2 shows the surface condition of porous asphalt and PARP in winter. The compacted snow on the porous asphalt pavement surface is bonded tightly, but the compacted snow on the PARP surface is debonded and removed.

Compacted Snow on the Porous Asphalt Compacted Snow on the PARP

Figure 6.2 Surface Conditions in Winter Season

It is believed that PARP also has a noise reduction effect. Figure 6.3 shows the measured tire noise. A microphone was set at 50 cm offset from the center of the back right tire of a passenger car and 15 cm above the road surface. Tire noise was measured at the speed of 50 km/h. It is considered that the rubber particles adhered to the surface reduced noise because the tires were cushioned by the particles.

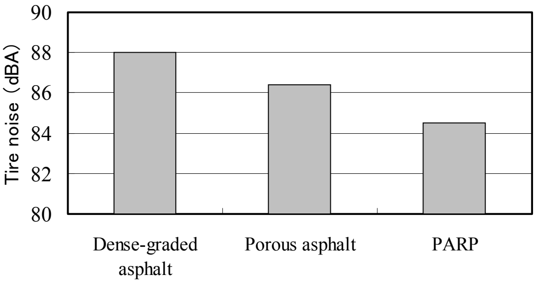


Figure 6.3 Tire Noise

7. Ultra-thin Surfacing of Asphalt Mastic with Rubber Particles

An ultra-thin surfacing of asphalt mastic with rubber particles (RA mastic) was developed in order to improve the deicing function and high cost of conventional methods[3), 4)]. Figure 7.1 illustrates the structure of the RA mastic surface treatment.

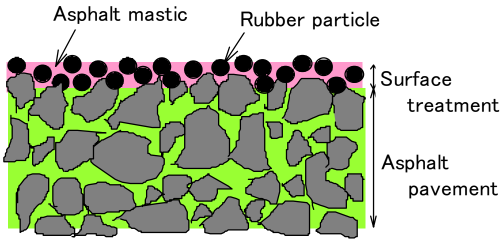


Figure 7.1 RA Mastic

The RA mastic is manufactured by mixing rubber particles, asphalt, filler, sand and fiber in a conventional asphalt plant. It is transported and

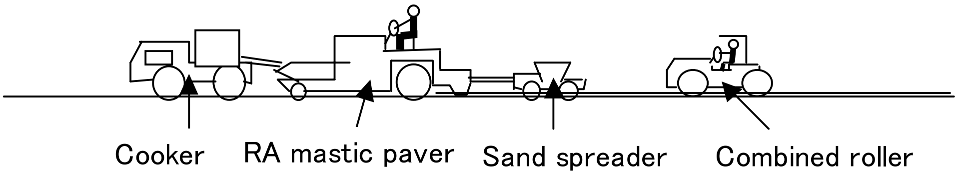


Figure 7.2 Paving Train for RA Mastic Construction

remixed by cooker/heater until it has appropriate liquidity for laying and placing with the thickness of 5 mm to 7 mm by a special asphalt paver that has a rubber blade. Figure 7.2 shows the construction process of RA mastic.

In the early stage, there were some troubles such as exfoliation between the RA mastic and the existing pavement. The causes were considered to be that the rubber particles absorbed oil from the asphalt and the RA mastic grew hard, reducing the bonding between the RA mastic and the existing pavement. Then rubber particles made by crushing remnants of oil-proof rubber products were examined. Figure 7.3 shows the results of shear tests to investigate the bonding between the RA mastic and asphalt mixture. The shear strength of the RA mastic with oil-proof rubber particles is greater than that with non oil-proof rubber particles. Therefore, it was decided to use oil-proof rubber particles for RA mastic.

A standard composition of the RA mastic is presented in Table 7.1. Modified asphalt is used because it has better ability of grasping rubber particles. The RA mastic surface treatment was used on actual roads in heavy snow and cold areas. Figure 7.4 shows the winter state of the road with RA mastic surface treatment. It is apparent that the surface with RA mastic has less snow and ice compared with that without RA mastic.

Therefore, it was confirmed that RA mastic surface treatment is very effective in preventing snow from freezing on the road surface.

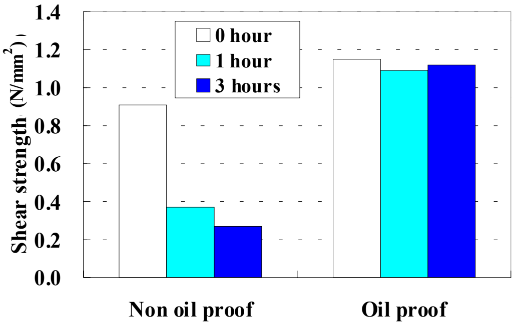


Figure 7.3 Shear Test Results

Figure 7.4 Pavement Surface Condition of RA Mastic in Winter

Table 7.1 Standard Composition of RA Mastic

Material	Percentage by mass
Filler	40−50 %
Sand	10−20 %
Rubber particle	15−25 %
Fiber	0.1−0.3 %
Modified asphalt	20−30 %

8. Conclusions

This paper focused on asphalt surface courses containing rubber particles having an anti-icing function. The following conclusions were obtained.

(1) Some asphalt surface courses containing rubber particles have an anti-icing function due to the stress concentration in the ice layer around the rubber particles on the pavement surface under traffic loading.

(2) Rubber particles produced by crushing remnants of scrapped rubber packing are suitable for the developed anti-icing asphalt mixtures.

(3) Particular rubber particles containing epoxy resin are suitable for rubber particles adhered to the asphalt surface.

(4) Gap-graded asphalt mixture with rubber particles has applicability as an anti-icing pavement.

(5) Porous asphalt pavements with rubber particles adhered to the surface have an excellent

anti-icing function as well as tire noise reduction effect.

(6) RA mastic surface treatment is very effective for anti-icing.

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