Research of Modified Asphalt for the Intense Cold Region

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ABSTRACT: In general, the damage to the pavement will be more serious in the low temperature regions where it will be exposed to much severe conditions. The damage depends on the type of pavement; thermal cracks and aggregate scaling are the main problems to be solved in Japan.

Meanwhile, much intense cold regions below −30°C are found in the world where the pavement is required to be more durable not to cause such damages. There are many cases in Japan to employ modified asphalt for the pavement in the low temperature region to restrain such damages.

The polymer in modified asphalt will act to restrain thermal cracks and aggregate scaling. So, modified asphalt will be effective to prevent them in the intense cold region abroad, too.

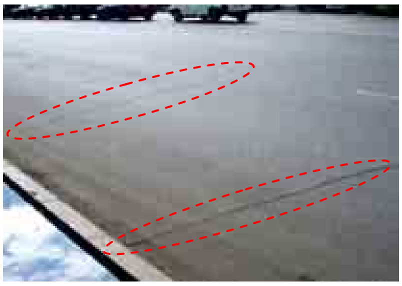
This thesis is to report on the research of modified asphalt for pavements which will be effective in the intense cold regions abroad utilizing our technology for modified asphalt pavements by which we have constructed in Asian countries.

KEY WORDS: Plant (on-site) mix type modifier, thermal cracks, aggregate scaling.

1 INTRODUCTION

Asphalt pavement in cold regions is often exposed to severe conditions which causes damages from cracks by thermal stress (hereinafter referred to as “thermal cracks”) and aggregate scaling by friction. Such damages which do harm to serviceability of roads have become serious problem in Japan.

Much intense cold regions are observed outside Japan. Photograph 1 shows thermal cracks on the surface of a road in intense cold region. Thermal cracks appear at regular intervals on the surface of dense graded pavement.



[Definition of Intense Cold Region]
- The ambient temperature falls to −40°C or below in winter.
- Lowest temperature a day is below freezing point at least half the year.

Photograph1: Thermal cracks on the surface of a road

The cause of thermal cracks and aggregate scaling is considered to be both of contraction of asphalt mixture and decrease in ductility and tenacity of asphalt due to a cold environment. Therefore, a property of high flexibility is required for asphalt used in cold regions.

The use of modified asphalt will take effect to prevent such damages in cold regions because modified asphalt can widely improve properties of asphalt mixture. Modifier for modified asphalt is generally classified into two groups; premix type and plant (on-site) mix type. Both of them can improve properties of asphalt by modifying effect of polymer.

Plant (on-site) mix type of modifier is of great advantage because “The required quantity may be moved to the required location in a vast country where modified asphalt can be produced by it” and “It can be stored at normal temperature in a paper bag for a long period.”

Our company has developed this plant (on-site) type of modifier and technology to produce modified asphalt. The modifier that we use today (hereinafter referred to as “the current product”) has a superior modifying effect. However, further improvement in properties resistant to low temperature is required for use in intense cold regions.

We have worked on our research project to develop a new plant (on-site) mix type of modifier for use in intense cold regions (hereinafter referred to as “the new product”).

This is to report the outcome of our research project.

2 DEVELOPMENT CONCEPT

Styrene-butadiene-styrene copolymer (SBS) is commonly used for polymer type modifier. SBS is melted at around 190°C and then dispersed in asphalt by mixing and heating. It has been founded since early stage of study that dispersion of SBS has an important effect on properties of asphalt. Furthermore, uniform dispersion of SBS is prerequisite to obtain reliable properties of modified asphalt. Particularly in a cold environment, properties of modified asphalt are much dominated by SBS. In addition, ideally uniform dispersion of SBS is vital to modified asphalt in cold regions (Hanyu, 2007).

In consideration of the above, we have regarded the following two points as critically important subject to develop the new product;

(1) Superior solubility and dispersibility in modified asphalt will be required.

(2) SBS itself will be required to be resistant to low temperature.

As-A (penetration grade 60/80) which is a commonly used for asphalt pavement, modified by SBS with mix rate of 6-8% will be greatly improved. Therefore, 8% mix rate of SBS into As-A will be adopted to secure sufficient modifying effect of SBS.

2.1 Solubility and Dispersibility

SBS itself has poor solubility and dispersibility in asphalt. We have added a compatibilizer to SBS to obtain solubility and dispersibility and then have developed the current product. (Photograph 2)

Compatibilizer is an additive used for producing copolymers from two types of polymer.

[Property]

- It is melted at around 170°C.
- It is stored at normal temperature.
- It produces high elastic modified asphalt with mix proportion of 12% into As-A, which corresponds to modified asphalt type H in Japan.
- It is widely used in Asian countries.

Photograph2: The current product

The solubility and dispersibility of SBS are connected with its fluidity. Melt Flow Rate (MFR) is used as an index of fluidity. Higher MFR shows superior solubility and dispersibility, so that we have developed the new product with higher MFR compared to the current product. Table 1 lists MFR and Fraass Breaking Points of three types of modified asphalt (Compound A, B and C) with different proportion of SBS in modifier. Modifier is mixed into As-A with proportion of 12%. MFR increases in inverse proportion to mix proportion of SBS. Fraass Breaking Point lowers as mix proportion of SBS increases while it does not get low at a certain point any more. Therefore, we have decided to adjust the MFR of 10 (g/10min) for the new product that can obtain optimum fluidity at low temperature while keeping superior solubility and dispersibility.

Table1: MFR and Fraass Breaking Point

Test item	Compound A	Compound B	Compound C	Current product
	Low ←	SBS/modifier	→ High	
MFR, 160°C, 2.16kg (g/10min)	13.4	10.0	5.1	2.0
Fraass breaking point (°C)	-20.0	-28.0	-28.0	-15.0

2.2 SBS Resistant to Low Temperature

Table 2 shows test results of Fraass Breaking Point test result of SBS test samples (SBS Type 1 to 4) with different molecular weights respectively. SBS is mixed into As-A with mix proportion of 8% while mix proportion of compatibilizer is the same for all test samples. Smaller molecular weight results in lower Fraass Breaking Point which means better property resistant to low temperature. As a result, SBS with smaller molecular weight has been adopted for the new product.

Table2: Fraass Breaking Point on SBS Type

Test item	SBS Type1	SBS Type2	SBS Type3	SBS Type4
	Small ←	SBS Molecular weight	→	Large
Fraass breaking point (°C)	-26.0	-23.5	-20.0	-19.5

3 TARGET PROPERTY

Table 3 lists target properties for the new product. We have targeted to develop the new product with properties required for use in intense cold regions outside Japan. It is said that pavement temperature in cold regions is about 10°C higher than the ambient temperature. Even in intense cold regions of North and Central Asia where the ambient temperature may fall to −40°C, the pavement temperature will be supposed to be around −30°C. Therefore, our target is to achieve properties resistant to low temperature which can secure serviceability of modified asphalt at pavement temperature of −30°C (Oguri, 1998).

Test items listed in Table 3 are typical for Japanese Standards. Target values are determined referring to Standard Requirements in Japan. Test results in details are described in Section 4 and 5 (Abe, 2006).

Table3: Target Properties of The New Product

Test items (test temperature in parentheses)		Mixture type	Item	Target	Standard requirement in Japan
Asphalt properties	Fraass breaking point test		Breaking point (°C)	-30 or below	-12 or below
	Bending test (-30°C)		Bending load ($\times 10^{-3}$ MPa)	400 or above	400 or above (-20°C)
			Bending stiffness (MPa)	100 or below	100 or below (-20°C)
Asphalt mixture properties	Bending test (-30°C)	Dense	Bending strain ($\times 10^{-3}$ mm/mm)	4.0 or above	-
	Thermal stress test		Stress relaxation limit temperature (°C)	-30 or below	-
	Cantabro test (-30°C)	Porous	Aggregate scaling ratio (%)	20 or below	20 or below (-20°C)
	Wheel tracking test (60°C)	Dense and porous	Dynamic stability (pass/mm)	3000 or above	1500 or above

4 ASPHALT PROPERTY

Asphalt Property resistant to low temperature has been inspected using the following types of asphalt with different penetration grades: As-A from Japan (penetration grade 60/80), As-B from Japan (penetration grade 150/200), and As-C from abroad (penetration grade 60/90). Each asphalt is mixed with either the current or new product of modifier. Mix proportion of modifier is varied at 2% intervals in the following range: 12–16% in As-A, 14–18% in As-B, and 10–14% in As-C. Mix proportion of modifier is varied depending on penetration grade which gives different modifying effect on properties such as solubility and dispersibility.

A property of viscosity of asphalt at high temperature increases with mix proportion of modifier, so that such proportion will be also selected in the range of viscosity which provides enough workability for spreading the asphalt mixture.

4.1 Asphalt Property

Table 4 shows test results of asphalt properties; Penetration, Softening Point and other typical items. Among specimens with various mix proportions of modifier into asphalt, 12–16% in As-A, 14–18% in As-B, and 10–14% in As-C, properties of each of asphalt with max proportion of modifier are listed, which shows best values in all items.

Modified asphalt by the new product is superior to the same by the current product on test items of Fraass Breaking Point, Bending Load and Bending Stiffness. Modified asphalt by the new product satisfies our target values resistant to low temperature.

Table4: Modified Asphalt Property Test Data

Type of modifier	No modifier			New product			Current product		
Base asphalt	As-A (60/80)	As-B (150/200)	As-C (60/90)	As-A (60/80)	As-B (150/200)	As-C (60/90)	As-A (60/80)	As-B (150/200)	As-C (60/90)
Modifier mixing proportion (%)	0	0	0	16	18	14	16	18	14
Penetration (1/10mm)	75	174	66	41	60	43	35	50	40
Softening point (°C)	47.5	40.0	53.5	88.0	86.0	83.0	93.5	92.5	88.0
Fraass breaking point (°C)	-8	-20	-18	-36	-40	-36	-25	-30	-28
Bending load ($\times 10^{-3}$MPa)	-	-	-	219	2317	1815	101	185	368
Bending stiffness (MPa)	-	-	-	184	29	23	452	303	116

[Fraass Breaking Point test]
Fraass Breaking Point test indicates the flexibility of asphalt at a low temperature. A bending load will be applied to asphalt –coating steel plate while cooling down to observe the temperature at which the first crack appears in asphalt coating.

[Asphalt Bending test]
A load will be applied at the rate of 100mm/min to the center of the specimen cooled down to −30°C to observe max. Bending Stress and Strain.
The following are derived from the results:
Bending Load = stress × strain
Bending Stiffness = stress/strain

4.2 Correlation between Fraass Breaking Point and Bending Stiffness

As shown in Figure 1, a significant correlation between Fraass Breaking Point and Bending Stiffness is recognized. Therefore, we adopt Bending Stiffness as an index of property resistant to low temperature as well (Motomatsu, 2001).
The red line in the graph shows the target values. Fraass Breaking Point with the target value does not necessarily ensure the target value of Bending Stiffness. In other words it will be difficult to obtain satisfactory value of Bending Stiffness than that of Fraass Breaking Point.
Figure 1 shows that some specimens of modified asphalt by the new product satisfy the target values; As-B with mix proportion of 16% and 18%, As-C with mix proportion of 12% and 14%.
As shown in Figure 2, As-B and As-C with higher mix proportion prove to have better properties resistant to low temperature showing Bending Stiffness less than 100 (MPa) at −35°C.
This Bending test is conducted by varying the specimen temperature from −20°C to −35°C. Consequently, As-B modified with mix proportion of 18% or As-C with mix proportion of 14% will be recommendable.

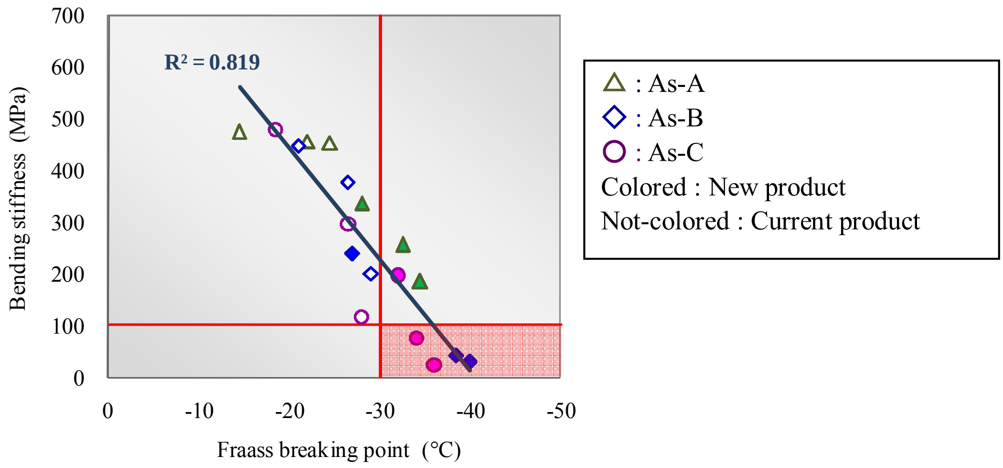


Figure1: Fraass Breaking Point and Bending Stiffness

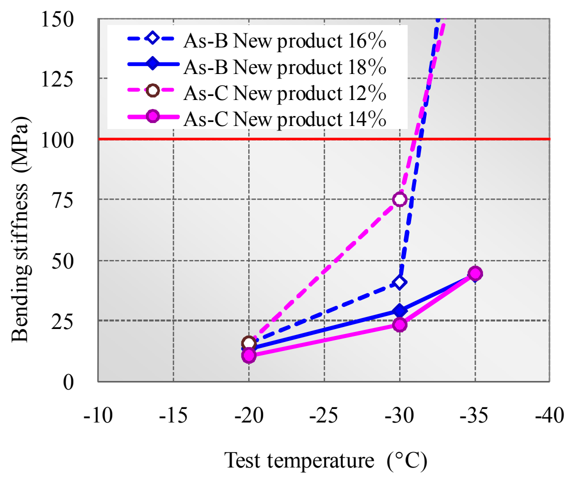


Figure2: Test Temperature and Bending Stiffness

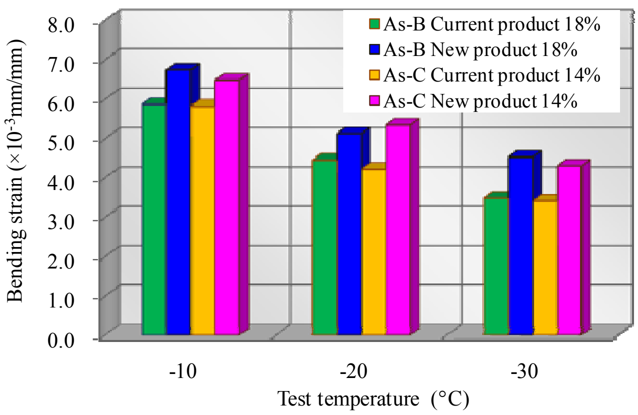
5 ASPHALT MIXTURE

5.1 Prevention of Thermal Cracks

It is generally recognized that thermal cracks are caused by accumulated Bending moment and internal stress due to a fall in pavement temperature. Dense graded asphalt mixture is particularly susceptible to thermal cracks. Therefore, we have conducted Bending test and Thermal Stress test on specimens of dense graded asphalt mixture to observe flexibility and stress relaxation property at low temperature (Mizushima, 1994).

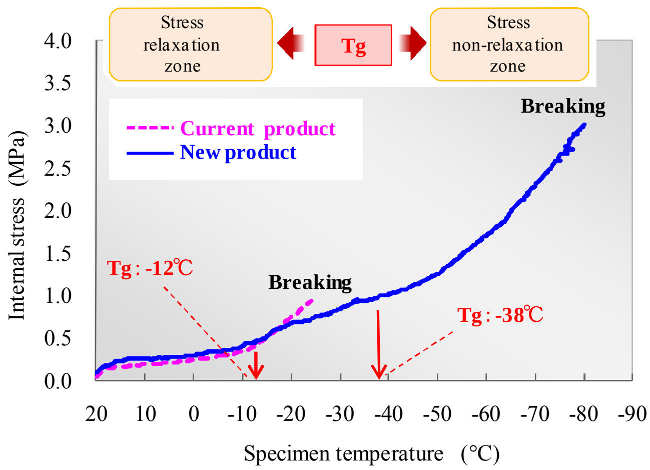
Figure 3 shows the relationship between the Bending Strain and Test Temperature. On the whole, Bending Strain decreases as temperature falls. The new product proves to be superior to the current product as shown in figure 3, which becomes more evident as temperature further falls. Asphalt mixture modified by the new product keeps good flexibility over all temperatures to meet the target value of min. 4.0.

Thermal Stress test has been conducted on specimens of As-B modified with mix proportion of 18%. Figure 4 shows the relationship between Specimen Temperature and Internal Stress. Internal Stress of specimen increases sharply at a certain point with a fall in temperature which demarcates stress relaxation zone and stress non-relaxation zone. This temperature point is known as the stress relaxation limit temperature (Tg). The new product successfully lowers Tg by about 25°C compared with the current product. Thus, we have confirmed that the new product improves stress relaxation property by lowering Tg to a point below −30°C of target temperature. The new product can be expected greatly to contribute to prevention of thermal cracks in intense cold regions.



[Bending test]
A load will be applied at the rate of 50mm/min to the center of a specimen to observe Bending stress and strain at breaking as an index of flexibility of asphalt mixture.

Figure3: Bending Test for Dense Graded Asphalt Mixture



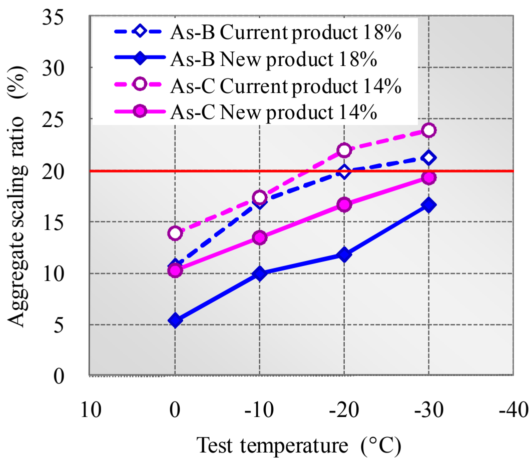
[Thermal Stress test]
A specimen fixed at both sides will be cooled down at the rate of -10°C/h.
Internal stress of a specimen will be observed every 1°C.
The relationship between Temperature of specimen and Internal stress is plotted so a turning point of rising ratio on Internal stress will be found.

Figure4: Thermal Stress Test for Dense Graded Asphalt Mixture

5.2 Prevention of Aggregate Scaling

Aggregate scaling is usually caused by friction between the road surface and the tire particularly at a low temperature. Further, porous asphalt pavement is susceptible to aggregate

scaling as well. Therefore, we have conducted Cantabro test using four types of specimens of porous asphalt mixture described in Figure 5 at low temperatures to observe how much such mixture would be resistant to friction so as not to suffer damage of aggregate scaling.
For this test, the percentage of air void is 17% which is the standard ratio for porous asphalt pavement in cold regions in Japan.
Figure 5 shows the test results of the relationship between Test Temperature and Aggregate Scaling ratio. Asphalt mixture modified by the new product proves to be superior to asphalt mixture by current product over all temperatures. Even at the temperature of −30°C, both of asphalt mixture modified by the new product show Aggregate Scaling ratios below 20% of target value to indicate stronger cohesion of aggregate. The new product, therefore, can be expected greatly to contribute to prevention of aggregate scaling in intense cold regions.

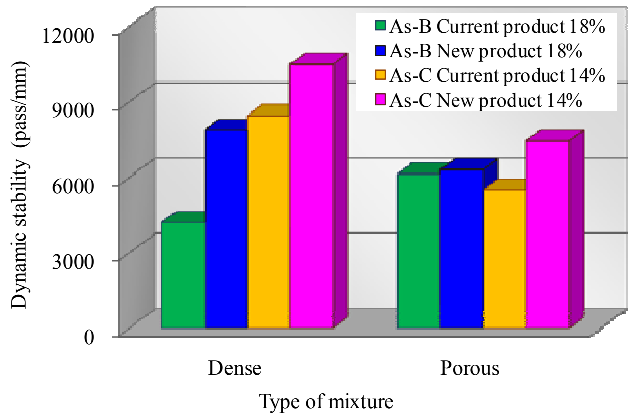


[Cantabro test]
At low temperatures from 0°C to −30°C, impact is applied to a specimen 300 times. The balance of weights before and after the test indicates aggregate scaling ratio. Los Angeles Abrasion Test Equipment is used for the test.

Figure5: Cantabro Test for Porous Asphalt Mixture

5.3 Dynamic Stability

Asphalt pavement suffers plastic deformation at a high temperature. Therefore enough resistance to plastic deformation will be required for it. We have conducted Wheel Tracking test using four types of specimens mentioned in the above 5.2. Figure 6 shows the test results that Dynamic Stability for all specimens is over 3,000 (pass/mm). It indicates that sufficient resistance to plastic deformation is secured for all specimens.



[Wheel Tracking test]
A load of 686N will be applied to the center of a specimen heated up to 60°C using wheel track at a speed of 42pass/min for one hour.
Dynamic Stability is determined from the relationship between time and deformation.

Figure6: Wheel Tracking Test for Asphalt Mixture

6 CONCLUSION AND FUTURE CHALLENGES

The modifier that we have newly developed in this research project for use in intense cold regions has proved its effect to satisfy the required properties of modified asphalt, especially stress relaxation property and cohesion of aggregate. Therefore, the new modifier can be expected greatly to contribute to prevention of thermal cracks and aggregate scaling in intense cold regions.

This new modifier also has the advantage of plant (on-site) mix type modifier as described in Section 1 in this report.

Our future challenge is further improvement of the new product and trial construction toward full-scale construction of pavement in intense cold regions in Japan and abroad.

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