SMA with Special Modified Asphalt Aimed to Extend Pavement Lifespan

N. Oguri, T. Kanou, M. Konno
Senior Researcher, Institute of Research and Development, Taisei Rotec Corporation, Kounosu, Saitama, Japan

ABSTRACT: We have developed "high durability SMA" which uses special modified asphalt with improved susceptivity to change in temperature and viscoelasticity compared to conventional asphalt. The high durability SMA using special modified asphalt has a breakage resistance at least 100 times greater than that of the SMA using the polymer modified asphalt II type. The high durability SMA using special modified asphalt has the same resistance to plastic flow as the SMA using the polymer modified asphalt II type. In addition, the results of the temperature stress test and static bending test have shown that it has excellent performance related to stress-relaxation, resistance to brittleness and flexibility at low temperature. At points where the high durability SMA was used as the surface layer of the composite pavement, excellent reflection crack restraining effect and resistance to plastic flow have been observed compared with the conventional reflection crack restraining method. Calculation of these life cycle costs show that the cost of the paved section with high durability SMA is about 56 % of that of the paved section of the conventional method. This is over an analysis period 40 years. Therefore, it can be concluded that employment of the high durability SMA for the maintenance and repair of the composite pavement will contribute to the longer life of the pavement, a shortened construction period and reduced cost.

KEY WORDS: Modified asphalt, SMA, reflection cracking, rehabilitation, life cycle cost

1 INTRODUCTION

In our country, recently the pavement stock has increased and the traffic load has become severer as the traffic volume increases, resulting in an accumulated damage of the pavement. Therefore, the importance of the maintenance and repair construction of the pavement has been growing more and more. However, this maintenance and repair construction is a tremendous expense and also causes a lot of time loss due to traffic interruption. It is therefore anticipated that from now on that a pavement of longer life, featuring excellent durability will be needed. This is because pavement of this type can reduce the total cost by reducing maintenance repair frequency, while also maintaining a more comfortable service performance.

One of the pavements that can provide such a longer life is the composite pavement. However, with composite pavement, a lower cement-based pavement moves with the traffic load or temperature change. Therefore, reflection cracks occur because the stress concentrates on the joint between the cement-based pavement and when the asphalt pavement on cracks. In this way, the composite pavement often breaks up comparatively early.

Currently, as the method to restrain the reflection cracks, various methods, such as providing bitumen-based crack control sheets and cushion layer, have been considered. However, little attention has been paid to the heating of the asphalt mixture used for the overlay application.

In this paper, we will report examination results regarding the high durability SMA which focuses on at the extended life of the pavement. This high durability SMA uses the special modified asphalt which has greatly improved properties such as flexibility, stress-relaxation and resistance to brittleness at a low temperature, compared with conventional asphalt.

2 DEVELOPMENT OF HIGH DURABILITY SMA FOR WITH A LONGER LIFE EXPECTANCY

2.1 Summary of the Development

For the heating of the asphalt mixture to be used for the surface layer of the composite pavement, we have developed SMA which uses the special modified asphalt, where the susceptivity to change in temperature and stress-relaxation property has been improved.

The developed special modified asphalt is a polymer modified asphalt to which the SBS (styrene butadiene co-polymer) has been added. This SBS is generally used as a reforming material. Also another special additive is included. This is based on the following concept.

(1) This mixture should retain stress-relaxation and flexibility, which are characteristics of an asphalt mixture, within a broad temperature range from a low temperature to normal temperatures by reducing as much as possible the asphalt's susceptivity to change in temperature.
(2) This mixture should be able to attain plastic flow resistance.
(3) It should be possible concerning this asphalt mixture, that it could be manufactured and used in the same way as a normal modified asphalt mixture.

The following are reasons why SMA has been chosen as this asphalt mixture.
1) The SMA has a large amount of suitable asphalt in comparison with the normal mixture and it is can easily reflect the characteristics of the asphalt used in the mixture.
2) The plastic flow resistance as shown in the development concept (2) above can be easily attained.

The examples of the properties of the special modified asphalt and the SMA which uses it (hereinafter referred to as high durability SMA) are shown as follows.

2.2 Special Modified Asphalt

Table1 shows an example of the comparison of the properties of the special modified asphalt with those of the polymer modified type II asphalt type and petroleum asphalt 60/80 used for pavement.

Table 1: Example of properties of special modified asphalt

Item	Unit	Special modified asphalt	Polymer modified type II asphalt	StAs60/80
Penetration (25 ºC)	1/10mm	177	55	69
Softening point	ºC	84.0	61.5	48.0
Ductility (15 ºC)	cm	100+	86.0	100+
Ductility (4 ºC)	cm	90	54	7
Fraas breaking point	ºC	-23	-11	-12
60 ºC viscosity	Pa▪s	11,300	1,457	208
Bending strain (-10 ºC)	($x10^{-3}$)	384	-	49

From Table1, the following can be known concerning the special modified asphalt.
1) Although the special modified asphalt has penetration 100 (1/10mm) or greater than that of the petroleum asphalt 60/80 and polymer modified type II asphalt, the special modified asphalt has a softening point about 20 ºC higher than the polymer modified type II asphalt and a smaller susceptivity to change in temperature.
2) Fraas breaking point is about 10 ºC lower than those of the 60-80 petroleum asphalt and polymer modified type II asphalt. Also it has a great ductility at 4 ºC and bending strain at -10 ºC, featuring excellent resistance to brittleness and flexibility in low temperature areas.

3 HIGH DURABILITY SMA

3.1 Mix Proportion and Basic Properties

Table 2 shows the mix proportion and basic properties of high durability SMA .

Table 2: Mix proportion and properties of high durability SMA

asphalt content	Sieve size (mm) and Weight passing sieve (%)							Air voids	Stability	Flow value
	19.0	13.2	4.75	2.36	0.600	0.300	0.075	%	kN	1/100cm
5.7 %	100.0	98.8	40.7	27.5	18.9	16.3	11.0	2.6	6.5	29

3.2 Plastic Flow Resistance

The evaluation of the plastic flow resistance was carried out by the wheel tracking test (hereinafter referred to as the WT test). In the WT test, a solid tire weighing 686N is allowed to run for 60 minutes over an HMA test piece in the test room of 60 ºC. The number of runs per 1 mm deformation is evaluated as the dynamic stability (times/mm). The one having a greater dynamic stability is considered to have a greater plastic flow resistance.

The test result is shown in Table3. The dynamic stability of the high durability SMA is 5,250 (times/mm). This satisfies the target value 3,000~5,000 (times/mm) of the dynamic stability of the road which has the commercial vehicles volume of more than 3,000 (cars/day/lane).

Table 3: Dynamic stability (unit: times/mm)

Kind of mixture	High durability SMA	Polymer modified type II asphalt SMA
Dynamic stability	5,250	more than 6,000

3.3 Bending Fatigue Resistance

The bending fatigue test was performed to evaluate fatigue resistance of the tensile strain which acts on the lower surface of the pavement. The test was conducted on the special modified asphalt as well as to the SMA mixture using polymer modified type II asphalt so that they can be compared with each other. Table4 shows the test conditions and the number of cycles until rupture which was obtained by the bending fatigue test.

Table 4: Test conditions and the number of cycles until rupture

Strain level	High durability SMA	Polymer modified type II asphalt SMA	Test Conditions
300μ	1000000+	121200	Loading method : Two-point loading, both ends fixed Test specimen dimensions : 4×4×40 (cm) Span: 30 (cm) Test method: Strain control Test temperature: 5 (ºC) Frequency: 5 (Hz)
500μ	1000000+	5215	
700μ	133067	704	

In the case of the high durability SMA, rupture did not occur when the number of load cycles exceeded 1 million times for the strain levels of 300 μ and 500 μ. Since the number of cycles until rupture for 700 μ is over 100 times larger than that of the polymer modified type II asphalt SMA, it can be said that the high durability SMA has high resistance to the crack formation from bending fatigue. The resistance to fatigue due to tensile strain which works on the lower surface of the pavement has been improved. It was also found out that the high durability SMA was effective in restraining crack formation.

3.4 Effect of Restraining Temperature Crack Formation during a Time of Low Temperature

3.4.1 Stress-Relaxation at Time of Low Temperature

The temperature stress test was performed to evaluate stress-relaxation performance during the time of a low temperature. In this test, as shown in Fig1, the temperature of the test specimen which is fixed on both ends is lowered to a certain gradient. Based on the relationship between the temperature and the stress produced, the stress-relaxation performance is evaluated. When the temperature of the restricted test specimen is reduced, internal stress is generated. This stress is relaxed within a temperature range where stress-relaxation can occur. However, when the temperature drops below a certain temperature (stress relaxation limit point), the generated stress (tensile stress) increases linearly as the temperature drops. The test specimen eventually ruptures. The lower the stress-relaxation limit point, the greater the superiority of the stress-relaxation performance can be within in a broad temperature range.

The temperature stress test results are shown in Fig2. The stress limit point of the high durability SMA is located about 10 ºC below that of the polymer modified type II asphalt SMA, thus showing that the high durability SMA has excellent stress-relaxation performance. In addition, the breaking point of the high durability SMA is located more than 10 ºC lower than that of the polymer modified type II asphalt SMA. Thus, it can be expected that the high durability SMA is able to restrain temperature cracks at a temperature at least 10 ºC lower than the temperature where cracks occur in the polymer modified type II asphalt SMA.

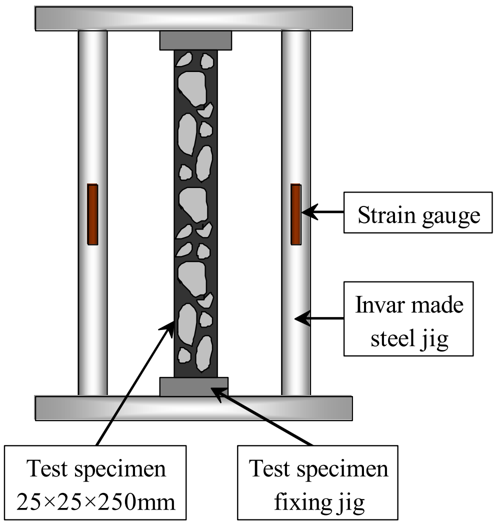

Figure 1: Schematic view of Temperature Stress Test

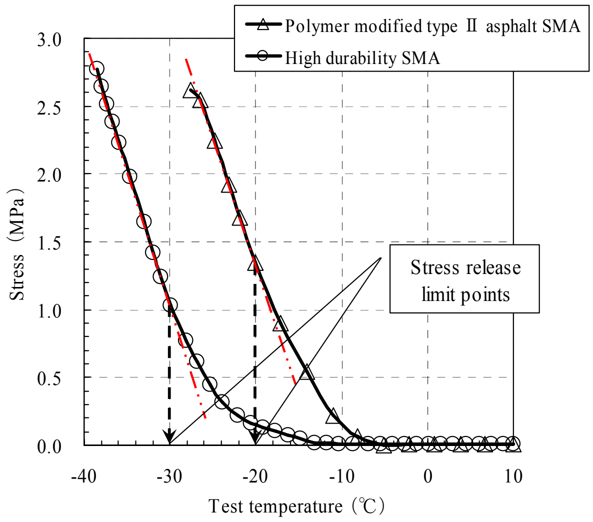

Figure 2: Temperature stress test results

3.4.2 Deformability at Low Temperature

The static bending test was carried out, using the test specimen dimensions of 5×5×30cm, with the two-point support center loading method. The loading speed was 50mm/min, and the length between the fulcrums was 20cm. In addition, the test temperature of the high durability SMA was -15 to 5 ºC, and the test temperature of the polymer modified type II asphalt SMA was -10 to 15 ºC. The results of the bending test are shown Fig3 and Fig4.

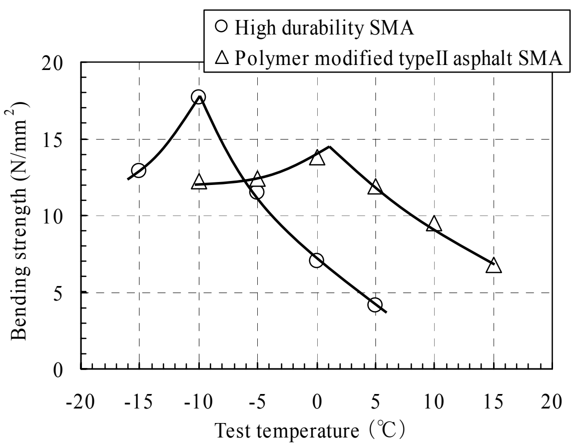

Figure 3: Comparison of bending strength

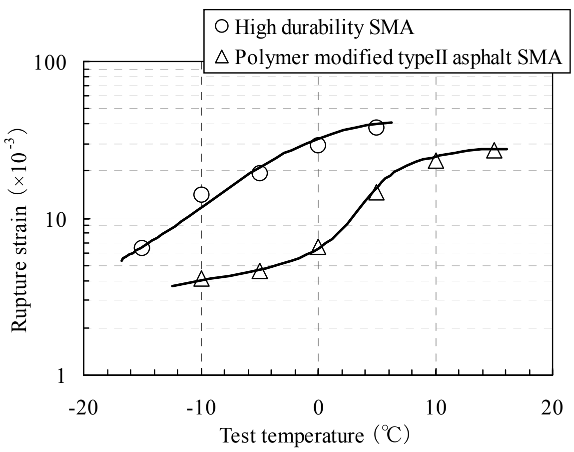

Figure 4: Comparison of bending rupture strain

As shown in Fig3, the brittle point of the high durability SMA was around -10 ºC. This is at least 10 ºC lower than that of the polymer modified type II asphalt SMA. In addition, as shown in Fig4, in the temperature range from -10 ºC to - 5 ºC, the breaking strain of the high durability SMA is about 2 to 5 times greater than that of the polymer modified type II asphalt SMA. Therefore, we have confirmed that the high durability SMA has excellent low temperature brittleness and flexibility and has the possibility of providing the reflection crack restraining effect.

4 VERIFICATION OF DURABILITY OF ACTUAL ROAD

Concrete pavement overlay repair construction was carried out on a national highway in Niigata prefecture. Because this construction was done by overlay by the heating asphalt mixture, measures to restrain reflection cracks were taken. For part of the construction sections, we used the high durability SMA for the purpose of verifying its durability and reducing the construction cost.

The following is a brief description of the construction and a follow-up inspection results 47 months after the construction.

4.1 Brief Description of Construction

For the general paved section of this construction, the cushion layer (t=30mm) of the heated type of rubber asphalt was placed on the existing concrete pavement. Then, on this layer, a dense graded asphalt mixture (13F) (t=30mm) using polymer modified type II asphalt was placed (hereinafter referred to as “general paved section”). For part of the paved section, the SMA (5mmTop) using the polymer modified type II asphalt (hereinafter referred to as “the polymer modified type II asphalt SMA (5)”) was applied on the existing concrete pavement as a water proof layer and reflection crack restraint layer. Then, the high durability SMA was set on the surface layer (hereinafter referred to as “high durability SMA paved section”).

The summary of this repair construction is shown as follows. Table5 shows the mix proportion of high durability SMA and polymer modified type II asphalt SMA.

· Construction time: August, 2003
· Construction area: 35,100m^2
  (Of which, the test paved section by the high durability SMA accounts for 650m^2)
· Pavement structure: As shown in Fig5

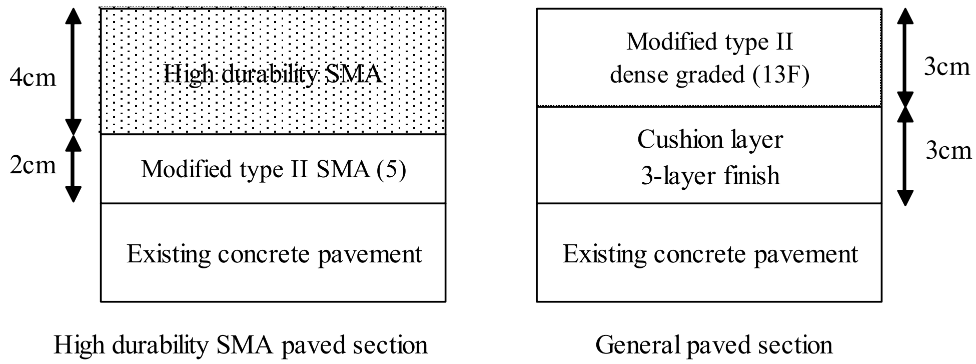

Figure 5: Pavement structures

Table 5: Mix proportion of various SMA used in repair construction

Kind of asphalt mixture	asphalt content	Sieve size (mm) and Weight passing sieve (%)					
		19.0	13.2	4.75	2.36	0.30	0.075
High durability SMA (13mmtop)	6.0 %	100.0	97.6	39.6	27.2	13.3	8.7
Polymer modified type II asphalt SMA (5mmtop)	7.9 %	100.0	100.0	94.2	41.7	15.5	10.3

4.2 Follow-up Investigation

4.2.1 Road Surface Property Investigation

The road surface property investigation was conducted 27 and 47 months after the start of service. Table6 show the measurement results of the road surface obtained by the investigation. From the measurement results, the following has been confirmed regarding the road surface property of high durability SMA paved section 47 months after the construction.
(1) The crack rate was extremely small at 0.1%. This shows that there was an excellent restraining effect of reflection crack.
(2) The rut depth was 11.1 mm. When the rut or wear depth of the national highway in Japan reaches 30～40mm, the maintenance and rehabilitation are needed. Therefore, there is no problem concerning the resistance to plastic flow and the wear resistance of the actual road.
(3) The roughness was 1.35 mm. This is almost the same as the roughness of the general paved section (=1.31 mm). Therefore, there is no problem concerning the service performance, resistance to plastic flow, and the wear resistance of the high durability SMA as road pavement.

Table 6: Road surface property

Index	high durability SMA paved section		general paved section	
	after 27 months	after 47 months	after 27 months	after 47 months
clack rate (%)	0.1	0.1	2.8	10.2
rut depth (mm)	4.8	11.1	5.0	12.5
roughness (mm)	1.14	1.35	1.14	1.31

Photos1 show the road surface condition of high durability SMA paved section and general paved section 47 months after the start of service.

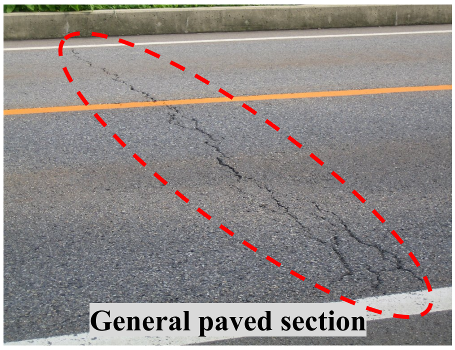

Photo 1: Road surface condition 47 months later the start of service

5 CALCULATION OF LIFE CYCLE COST

Based on the inspection results above we have calculated the life cycle cost (analysis period 40 years) of high durability SMA paved section and the general paved section.

5.1 Calculation Condition

The calculation condition is shown in Table7. The service life refers to a period until the MCI

(Maintenance Control Index) drops to 4. For the repair method, we have chosen the 6-cm-thick overlay method after scarification consisting of the surface layer + waterproof layer (The general paved section consists of the surface layer and cushion layer). The MCI is the evaluation index for road surface performance that has been developed by Ministry of Land, Infrastructure, Transport and Tourism as a means to perform maintenance on asphalt pavement. The MCI is prepared by comprehensively evaluating three factors of road surface damage (cracks, roughness, and rut). The lesser the number, the poorer the service performance was. The MCI is calculated by using the following four evaluation equations (1) to (4). The minimum of those values obtained is used as the MCI.

$$\boldsymbol{MCI} = 10 - 1.48\boldsymbol{C}^{0.3} - 0.29\boldsymbol{D}^{0.7} - 0.47\sigma^{0.2} \quad \cdots\cdots (1)$$
$$\boldsymbol{MCI_0} = 10 \cdot 1.51\boldsymbol{C}^{0.3} \cdot 0.30\boldsymbol{D}^{0.7} \quad \cdots\cdots (2)$$
$$\boldsymbol{MCI_1} = 10 \cdot 2.23\boldsymbol{C}^{0.3} \quad \cdots\cdots (3)$$
$$\boldsymbol{MCI_2} = 10 \cdot 0.54\boldsymbol{D}^{0.7} \quad \cdots\cdots (4)$$

Here; C: Crack rate (%), σ: Roughness (mm) , D: Average depth of rut (mm)

Table 7: Calculation condition

Item	LCC calculating condition	
Paved section	high durability SMA paved section	general paved section
Application mixture	High durability SMA, 4cm + Modified type II SMA, 2cm	Modified type II dense graded, 3cm + Cushion layer, 3cm
Repair construction method	Overlay after scarification	
Traffic volume division	N6	
Construction extension	3,000m	
Construction width	3.0m	
In-service period	132 months	66 months
Direct cost of construction	5,880 yen/m^2	5,600 yen/m^2
Traffic control days	5 days	10 days
Analysis period	40 years	

5.2 Service Performance Curve

Fig6 shows the service performance curve (life cycle) used for the calculation.

The number of repairs carried out in the 40 years of the analysis period is three times for high durability SMA paved section, and seven times for general paved section.

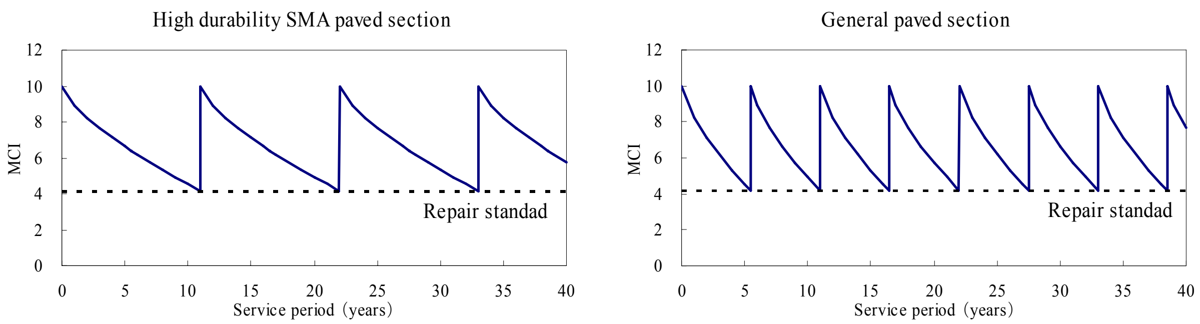

Figure 6: Service performance curve (analysis period 40 years)

5.3 Calculation Result

Table8 shows the calculation result when the analysis period is set at 40 years.

In the case where the high durability SMA is used, the expenses road management has to bear for road maintenance and repair can be reduced by about 44% when compared comparison with the general paved section.

On the other hand, the expenses that the road users have to bear due to the construction traffic control, which consist of the time loss expense and vehicle running expense, can be reduced about 44 % in comparison with that of the general paved section.

As a result, the total cost, which is obtained by deducting the residual value from the total of road management expense and the road user expense, becomes about 56% of that for the general paved section.

Therefore, it can be concluded that employment of the high durability SMA for the maintenance and repair of the concrete pavement will contribute to the longer life of the pavement, shortened construction period and reduced cost.

Table 8: Calculation result of life cycle cost

Item			Cost (1 million yen)	
Paved section			High durability SMA paved section	General paved section
Repair method			Overlay after scarification	
Road management cost			242.7	434.8
	Maintenance cost		31.0	31.6
	Repair cost		211.7	403.2
Road user cost			517.7	924.7
	Time loss cost due to the construction traffic control		116.3	465.2
	Vehicle run cost		401.4	459.4
		Vehicle running cost when passing construction traffic control section	4.2	17.0
		Vehicle running cost due to worsening of road surface condition	397.2	442.5
Residual value			9.6	22.9
Total cost			750.8	1,336.6

6 SUMMARY

We have evaluated the performance of the SMA which, for the purpose of extending life of the pavement, uses the special modified asphalt with greatly improved properties such as flexibility, stress-relaxation and resistance to brittleness at a low temperature.

The following are the findings that we have obtained.

6.1 Special Modified Asphalt

(1) It has been confirmed that the special modified asphalt has excellent performance regarding the resistance to brittleness and flexibility in low temperature areas by measuring the Fraas breaking point, low temperature ductility and bending strain.

6.2 High Durability SMA

(1) Because the dynamic stability is 5,000 (times/mm) or greater, it can be applied to a heavy traffic road.
(2) The bending fatigue test found that the resistance to fatigue due to tensile strain which works on the lower surface of the pavement drastically improved. Therefore, the high durability SMA is effective in restraining crack formation.
(3) It can be expected that the high durability SMA has excellent stress relaxation performance and is able to restrain generation of temperature cracks at a temperature at least 10 ºC lower than that of the polymer modified type II asphalt SMA.
(4) The braking strain of the high durability SMA by the static bending test is 2 to 5 times greater than that of the polymer modified type II asphalt SMA. Therefore, it has been confirmed that the high durability SMA is the mixture which has excellent resistance to low temperature brittleness and flexibility and is able to provide reflection crack restraining effect.

6.3 Application on an Actual Road

(1) When the high durability SMA was applied to the upper part (4cm) of the overlay (6cm) on concrete pavement, the crack rate was 0.1 % whereas the rate for the general paved section (cushion layer 3cm) was 10.2 %.
(2) The service ability of the high durability SMA as a road pavement was also comparable to that of other pavement cross-section.
(3) The life cycle cost of the paved section with high durability SMA is about 56 % of that of the general paved section. Therefore, it can be concluded that employment of the high durability SMA for maintenance and repair will contribute to a longer life of the pavement, shortened construction periods and reduced cost.

7 CONCLUTION

The SMA which uses special modified asphalt has improved properties such as flexibility, stress-relaxation and resistance to brittleness at low temperatures, and therefore has an excellent reflection crack restraining effect. It is expected that the employment of this asphalt for the pavement maintenance and repair can lengthen the life of the road.

We are determined to continue follow-up inspections for longer periods of time to accumulate data and confirm the durability concerning the reflection crack restraining effect.

REFERENCES

Hayashi, et al, 2006. *Follow-up inspection result of the reflection crack preventive construction method by using special modified asphalt mixture.* The tenth Hokuriku road pavement meeting, Japan.

Japan Asphalt Association, 1993. *Guide to design and construction of mixture which uses modified asphalt.*

Koseki, Suzuki, Ikeda, 1996. *Second international meeting on pavement reflection crack*, Asphalt, pp.57-62, Japan.

Nakamura, et al, 1994. *Fatigue tests of asphalt mixture*, Civil engineering technical data, Japan.

Yamanokuchi, Maruyama, 1997. *"Super" introduction to pavement studies*, asphalt pavement repair technology, Sankaido, Japan.