Long-term Properties of Recycled Asphalt in Cold, Snowy Regions

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ABSTRACT: The properties of asphalt were examined by repeatedly recycling straight asphalt used in cold, snowy regions with a penetration value of 20 (1/10 mm) – the lowest current standard for old asphalt adhering to recycled asphalt aggregate in Japan. The results revealed that the straight asphalt pen.80-100 used in cold, snowy regions becomes more susceptible to deterioration, and that the influence of recycling additives as well as the asphalt's chemical and physical properties varied more dramatically than with the straight asphalt pen.60-80 used in Japan's main island of Honshu and other regions. In addition, the results of a test in which straight asphalt pen.80-100 was repeatedly recycled confirmed the feasibility of controlling the amount of additives and variations in physical and chemical properties by selecting appropriate recycling additives.

KEY WORDS: Cold snowy regions, recycled asphalt, rejuvenator, repetition recycling

1 INTRODUCTION

In response to international interest in environmental conservation in recent years, measures for the establishment of a recycling-oriented society have been promoted in various fields.

The field of road pavement is no exception, and recycling of asphalt pavement materials has been conducted on a full-scale basis in Honshu and other regions since the 1980s. In Hokkaido, which is a cold, snowy region, recycled asphalt aggregate has been used for surface mixtures since 1998. As such aggregate will be recycled for the second and subsequent times in the future, a deterioration in the penetration value of some recycled aggregate is expected.

The current standard for recycled asphalt using recycled aggregate is a penetration value of 20 (1/10 mm) or higher (Japan Road Association, 2004) as determined using the results of test pavement containing recycled aggregate produced from the straight asphalt with a penetration value of 60-80 used for pavement in Honshu(Yasuzaki et al. 1989). However, straight asphalt pen.80-100 is used in Hokkaido in consideration of thermally induced cracking and other problems found in low-temperature environments.

Since recycled asphalt requires a level of quality equal to that of new material, rejuvenator is added to asphalt hardened by deterioration to restore a penetration value of 90 (1/10 mm) in Hokkaido. The aim is to restore a value of 70 (1/10 mm) in cold, snowy areas of Honshu and 50 (1/10 mm) in other areas (Japan Road Association, 2004).

If penetration in asphalt that has undergone deterioration to the lowest standard value of 20 (1/10 mm) is restored under the above conditions and its deterioration and recycling are repeated, the range of restoration of penetration is 70 (1/10 mm) in Hokkaido, while the corresponding value is 30 or 50 (1/10 mm) in Honshu and other regions. Since the range of restoration of penetration is greater in Hokkaido, the influences of deterioration and the properties of additives accumulated in pavement materials are expected to manifest more significantly and result in greater variations in asphalt properties.

In this study, the properties of asphalt after repeated recycling were examined using two types of straight asphalt in order to develop a method for the long-term use of pavement materials. The influence of the properties of additives on asphalt properties at the time of recycling was also clarified by using three different types of additive.

2 DIFFERENCES IN LONG-TERM PROPERTIES BY QUALITY STANDARDS OF STRAIGHT ASPHALT

2.1 Evaluation Method

Straight asphalt pen.80-100 used in cold, snowy regions and straight asphalt pen.60-80 were deteriorated and recycled repeatedly, and their physical and chemical properties were evaluated in six stages as shown in Figure. 1. The stages will be referred to here as shown on the right side of the figure. The details of the deterioration, recycling and evaluation tests are described below. Our evaluation was based on laboratory aged asphalt, and not on field aged asphalt.

a) Deterioration method

The RTFOT and PAV test methods (Japan Road Association, 2007) were used. While the RTFOT is a test to simulate heat deterioration during plant mixing, the PAV test simulates deterioration during long-term use.

The RTFOT procedure was conducted at 163 degrees C for 85 minutes, and the specimens after the completion of the test were deteriorated with a pressure of 2.1 MPa (air) at 100 degrees C until a penetration value of 20 (1/10 mm) was reached.

The deterioration times for straight asphalt 80-100 were 1.25 times (Cycle 1), 1.4 times (Cycle 2) and 1.5 times (Cycle 3) longer than those for straight asphalt 60-80, indicating a tendency for the difference in deterioration time to increase with the deterioration frequency.

Accordingly, it was presumed that differences in asphalt properties would increase with more repetitions of deterioration.

b) Recycling method

Penetration was adjusted using additives in accordance with the Manual for Pavement Recycling (Japan Road Association, 2004), recycled asphalt was restored to satisfy the respective penetration standards, and asphalt was added to perform recycling at a recycled mixture rate of 50%.

The target penetration value was 90 (1/10 mm) for straight asphalt pen.80-100, and that for straight asphalt pen.60-80 was set at pen.70 (1/10 mm) (Japan Road Association, 2004) with cold, snowy areas of Honshu and other regions in mind.

c) Evaluation test

The four tests listed in Table 1 (involving three physical property items and one chemical property item) were conducted at the six stages shown in Figure. 1.

The penetration, softening point and component analysis methods were implemented in accordance with the Pavement Test Method Manual, and the Moriyoshi breaking point test was conducted.

This breaking point investigation is a heat stress test to directly measure the destruction temperature of asphalt by heat stress at low temperatures. In the test, a specimen with a thickness of around 3 mm is prepared by placing approximately 50 g of asphalt in a stainless steel container measuring 14 cm in diameter, and is soaked in a low-temperature tank filled with methyl alcohol to find the temperature at which asphalt breaks from heat stress (known as the Moriyoshi breaking point). This test is performed twice for each specimen, and is conducted again if the Moriyoshi breaking point varies by 2 degrees C or more.

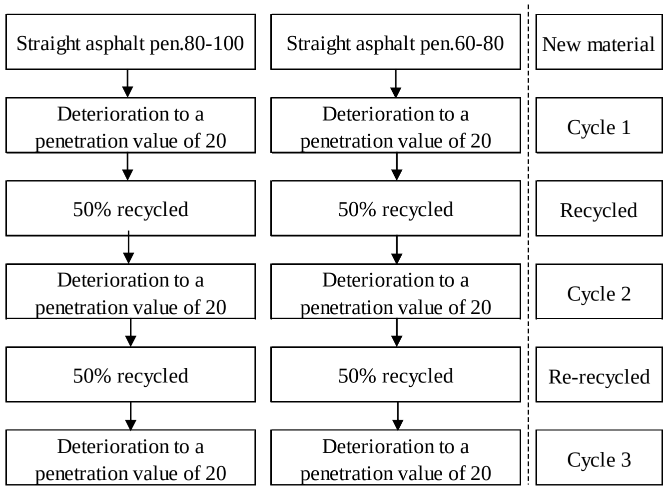

Figure1: Recycling procedure

Table 1: Evaluation test

Test item	Test method
Penetration test	Pavement survey・Pavement Test Method Manual A041
Softening point test	Pavement survey・Pavement Test Method Manual A042
Moriyoshi breaking point test	As described separately
Component analysis test	Pavement survey・Pavement Test Method Manual A055

2.2 Evaluation Test Conditions

Table 2 shows the additive addition rates at each stage. The degree of penetration to be restored varies, as the target penetration value for straight asphalt pen.80-100 is 90 (1/10 mm) and that for straight asphalt pen.60-80 is 70 (1/10 mm). The rates were therefore higher for the former than for the latter in both recycling and re-recycling, and also tended to be higher in re-recycling than in recycling for both types of asphalt.

From the above results, it was presumed that the additive addition rate would become higher through repeated recycling, and that the influence of the nature of additives would become more significant for straight asphalt pen.80-100 than for straight asphalt pen.60-80.

Table 2: Recycling additive addition rates

Condition	Straight asphalt pen.80-100		Straight asphalt pen.60-80	
	Recycled	Re-recycled	Recycled	Re-recycled
Recycling additive(%)	14	18	9	11

※ Components of recycling additives:Saturation fraction 57.9%, Aromatic fraction 36.6%, Resin fraction 5.5%

2.3 Physical Property Evaluation Results

a) Penetration

Figure 2 shows the results of the penetration test under different conditions. Penetration for both types of asphalt tended to increase with repeated recycling. However, the penetration standards of 80 to 100 and 60 to 80 for the respective types were satisfied.

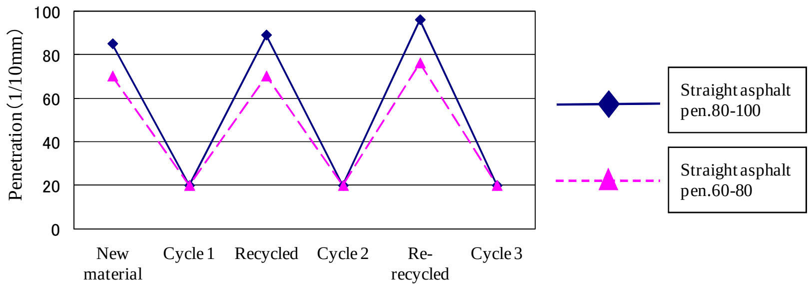

Figure2: Penetration test

b) Softening point

Figure 3 shows the results of the softening point test under different conditions. The softening points of both straight asphalt pen.80-100 and pen.60-80 tended to increase as the cycles were repeated. The increase rate of the softening point was especially high for straight asphalt pen.80-100, and exceeded 80°C in the second and subsequent cycles, indicating a more significant tendency of increase for the softening point than that for straight asphalt pen.60-80. This was thought to be because the reduction rate of penetration for straight asphalt pen.80-100 was about 20 greater than that for straight asphalt pen.60-80.

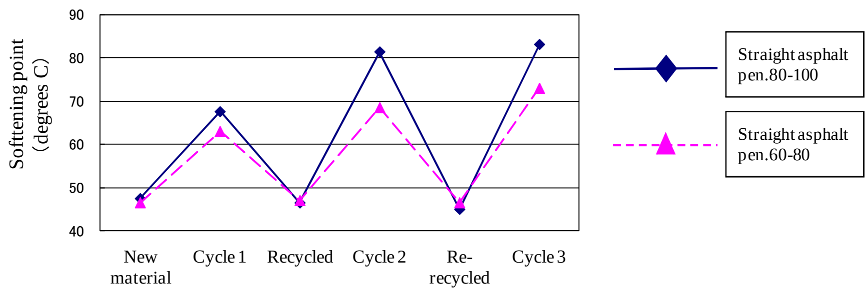

Figure3: Softening point test results

c) Moriyoshi breaking point

Figure 4 shows the results of the Moriyoshi breaking point test under different conditions. Asphalt with a low Moriyoshi breaking point is preferable for cold, snowy regions, as damage at low temperatures can be prevented more if the breaking point is lower.

While the values for straight asphalt pen.80-100 and pen.60-80 were similar for Cycle 1, the tendency changed after recycling.

For straight asphalt pen.60-80, the reduction in the Moriyoshi breaking point (possibly due to the influence of the additive) was more significant than its increase due to deterioration. When recycling was repeated while adjusting the penetration, the value gradually became lower than the Moriyoshi breaking point of new material, resulting in an improvement of properties at low temperatures.

While the reduction rate for the breaking point of straight asphalt pen.80-100 was higher than that for straight asphalt pen.60-80 in recycling and re-recycling, the increase rate of the Moriyoshi breaking point during deterioration was also higher at around -16 degrees C, which was approximately 8 degrees C higher than that of new material, and the tendency was different from that of straight asphalt pen.60-80.

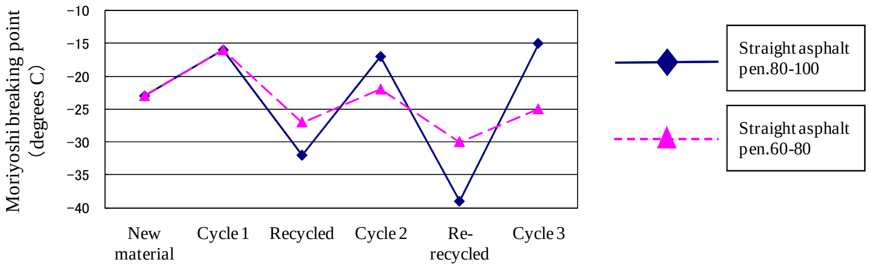

Figure4: Moriyoshi breaking point test results

2.4 Chemical Property Evaluation Results

Figures 5 shows the results of component analysis by asphalt type under different conditions.

It has been reported that asphaltene and the resin fraction generally increase and the aromatic and saturation fractions decrease with deterioration, and that the component composition can be restored using an additive mainly consisting of aromatic and saturation fractions in recycling (Taniguchi et al. 1990).

In the test results of this study, the saturation fraction tended to increase with repeated recycling of both asphalt types under the influence of the composition of an additive in which the saturation fraction accounts for approximately 60%. Especially in the case of straight asphalt pen.80-100, the saturation fraction (which was 23.3% for new material) increased to 37.3% after re-recycling, indicating a significant increase with repeated recycling.

Asphaltene tended to accumulate with repeated deterioration for both types of asphalt. The accumulation tendency was more significant for straight asphalt pen.80-100 than for straight asphalt pen.60-80.

It was presumed from the above results that the component composition of straight asphalt pen.80-100 with a higher penetration standard fluctuated more significantly before and after deterioration and recycling, and that restoration of a composition similar to that of new material would become more difficult after repeated recycling than that for straight asphalt pen.60-80 with a low penetration standard.

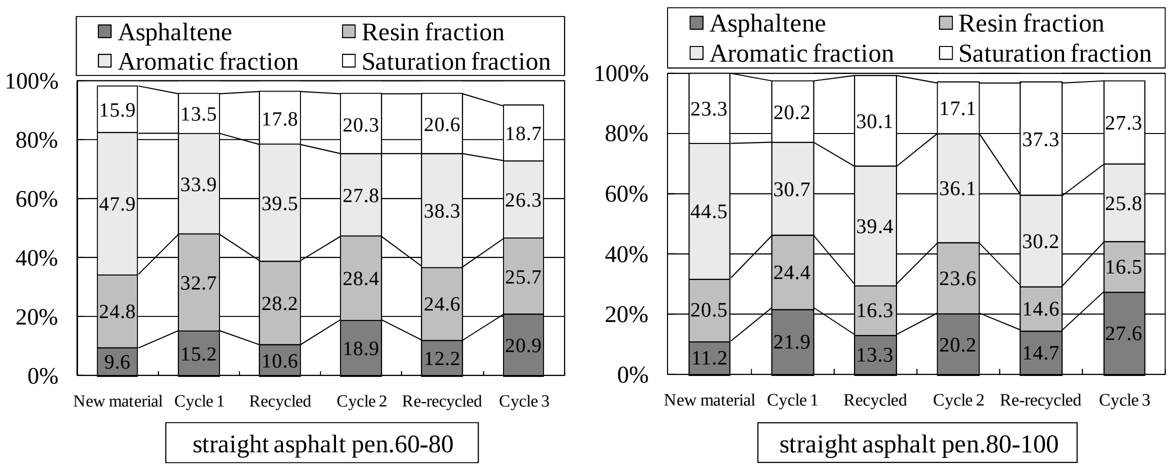

Figure5: Component analysis test results

3 EVALUATION BY DIFFERENCES IN ADDITIVES

3.1 Evaluation Method

The above results confirmed that straight asphalt pen.80-100 was influenced more by the composition of the additive through repeated recycling and that the composition of asphalt fluctuated more significantly than with straight asphalt pen.60-80, and that fluctuations in the softening point and other physical properties were also greater if deterioration occurred under the same penetration conditions.

Accordingly, straight asphalt pen.80-100 was recycled repeatedly using additives with different properties, and the influence of these properties was examined by evaluating the physical and chemical properties of the asphalt at each stage.

Figure 6 shows the flow chart of this study. Each evaluation stage will be referred to here as shown on the right side of the figure. An overview of the additives and the deterioration, recycling and evaluation test methods is given below.

a) Additives

Table 3 shows the properties of the additives used in this study. Three types with different component compositions were selected. The viscosity ratio and the mass change rate after the film heating test can evaluate heat resistance performances of recycling additives. Standard values for both ratios are between plus and minus 3%. The ratios of additives used in this study are within this range. Additive C was the same as that used in “2. Differences in long-term properties by quality standards of straight asphalt.”

b) Deterioration method

Three deterioration conditions were set using the RTFOT and PAV tests. A deterioration condition of 20 hours (the standard PAV test time) was adopted to simulate the conditions of recycling asphalt deteriorated to the level of material used for 5 to 10 years (Tonishi et al. 1995) deterioration until the penetration value reached 20 (1/10 mm) was adopted by adjusting the PAV test time to simulate the conditions of repeated recycling at the lowest current standard value for recycled asphalt in recycled asphalt aggregate, and deterioration until the penetration value reached 30 was adopted to simulate repeated recycling with a higher standard value.

c) Recycling method

As described in chapter two, the recycling additives shown in the Manual for Pavement Recycling were used to adjust the level of penetration. The target penetration value was 90 (1/10 mm), and the recycled mixture rate was 50%.

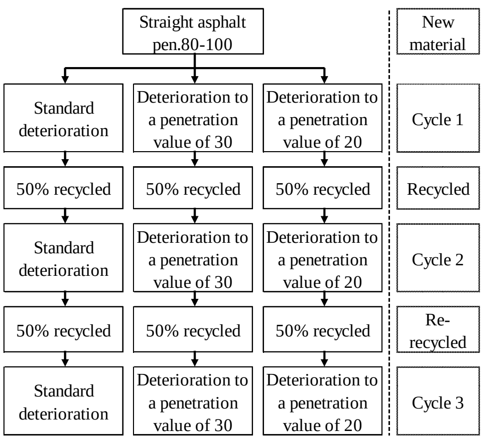

Figure6: Recycling procedure

d) Evaluation test

A total of five tests (involving four physical property items and one chemical property item as shown in Table 1 and ductility test) were conducted at the six stages shown in Figure. 6.

Table 3: Recycling additives

		Recycling additives		
		A	B	C
Density (15 degrees C)	(g/cm^3)	1.011	0.984	1.014
Kinetic viscosity (60 degrees C)	(mm^2/s)	196	94.9	99.6
Flash point	(degrees C)	256	240	242
Viscosity ratio after film heating	(%)	1.4	1.2	1.2
Mass change rate resulting from film heating	(%)	0.4	-1.2	-1.6
Asphaltene	(%)	0.8	0.7	0.0
Saturation fraction	(%)	40.7	30.5	57.9
Aromatic fraction	(%)	50.8	44.3	36.6
Resin fraction	(%)	7.8	24.5	5.5

3.2 Evaluation Test Conditions

Table 4 shows the additive addition rates in recycling, and those in re-recycling. Although the amounts of penetration to be restored in recycling and re-recycling are uniform in the cases of deterioration to penetration values of 20 and 30 since penetration after deterioration is fixed, the necessary additive rate tended to be higher for re-recycling than for recycling regardless of deterioration conditions or additive types. The additive addition rate under the same deterioration conditions tended to increase in the order of A, B and C.

Table 4: Recycling additive addition rate

Condition	Recycled									Re-recycled								
	Standard deterioration			Deterioration to a penetration value of 30			Deterioration to a penetration value of 20			Standard deterioration			Deterioration to a penetration value of 30			Deterioration to a penetration value of 20		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Recycling additives (%)	6	8	8	6	8	7	9	11	14	5	6	7	7	9	11	11	14	18

3.3 Physical Property Evaluation Results

a) Penetration

The left side of table 5 shows the results of the penetration test under different conditions. Since the deterioration time was fixed in the case of standard deterioration, fluctuations in the level of penetration were observed after deterioration. However, since the amount of penetration was fixed by adjusting the deterioration time in the cases of deterioration to penetration values of 30 and 20, the penetration values for each cycle were uniform.

b) Ductility

The right side of table 5 shows the results of the ductility test under different conditions. While the standard value of 100 cm or more (Japan Road Association, 2004) for the recycled asphalt ductility test was satisfied in both recycling and re-recycling in the cases of standard deterioration and deterioration to a penetration value of 30, this value was not satisfied when Additive C was used for re-recycling in the case of deterioration to a penetration value of 20.

Table 5: Penetration test and Ductility test results

Condition		Penetration (1/10mm)						Ductility (cm)					
		New material	Cycle 1	Recycled	Cycle 2	Re-recycled	Cycle 3	New material	Cycle 1	Recycled	Cycle 2	Re-recycled	Cycle 3
Standard deterioration	A			89	37	87	38			100	8	100	8
	B		26	85	36	82	37		5	100	7	100	7
	C			84	39	86	34			100	7	100	5
Deterioration to a penetration value of 30	A			84	30	88	30			100	5	100	4
	B	85	30	85	30	94	30	100	6	100	5	100	5
	C			81	30	90	30			100	5	100	4
Deterioration to a penetration value of 20	A			82	20	86	20			100	3	100	3
	B		20	85	20	88	20		0	100	3	100	3
	C			89	20	96	20			100	3	65	2

c) Softening point

The left side of table 6 shows the results of the softening point test under different deterioration conditions. In the case of standard deterioration, the softening point after each cycle was around 55 to 60 degrees C regardless of the number of cycles.

While the softening point increased with a higher number of cycles regardless of the additive type in the case of deterioration to a penetration value of 30, the value was around 60 degrees C for each cycle.

In the case of deterioration to a penetration value of 30, the softening point increased dramatically with a higher number of cycles, and exceeded 70 degrees C for Cycle 2. The increase in the softening point was especially significant when Additive C was used, and exceeded 80 degrees C for Cycles 2 and 3.

While it has been reported in a study on highways that the number of cracks increases when the softening point reaches 60 to 63 degrees C (Tonishi et al.,1995), this value was far exceeded in the case of deterioration to a penetration value of 20 regardless of the type of additive.

d) Moriyoshi breaking point

The right side of table 6 shows the results of the Moriyoshi breaking point test under different deterioration conditions. Regardless of the type of additive, the fluctuation range of the Moriyoshi breaking point was greater in the order of standard deterioration, deterioration to a penetration value of 30 and that to a value of 20, and fluctuations in the breaking point tended to increase with repeated deterioration and recycling. Fluctuations in the breaking point tended to be greater when additive C was used compared with additives A and B, regardless of deterioration conditions.

Table 6: Softening point test and Moriyoshi breaking point test results

Condition		Softening point(degrees C)						Moriyoshi breaking point(degrees C)					
		New material	Cycle 1	Recycled	Cycle 2	Re-recycled	Cycle 3	New material	Cycle 1	Recycled	Cycle 2	Re-recycled	Cycle 3
Standard deterioration	A			45.5	55.0	45.0	56.0			-27	-23	-29	-23
	B		60.2	45.0	56.0	45.5	55.0		-20	-26	-23	-29	-25
	C			47.0	57.5	46.5	61.5			-28	-21	-31	-19
Deterioration to a penetration value of 30	A			45.0	61.5	46.0	62.5			-28	-24	-31	-23
	B	47.5	58.6	45.0	61.0	45.0	62.0	-23	-22	-26	-26	-31	-26
	C			49.0	61.2	46.0	63.6			-29	-21	-34	-18
Deterioration to a penetration value of 20	A			45.5	72.5	45.5	73.5			-28	-24	-30	-21
	B		67.5	45.0	72.5	45.0	76.0		-16	-30	-21	-33	-22
	C			46.5	81.3	45.0	83.0			-32	-17	-39	-15

3.4 Chemical Property Evaluation Results

The left side of table 7 shows the results of component analysis in the case of deterioration to a penetration value of 30 by additive type. Asphaltene tended to accumulate gradually with a higher number of cycles, regardless of the type of additive used. No marked difference in component composition change by additive was observed in the three cycles of this study.

The right side of table 7 shows the results of component analysis in the case of deterioration to a penetration value of 20 by additive type. Similarly to the case of deterioration to a penetration value of 30, asphaltene tended to accumulate gradually with a higher number of cycles regardless of the type of additive used, and the percentage of asphaltene was even higher. Since past studies reported that asphaltene increases with longer PAV deterioration times(Kimura et al. 1999), the difference in the percentage of asphaltene between the two cases here was thought to be due to the deterioration time.

The saturation fraction percentages after the three cycles were 17.9, 18.8 and 27.3% in the cases with additives A, B and C, respectively. As shown in Table 4, the values differed greatly in the case using additive C with a high saturation fraction rate.

While the influence of differences in additive composition on the components of asphalt was not remarkable in the case of deterioration to a penetration value of 30, such a difference manifested in the case of deterioration to a penetration value of 20, probably because of the high additive addition rate.

Table 7: Component analysis test results

	Recycling additives	Deterioration to a penetration value of 30						Deterioration to a penetration value of 20					
		New material	Cycle 1	Recycled	Cycle 2	Re-recycled	Cycle 3	New material	Cycle 1	Recycled	Cycle 2	Re-recycle	Cycle 3
Asphaltene	A	11.2	16.7	14.0	19.2	13.8	22.7	11.2	21.9	13.5	23.9	15.5	27.3
	B			13.0	19.7	14.7	20.6			13.5	18.9	13.4	25.2
	C			13.4	19.7	14.4	20.3			13.3	20.2	14.7	27.6
Resin fraction	A	20.5	27.5	22.7	24.6	23.7	21.1	20.5	24.4	25.8	23.3	21.9	20.5
	B			23.7	25.9	22.0	20.1			17.6	28.3	19.6	19.7
	C			21.7	27.7	23.6	25.3			16.3	23.6	14.6	16.5
Aromatic fraction	A	44.5	37.1	39.2	31.9	41.6	29.5	44.5	30.7	39.8	29.3	40.6	27.4
	B			42.5	32.0	40.1	31.4			33.3	29.0	35.9	27.8
	C			36.7	31.4	36.8	30.2			39.4	36.1	30.2	25.8
Saturation fraction	A	23.3	15.9	20.9	18.4	16.6	21.0	23.3	20.2	18.1	17.2	16.6	17.9
	B			16.9	17.2	20.2	17.6			34.3	16.7	28.8	18.8
	C			25.4	17.0	21.7	19.7			30.1	17.1	37.3	27.3

3.5 Relationship Between Additives and Various Properties

The fluctuations in the asphalt softening point, Moriyoshi breaking point and composition after repeated recycling tended to be greater in the cases using additive C (with a higher rate of saturation fraction than aromatic fraction) than those using additives A and B (with a higher rate of aromatic fraction than saturation fraction). Thus, the additive A and B, which contain more saturates compare to additive C, have possibility to keep longer pavement’s life in better condition.

4 CONCLUSIONS

The findings of the study are as follows:

(1) When material that had undergone penetration to a value of 20 (1/10 mm) was recycled repeatedly, fluctuations in physical and chemical properties were more significant for straight asphalt pen.80-100 than for straight asphalt pen.60-80.
(2) With increases in the adjustment range of penetration and the frequency of recycling, the influence of the nature of additives on the physical and chemical properties of asphalt becomes greater.
(3) As a result of repeatedly recycling asphalt that had undergone deterioration to a penetration value of 20 using three additives with different component compositions, the softening point increased greatly and asphaltene tended to accumulate regardless of the additive type.
(4) While a tendency for asphaltene accumulation was seen with asphalt that had undergone deterioration to a penetration value of 30, no significant increase in the softening point was observed.

5 FUTURE TASKS

The implementation of quality control with a penetration value of 20 (1/10 mm) – the lowest standard for recycled asphalt in recycled aggregate in Hokkaido, where straight asphalt pen.80-100 is used – may result in a significant increase in the softening point of asphalt and dramatic fluctuations in component composition.

The penetration value of recycled asphalt for recycled aggregate in Hokkaido is currently around 36 (1/10 mm), which is higher than the standard value of 20 (1/10 mm). However, since the emergence of recycled aggregate with a penetration value of 20 (1/10 mm) is expected in the near future, there is an urgent need to consider certain quality control standards.

This study primarily focused on asphalt itself. However, since it was found possible to control fluctuations in the softening point and component composition by applying a higher penetration standard, the authors plan to continue the development of quality control standards suitable for cold, snowy regions through further studies. These include the examination of mechanical properties in asphalt mixtures and comparison of laboratory test results and the properties of recycled asphalt pavement in service.

REFERENCES

Japan Road Association, 2004. *Manual for Pavement Recycling*

Japan Road Association, 2007. *Pavement Test Method Manual*

Kimura, M and Ikeda, T., 1999. A study of an accelerated degradation method for asphalt mixtures, Proceedings of the 54th Annual Conference of the Japan Society of Civil Engineers, Part 5.

Moriyoshi, A., Takahashi, M and Zhang, Y., 1987. *Test method for asphalt cracking at low temperature*, Bulletin of The Japan Petroleum Institute, Vol. 30, No. 4.

Taniguchi, T., and Ito T.,1990, *Deterioration of asphalt, ASPHALT*, Vol. 33 No. 164.

Tonishi, T., Nitta, H., Sakamoto, H., and Kawakami, K.,1995. A study on a method for deterioration testing of asphalt binders, Pavement 30 – 6.

Yasuzaki, H., Katakura, H., and Takagi, N.,1989. *Performance evaluation of recycled hot asphalt*, Civil Engineering Journal, 31 – 9.