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Laboratory Performance Evaluation of Recycled Asphalt Binders with Differing Rejuvenators

재생 첨가제를 활용한 재활용 아스팔트 바인더의 실내 공용성 평가

Kim, Yeong Min	김영민	Member · Korea Institute of Civil Engineering and Building Technology · Senior Researcher (E-mail : choozang@kict.re.kr)
Im, Jeong Hyuk	임정혁	Member · Korea Institute of Civil Engineering and Building Technology · Senior Researcher · Ph.D. Corresponding Author (E-mail : jhim@kict.re.kr)
Hwang, Sung Do	황성도	Member · Korea Institute of Civil Engineering and Building Technology · Research Fellow · Ph.D. (E-mail : sdhwang@kict.re.kr)
Jeong, Kyu Dong	정규동	Member · Korea Institute of Civil Engineering and Building Technology · Senior Researcher · (E-mail : kdjeong@kict.re.kr)
Rhee, Suk Keun	이석근	Member · Kyung Hee University · Professor · Ph.D. (E-mail : skrhee@khu.ac.kr)

ABSTRACT

PURPOSES : The objective of this study is to investigate the properties of recycled asphalt binders with five different rejuvenators, in order to evaluate the applicability of the recycled asphalt binders compared with the original asphalt binder.

METHODS : In order to simulate recycled asphalt binders, fresh asphalt binders are aged by various Superpave aging procedures, such as the rolling thin-film oven (RTFO) and the pressure aging vessel (PAV). Then, selected rejuvenators are added to the aged asphalt binders in the amount of 5%, 10%, and 15%. The asphalt binder properties are evaluated by the dynamic shear rheometer (DSR), the rotational viscometer (RV), and the bending beam rheometer (BBR). In this study, AP-5 (penetration grade 60-80, PG 64-16) asphalt binder is used. A total of five types of rejuvenators are employed.

RESULTS AND CONCLUSIONS : When considering aged asphalt without a new asphalt binder, it seems that the percentage of rejuvenator used in Korea is a bit too low, and that it fails to possess the characteristics of the original binder. From the current practice of evaluating the properties of recycled binder based on penetration ratio only, the amount of rejuvenator required is similar for the long-term-aged binder, but is excessive for the longest-term aged binder, causing deterioration of workability and stiffness of the recycled binder.

Keywords
recycled asphalt binder, asphalt binder aging, rejuvenator, asphalt binder grade

Corresponding Author : Im, Jeong Hyuk, Senior Researcher
Highway and Transportation Research Institute,
Korea Institute of Civil Engineering and Building Technology, 283, Goyangdae-ro, Ilsanseo-gu, Goyang-si, Gyeonggi-do, 10223, Korea
Tel : +82.31.995.0894 Fax : +82.31.910.0161
E-mail : jhim@kict.re.kr

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1. INTRODUCTION

As the interest in the environmental issues has been increased over time, the need of recycling of construction wastes has been increased as well in Korea. Especially, in pavement industry, contractors who have more than 22 million dollars of yearly amount of construction must recycle waste soil, concrete, asphalt, etc., which are necessarily produced during constructions. In Korea, the amount of asphalt wastes is 11,388 ton/day and 20,162 ton/day in 2000 and 2004 respectively. In general, the generation rate of asphalt wastes is increased 15.5% per year (National Institute of Environmental Research 2006). Therefore, Korean government promotes strongly a policy for the recycling of construction wastes (Nho 2013).

In order to recycle the asphalt wastes, the most important factors are the property of recycled asphalt, asphalt contents, and aggregate gradation. The asphalt contents and aggregate gradation can be evaluated easily by the Marshall Mix design, which is typically used for HMA mixture design to produce a new asphalt mixture (Jeong et al. 2002). In Korea, the property of recycled asphalt should be evaluated carefully to meet the requirements. The penetration ratio and PG (performance grade) methods are normally used in Japan and US, respectively (Huh et al. 2003).

2. OBJECTIVE

The objective of this study is to investigate the properties of recycled asphalt binders with five different rejuvenators in order to evaluate the recycled asphalt binders' applicability comparing with the original asphalt binder.

3. METHODOLOGY

3.1. Asphalt Binder Aging (Hardening)

Asphalt binder is one of the most famous materials obtained through fractional distillation of crude oil. The asphalt binder continuously experiences oxidative aging due to its organic nature (Dave et al. 2010). In general, as time increases, the penetration ratio and viscosity of the asphalt binder decrease. Hence, the asphalt binder shows more stiff and brittle properties (Lee et al. 2008, Kim et al. 2002, Morian et al. 2011).

Hardening effects increase the traffic loading-carry capacity and the rutting resistance of asphalt pavements. However, the hardening effects weaken the resistance for cracking, moisture, and abrasion of asphalt pavements. Therefore, this hardening of asphalt binder leads to the failure of pavement system (Houston et al. 2007, Charles et al. 2009, Lopes et al. 2012).

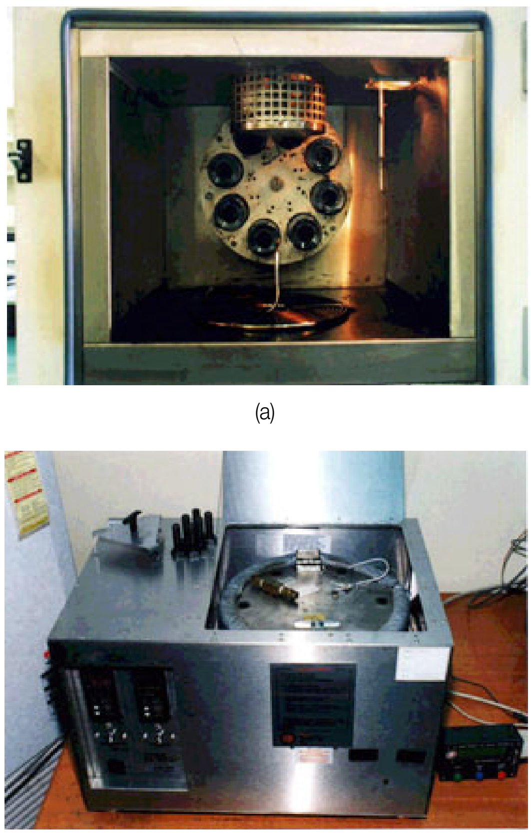
Asphalt binder aging hardening can be divided into two stages, such as short-term aging/hardening and long-term aging (in-situ field aging) (Mirza and Witczak 1996). The short-term aging occurs during mixing, transportation, and construction, while the long-term aging occurs during the service life of pavements (Dave et al. 2010, Lee et al. 2008).

3.2. Asphalt Binder Aging Methods

In order to simulate aging levels of asphalt binders, the rolling thin film oven (RTFO) and the pressure aging vessel (PAV) are used under the Superpave binder aging procedures (Asphalt Institute 2003).

3.2.1. Rolling Thin Film Oven (RTFO)

RTFO is a device to age thin layered asphalt binder in order to simulate aged asphalt binder during procedures of mixing with aggregate at asphalt plant, moving to construction site, and paving in field. For the RTFO aging, typically, 35g of asphalt binder is rotated in RTFO jar at 15 rpm at 163 ± 0.5℃



(a)

(b)

Fig. 1 (a) RTFO and (b) PAV

with air jet at 4000 ml/minute for 85 minutes. The RTFO-aged binder is calculated for mass loss and then used for the DSR test and the PAV aging. After aging, the mass loss is calculated, and then the aged binder is used for the DSR test and the RAV aging. The RTFO is specified by AASHTO T240 and ASTM D 2872. Fig. 1 (a) shows the RTFO device.

3.2.2. Pressure Aging Vessel (PAV)

In order to simulate the effect of long term in-service aging of asphalt, the PAV exposes the asphalt binder, which is aged by RTFO, to high pressure and temperature. AASHTO R 28 specifies the procedure that is to use 3.18 mm film thickness of RTFO-aged binder at a pressure of 2.07 Mpa for 20 hours at 90 to ± 0.5℃. The PAV-aged binder is normally used for the DSR test, the bending beam rheometer (BBR), and the direct tension test (DTT). Fig. 1 (b) shows the PAV device.

3.3. Asphalt Binder Property Test

3.3.1. Dynamic Shear Rheometer (DSR)

The DSR is a common device to characterize the elastic and viscoelastic behaviors of asphalt binders because both loading time and temperature affect asphalt behavior. Asphalt binder specimen is placed between fixed plate and oscillating plate in parallel. The viscous and elastic behavior of asphalt binder are characterized by the complex shear modulus (G*) and phase angle (δ) that are measured by the DSR. With normal pavement service temperatures and traffic loadings, the behavior of asphalt binder is characterized more completely by the outcome of the DSR (measuring G* and δ). Fig. 2 (a) shows the schematic of DSR test.

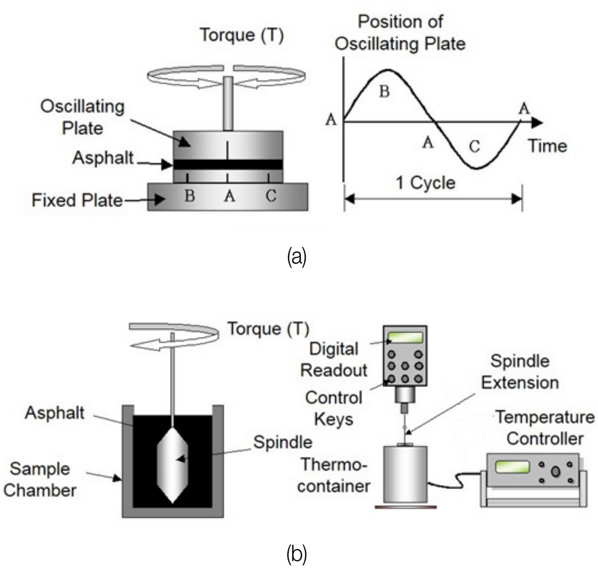


Fig. 2 Schematic of : (a) DSR Test and (b) RV Test

3.3.2. Rotational Viscometer (RV)

The RV test is normally used to provide workability i.e., fluid enough to pump and mix with aggregate, of asphalt binder at the hot mixing facility. The RV measures the viscosity of asphalt binder at the test temperature automatically by measuring torque when a rotational speed of a cylindrical spindle is constant. The RV test is shown in Fig. 2 (b) and specified by ASTM D4402.

3.3.3. Bending Beam Rheometer (BBR)

Since the performed asphalt pavement in actual field is affected by actual weather conditions, such as high, intermediate, and low temperatures, the BBR test was developed to characterize asphalt binder's behavior at low temperature. For the BBR test, the beam theory is applied to calculate the stiffness of asphalt beam samples under a creep load. The creep stiffness (s) and creep rate (m) can be obtained by measuring the center deflection of the beam specimen during four minutes test time. In this calculations, the creep load, creep stiffness, and m-value indicate thermal stresses in pavements, resistance of the asphalt binder to creep loading, and the change in asphalt stiffness with loading time, respectively. Fig. 3 shows the schematic of BBR.

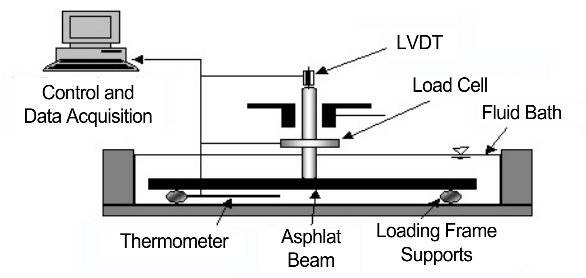


Fig. 3 Schematic of BBR TEST

3.4. Study Materials

3.4.1. Asphalt Binder

In this study AP-5, which is produced in Korea with the penetration grade 60-80, is used. Table 1 shows the properties and PG grade of AP-5. As a result, the PG grade of AP-5 used in this study is PG 64-16.

Table 1. AP-5 Properties and PG Grade

Property	Original			RTFO
Penetration, 1/10 mm	Average: 73			Average: 47
Flash Point, ℃	346			
Softening Point, ℃	Average: 42			Average: 47
Viscosity, cP	Average: 385			Average: 585
DSR, G*/sin δ (kPa)	52℃: 7.018 (pass) 58℃: 2.773 (pass) 64℃: 1.149 (pass) Failure Temperature: 64.9℃			52℃: 15.41 (pass) 58℃: 5.84 (pass) 64℃: 2.338 (pass) Failure Temperature: 64.3℃
BBR	6℃	Stiffness (Mpa) 113.31	m-value 0.33	-
PG Grade	64 ~ 16			
Mass Loss (%) after RTFO	0.72			

3.4.2. Recycling Agents (Rejuvenator)

Aged binder in existing asphalt pavement is not appropriate for reuse without modification in physical and chemical properties. The materials used to soften the asphalt binder and recover the viscosity to make the aged binder usable are called as recycling agents and/or rejuvenators.

In ASTM D4887 (2011), which is specified for "Standard Practice for Preparation of Viscosity Blends for Hot Recycled Bituminous Materials", rejuvenator is defined as the material, which enhances the final physical and chemical properties of asphalt binder when it added to aged asphalt binder. Also, the Pacific Coast User-Producer Group (PCUPG) defines rejuvenator as the hydrocarbon compounds with the physical properties required to enhance the aged asphalt binder to meet the regulations (Gardiner and Komas 2013). According to these definitions, soft asphalt binder may also be classified as a type of rejuvenator. Applying new soft asphalt binder only, however, is often not sufficient to modify the properties of aged asphalt binder to meet the penetration specification, and in this case, a specially designed rejuvenator may be used.

In this study, one type of rejuvenators (RS) produced in Korea and four types of rejuvenators (RC, RA, RF, and RW) produced in Japan or USA were employed. Table 2 shows the result of the thin layer chromatography (TLC) test performed to analyse the chemical components of rejuvenators. From Table 2 rejuvenators indicate very low asphaltene content and relatively high aromatics.

Table 2. TLC Results of Rejuvenators

Component, %	Rejuvenator				
	RC	RA	RF	RW	RS
Saturates	36.47	45.39	7.4	10.57	1.23
Aromatics	61.01	52.84	90.25	79.78	96.80
Resin	1.71	0.96	2.34	6.70	0.71
Asphaltene	0.81	0.82	-	2.94	1.15
Total	100	100	100	100	100

Table 3 shows the material properties of rejuvenators. Based on the property results, all the rejuvenators except RS were used because RS failed to meet the quality specification.

Table 3. Properties of Rejuvenators

Test	Rejuvenator				
	RC	RA	RF	RW	RS
Viscosity (60℃), cSt	620	116	808	104	80
Flash Point (COC), ℃	228	238	304	230	166
Mass Loss after RTFO, %	3.67	1.70	1.14	2.76	1.28
Viscosity after RTFO (60℃), cSt	1000	132	884	120	140
Viscosity Ratio, %	1.61	1.14	1.09	1.15	1.75

3.4.3. Recycled Asphalt Binder

In order to simulate the aging levels of asphalt binder, three types of aged asphalt binders are produced by the short/long-term aging test devices.

- RT: short-term aged AP-5 asphalt binder with a RTFO test device
- RP: short-term aged AP-5 asphalt binder with a RTFO test device, and then, long-term aged with a PAV test device
- PP: long-term aged AP-5 asphalt binder with a PAV test device twice

3.5. Test Flow Chart

In this study, asphalt binder properties, i.e., viscosity, penetration, and PG grade, are evaluated by different added ratios of rejuvenator, such as 0%, 5%, 10%, and 15%. Detail information on the laboratory tests can be seen in Fig. 4.

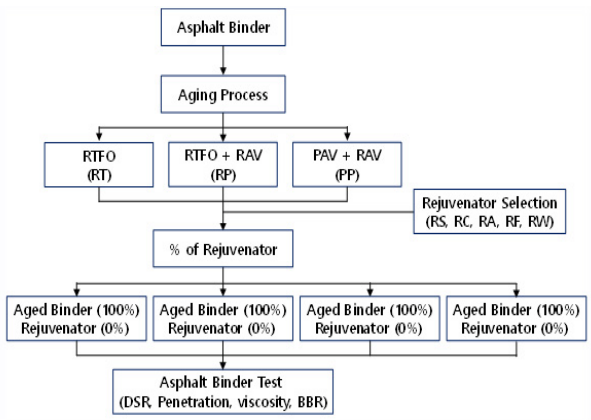


Fig. 4 Test Flow Chart

4. ANALYSIS OF TEST RESULTS

4.1. Properties of Aged Asphalt Binder

Before recycling aged asphalt binder, it is important to know the basic properties of aged asphalt binder. Basically, the aged binders were tested, and then recycled binders (aged binder and rejuvenator) were tested for the penetration, viscosity, and PG. Table 4 presents the basic properties of aged binder with and without rejuvenator.

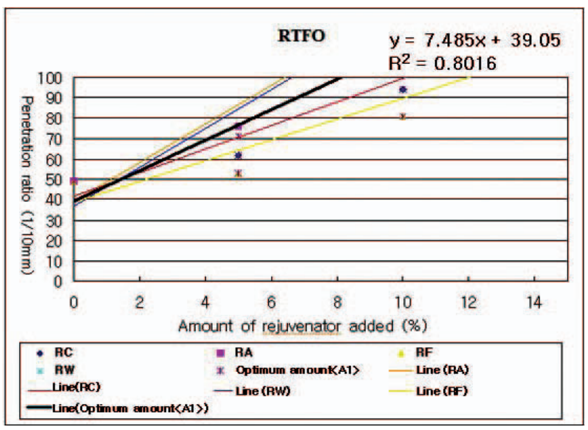
Table 4. Properties of Aged Binder with and without Rejuvenators

Test	Aged Binder			
		RF	RP	PP
Penetration (1/100cm)	-	49	17	13
Viscosity (135℃, cSt)	-	775	3025	10000 or higher
PG (DSR) (G*/sin δ)	52℃	13.67	180.1	505.6
	58℃	5.32	82.29	312.3
	64℃	2.22	36.71	162.4
DSR (Fail Temperature, ℃)		69.2	91.2	118.1
Aged Binder with Rejuvenator				
Type	Addition rate	Penetration (1/100cm)		
RC	5%	62	22	18
	10%	94	30	25
	15%	135	47	34
RA	5%	76	24	18
	10%	127	26	26
	15%	190	55	38
RF	5%	53	19	16
	10%	81	26	22
	15%	125	44	32
RW	5%	71	22	17
	10%	122	35	25
	15%	191	55	38

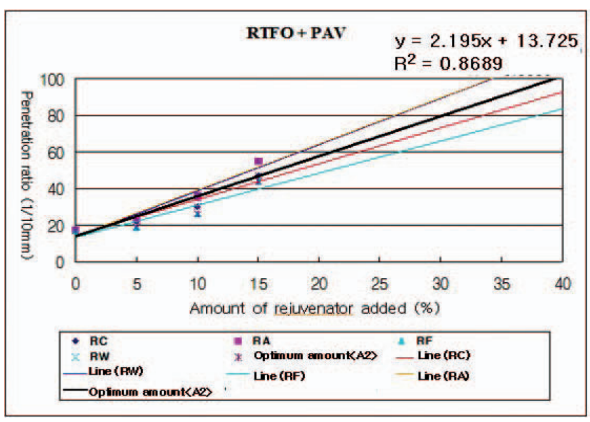
4.2. Recycling Based on Penetration Indicator

Based on the target penetration value of 70, the amount of required rejuvenator can be determined. Table 4 shows the recovery level of penetration with different amount of rejuvenator. The test result of the short-term aged binder RT shows that there are differences in the penetration ratio among the types of rejuvenator. RC and RF have failed to achieve the target penetration ratio with 5% of rejuvenator, while RA and RW have successfully achieved the target value. Based on the rejuvenator grade specified in ASTM D4552, RC and RF fall under RA5, while RA and RW fall under RA1. In the test for long-term-aged binders RP and PP, the difference in the penetration ratio between samples was not as wide as RT.

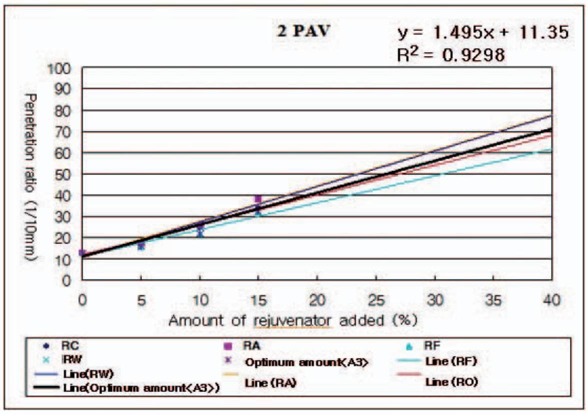
Fig. 5 (a) shows the penetration ratio when rejuvenator is added to short-term-aged RT. The formula on the graph is used to calculate the optimum amount of rejuvenator, where, R2 is the correlation coefficient between the experiment data and the trend line. The closer the correlation coefficient is to 1, the trend line becomes more like a straight line. The trend line is 0.8016, which is relatively straight.



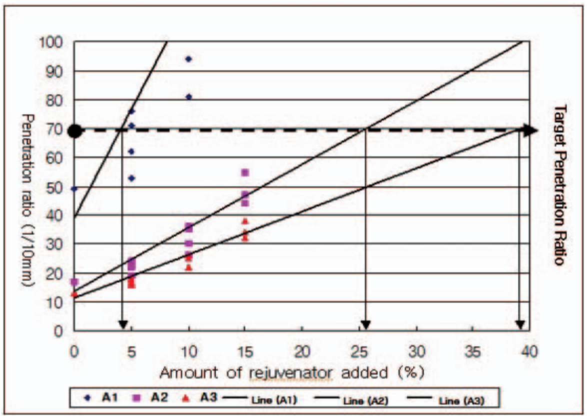
(a) Aged Binder RT



(b) Aged Binder PR



(c) Aged Binder PP



(d) Each Aged Binder

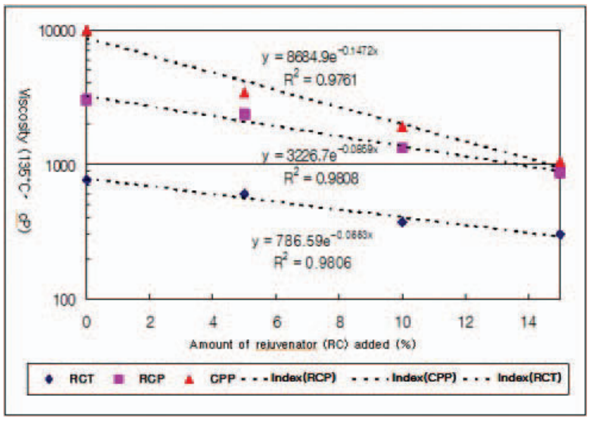
Fig. 5 Change of Penetration Ratio After Addition of Rejuvenators

Fig. 5 (b) and (c) show the change of penetration ratio when rejuvenator is added to long-term-aged binders RP and PP. The correlation coefficient R2 indicates that the trend line becomes more like a straight line for longer-term-aged binder. The inclination is 7.485 for RT, 2.195 for RP and 1.495 for PP. This indicates that the penetration ratio recovered with rejuvenator is lower for longer-term-aged binder.

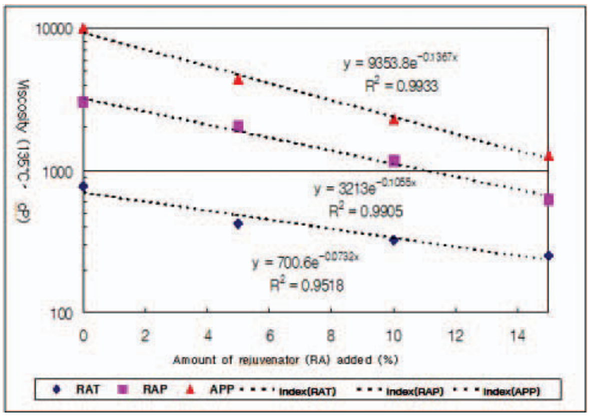
Fig. 5 (d) shows the optimum amount of rejuvenator for aged binders as the target penetration ratio is set to 70. The ratio of rejuvenator required to achieve the target penetration ratio was 4.14% for the recycling binder (the aged binder added with rejuvenator) A1 (RT+Rejuvenator), 25.64% for A2 (RP+Rejuvenator) and 39.23% for A3 (PP+Rejuvenator).

4.3. Recycling Based on Viscosity Indicator

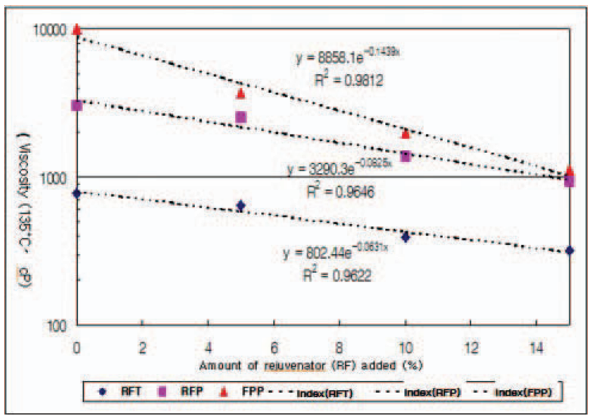
With the target viscosity of the recycling binder set to 400cP, the amount of rejuvenator required to achieve the target viscosity can be estimated. Fig. 6 (a) to (d) show the



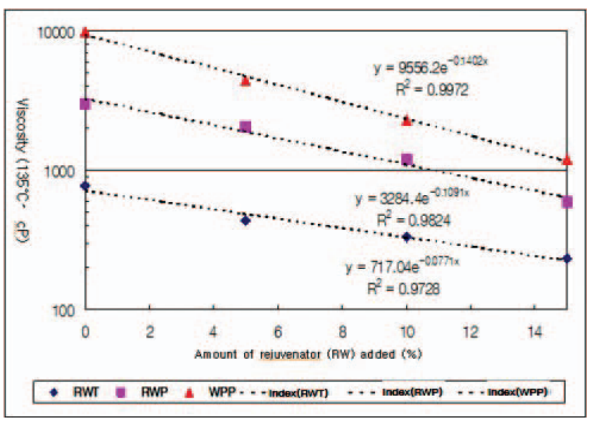
(a) RC



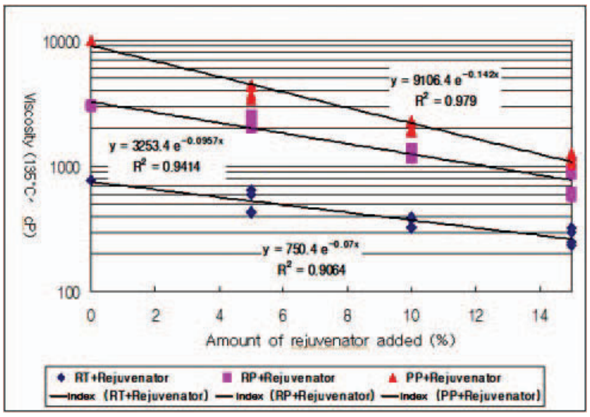
(b) RA



(c) RF



(d) RW



(e) All Types

Fig. 6 Change of Viscosity After Addition of Rejuvenators

result of addition of rejuvenator to short/long-term aged binders. The log function values are placed on axis Y to indicate the linear relative expression. An illustrated in Fig. 6, the correlation coefficient R2 of the linear equation is 0.9, which indicates very high correlation.

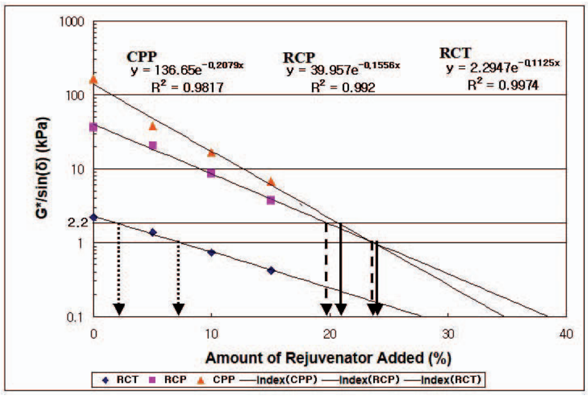
The top line on the plot shows the result of the longest-term-aged binder PP with rejuvenator, and the next lines are for RP and RT, respectively. As illustrated in the Fig. 6 (a), the inclination of the line becomes negative when rejuvenator is added to long-term-aged binders. This shows that the amount of rejuvenator required for the target viscosity becomes similar between the longer-term-aged binders.

The optimum amount of rejuvenator required to achieve the target viscosity of the aged binders can be estimated with the formulas in the Fig. 6 (e). Based on the target viscosity of 400cP, the amount of rejuvenator required can be determined 8.99%, 21.9%, and 22% for RT (RTFO), RP (RTFO+RAV), and PP (RAV+RAV) respectively.

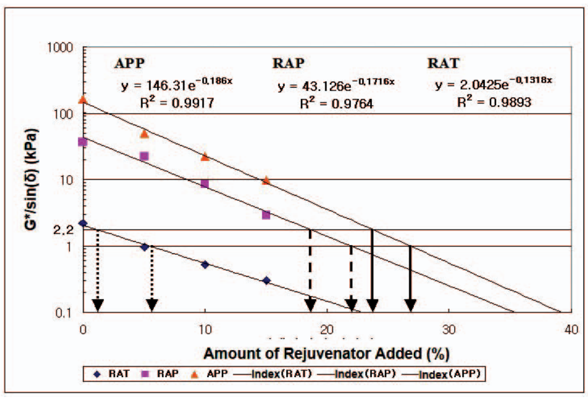
4.4. Recycling Based on PG Grade Indicator (at High Temperature)

The threshold temperature of each asphalt binder was found using the method of reclaimed asphalt pavement with Superpave specification. However, the threshold temperature of additional asphalt, i.e., the threshold temperature of rejuvenator cannot be found with this method. It is because the DSR test is not appropriate for rejuvenator due to low consistency. In this study, therefore, the PG grades were used to estimate the amount of rejuvenator required based on the PG grade 64 at high temperature. Two types of rejuvenator were selected. RA, which fall under RA1 in accordance with ASTM D4552 and RC, which fall under RA5, were mixed in different percentages. The test temperature was 52℃, 58℃ and 64℃, which were the same as the test for AP-5 original sample.

Fig. 7 (a) and (b) show he amount of rejuvenator required to achieve the target G*/sin(δ) (Original binder : 1.0kPa, RTFO binder : 2.2 kPa). The value between 1kPa and 2.2kPa falls under the target PG 64. The range marked with two arrows of the same shape indicates the amount of rejuvenator required to achieve the target PG.



(a) RC Mixed Binder



(b) RA Mixed Binder

Fig. 7 G*/sin(δ) at 64℃

Table 5 shows the amount of rejuvenator required to achieve the target PG 64 for the recycling binder mixed with RC and RA. There is difference in amount of rejuvenator required for the target PG between the RA1-type rejuvenator and the RA5-type rejuvenator. The amount of rejuvenator required (minimum to maximum) is 0 to 7.38% for RT, 17.34 to 23.7% for RP, and 26.85 to 19.86% for PP the longest-term-aged binder.

Table 5. Amount of Rejuvenator Required to Achieve the Target PG

Recycling Binder	G*/sin(δ)	
	1.0 kPa	2.2 kPa
RCT	7.38%	0.375%
RCP	23.70%	18.633%
CPP	23.65%	19.86%
RAT	5.49%	0%
RAP	21.94%	17.34%
APP	26.85%	22.57%

4.5. Comparison of Amount of Rejuvenator between Methods of Recycling Aged Binders

With AP-5 original binder as the reference for recovery of properties of aged binders, the amount of rejuvenator required was determined based on penetration ratio, viscosity and PG (high temperature) grade.

Fig. 8 shows the amount of rejuvenator required for each recycling method. RT, which is the short-term-aged binder, requires the least amount of rejuvenator for the recycling method based on the penetration ratio indicator (4.14%). RP, which is the long-term-aged binder, requires similar amount of rejuvenator for between the recycling methods based on viscosity and PG (high temperature), but requires more for the recycling method based on penetration ratio. For PP, which is the longest-term-aged binder, the amount for the recycling method based on penetration ratio is more than that based on viscosity and PG by at least 10%. It was found that in the recycling method based on penetration ratio the amount of rejuvenator required grows continuously as the age of the binder increases, while it slows down for the method based on viscosity and PG grade.

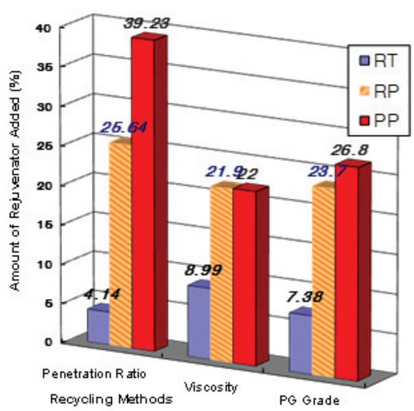


Fig. 8 Amount of Rejuvenator Required for Different Methods of Recycling

5. CONCLUSION AND RECOMMENDATION

The results of this study are as follows:

1. Change of properties of aged asphalt binders was found from the producing aged binder to simulate waste asphalt binders. As the binders age, the penetration ratio decreases but the decreasing rate gradually reduces, while the viscosity and stiffness gradually grows.
2. For the recycling method based on the penetration ratio indicator, with the target penetration ratio of 70, the amount of rejuvenator required to be mixed with aged asphalt is 4.14% for short-term-aged binder, 25.64% for long-term-aged binder and 39.23% for the longest-term-aged binder.
3. For the recycling method based on the viscosity indicator, with the target viscosity of 400cP, the optimum amount of rejuvenator required to achieve the target is 8.99% for short-term-aged binder, 21.9% for long-term-aged binder and 22% for the longest-term-aged binder.
4. For the recycling method based on the PG grade (high temperature), with the target PG of 64, the amount of rejuvenator required to achieve the target is 0~7.38% for short-term-aged binder, 17.34~23.7% for long-term-aged binder and 19.86~26.8% for the longest-term-aged binder.
5. The amount of rejuvenator required to achieve the goal in the penetration ratio, the viscosity indicator, and the PG grade is depending on the level of aging and the target level of the property to be recovered. The amount required is similar in long-term-aged binders, while, the longest-term aged binder require 10% more for the recycling method based on the penetration ratio indicator than for the methods based on viscosity or PG indicator.

It is found in the research of waste asphalt binder recycling methods based on penetration ratio, viscosity and PG grade, only the short-term-aged binder meets the current percentage of rejuvenator (less than approximately 15% used in Korea). When considering the aged asphalt without using new asphalt binder, therefore, it seems that the percentage of rejuvenator used in Korea is a bit too low, and that it fails to represent the characteristics of the original binder. From the current practice of evaluating properties of recycling binder based on penetration ratio only, as described above, the amount of rejuvenator required is similar for the long-term-aged binder, but is excessive for the longest-term-aged binder, causing deterioration of workability and stiffness of the recycling binder. Therefore, before using rejuvenator, it is required to define the optimum amount of rejuvenator through classification of rejuvenators based on quality, and at the same time, to perform overall evaluation of rejuvenators.

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