dosage rate of WMA additives for LEADCAP (3.0% of asphalt weight), Sasobit (1.5% of asphalt weight), and Rediset (2.0% of asphalt weight), which are recommended by supplier. Figure 2 shows the performance grades of three warm asphalts and base asphalt. As show in Figure 2, performance grade at high temperature increased two grades when LEADCAP and Sasobit additives were added into base asphalt, while performance grade at low temperature of warm and base asphalts stayed constant at -22. Based on the performance grade of warm asphalts, it can be postulated that LEADCAP and Sasobit additives would be effective to increase the performance grade at high temperature and rutting resistance of WMA pavement would be enhanced in the field.

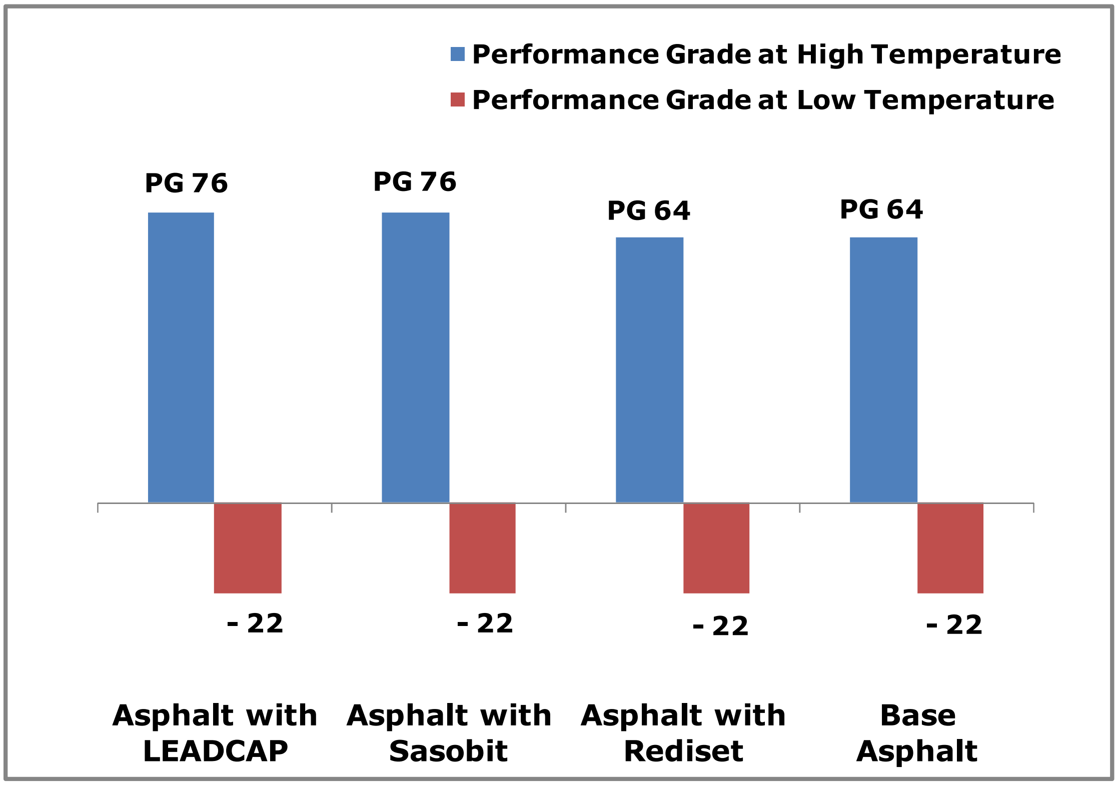


FIG. 2. Performance grades at high and low temperatures of warm and base asphalts

ENGINEERING PROPERTICES OF WMA MIXTURE

In order to evaluate engineering properties of laboratory WMA mixtures using LEADCAP additives along with the control HMA mixtures, moisture susceptibility test and wheel tracking test were conducted to determine moisture sensitivity and rutting resistance in the laboratory.

To produce consistent mixtures for the laboratory testing, aggregates were sieved and combined to produce dense gradation of nominal maximum aggregate size of 19.0mm. Following ASTM D 6927, optimum asphalt content was specified as 5.2% for both WMA and HMA mixtures (2006). The WMA testing specimens were prepared by a dry process using the dosage rate of LEADCAP additive (3.0% of asphalt weight). The

WMA mixtures were produced at 130°C and then heated at 115°C for 60 minutes in the oven to simulate a short-term aging process. The WMA mixtures were compacted at 115°C. While, the control HMA mixtures were produced at 160±5°C and then heated at 140°C for 60 minutes in the oven for short-term aging process. The control HMA mixtures were compacted at 140°C.

To evaluate the moisture sensitivity of WMA and HMA mixtures, the modified Lottman test following AASHTO T 283 was performed. Six specimens (three for dry condition and three for wet condition) for WMA and HMA mixtures were prepared (2007). For dry conditioning, three compacted specimens in a sealed pack were placed in the water bath at 25°C for 2 hours, and for wet conditioning, the other three specimens were placed in the water bath at 60°C for 24 hours followed by conditioning in the water bath at 25°C for 2 hours before the test. The moisture damage in asphalt mixtures is determined as a loss of strength due to the presence of moisture in terms of a tensile strength ratio (TSR) that is defined as a ratio of the indirect tensile strength of a wet specimen over that of a dry specimen. Figure 3 shows TSR values of WMA mixture and the control HMA mixture. As can be seen from Figure 3, the TSR value of WMA specimens was 81% whereas that of the control HMA specimens was 61%. This result indicates that WMA mixture would be less sensitive to a moisture damage than HMA mixture.

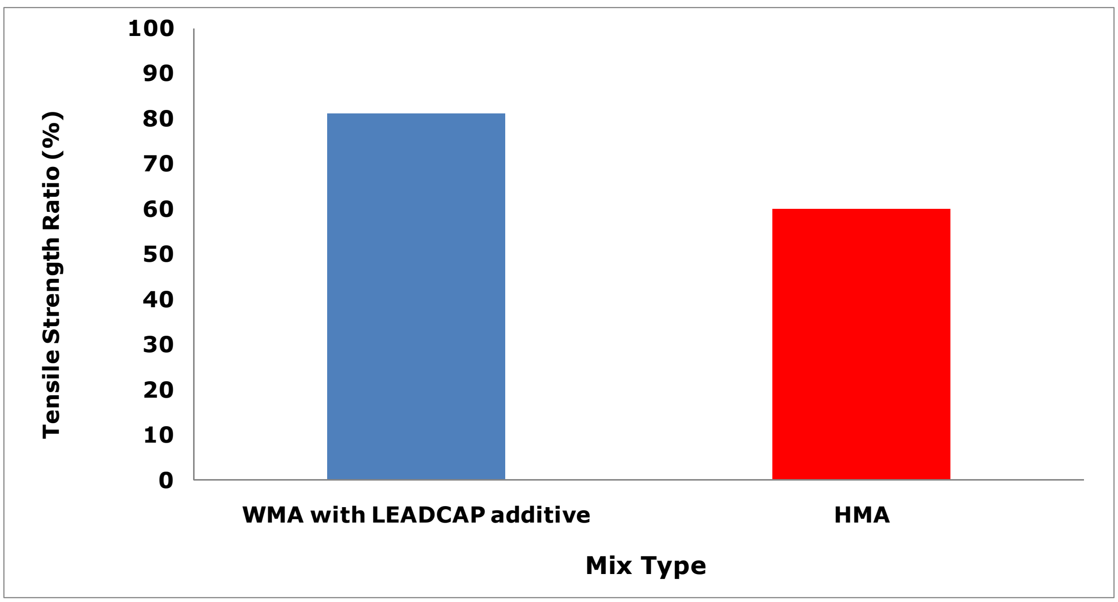


FIG. 3. Tensile strength ratio of laboratory produced WMA and HMA mixtures

To evaluate rutting potential of WMA mixture, wheel tracking test was performed at 60°C. Two slab samples (300 x 300 x 50 mm) were prepared at 4 % air void using a linear kneading compactor for each mixture. To measure the deformation over cycle, a rubber wheel was repeatedly moved back and forth on the slab sample at the speed of 42 pass/min with loading level of 690N. The deformations at 45 minutes and 60 minutes were measured and the dynamic stability was calculated by the following equation.

$$\text{Dynamic Stability (pass/mm)} = 42 \times (t_{60} - t_{45}) / (d_{60} - d_{45})$$

Where, t_{60}: time at 60 min, t_{45}: time at 45 min, d_{45}: deformation at 45 minutes (mm), d_{60}: deformation at 60 minutes (mm), respectively.

As shown in Figure 4, the dynamic stability value of WMA mixtures was 3,400 whereas that of the control HMA mixtures was 500. This result indicates that WMA mixture using LEADCAP additive would be more resistance to rutting than the HMA mixture.

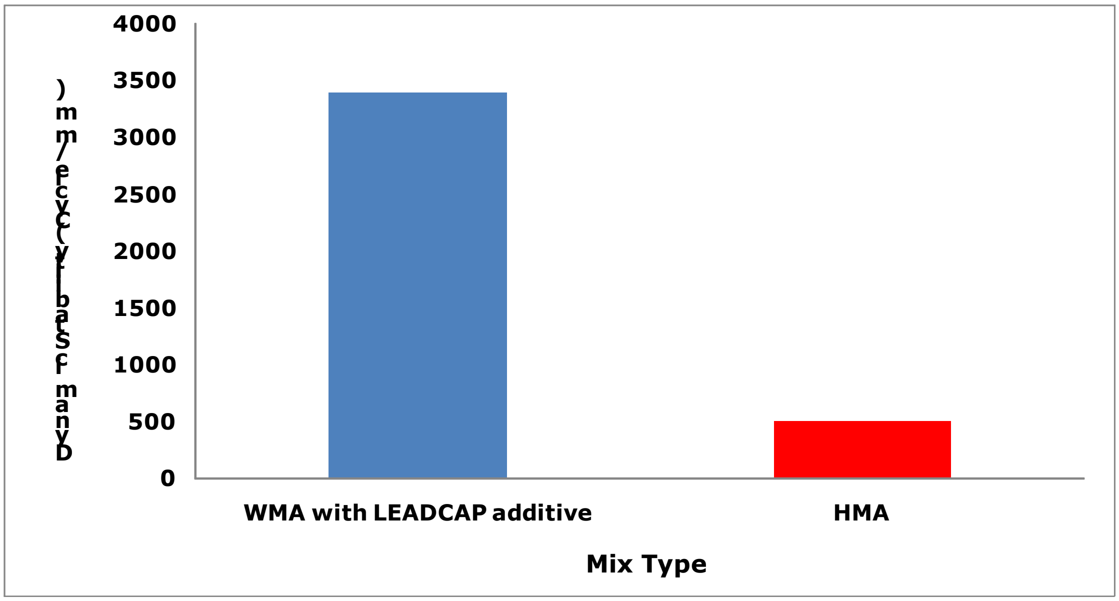


FIG. 4. Dynamic stability values of laboratory produced WMA and HMA mixtures

MEASUREMENTS OF FUEL CONSUMPTION AND EMISSIONS

To investigate workability and compactibility of WMA mixture using LEADCAP additive, the field trial section of WMA pavement was constructed on MooReung-Sabuk road in the city of Wonju, Korea on Aril 23, 2009. The optimum asphalt content of 5.2% was determined by Marshall mix design for both WMA and HMA mixtures. As shown in Figure 5, approximately 170 tonnes of 19mm dense- graded WMA mixtures using 3% LEADCAP of asphalt weight were produced at 125±5°C and compacted at 120°C±5°C and another 100 tonnes of 19mm dense-graded HMA mixture were produced at 155°C±6°C and compacted at 150°C±5°C.

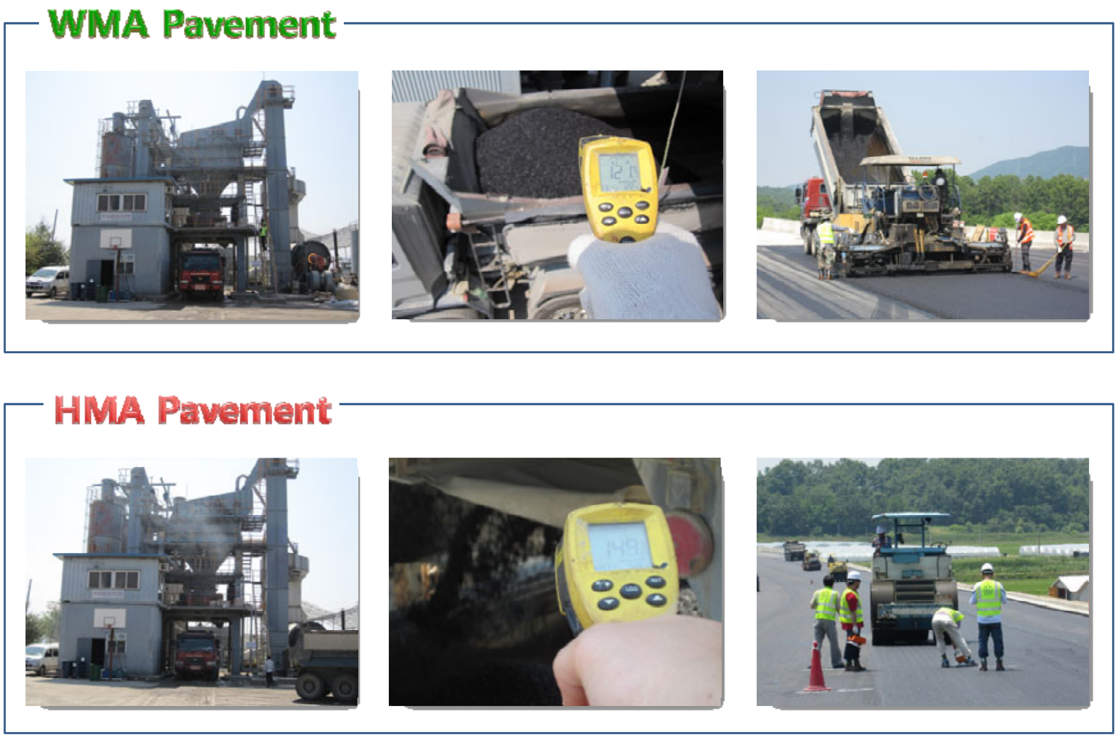


FIG. 5. Production and placement of WMA and HMA mixtures

During the production of WMA and HMA mixtures in the plant, as shown in Figure 6, the use of bunker C oil and the following pollutants were measured: 1) carbon dioxide (CO_2), 2) carbon monoxide (CO), 3) sulfur dioxide (SO_2), and 4) nitric oxides (NO_X). As summarized in Table 1, the decreased production temperatures lead to energy savings of 32%, which results in 32% reduction of CO_2, 18% reduction of CO, 24% reduction of SO_2, and 33% reduction of NO_X. It indicates that LEADCAP additive would be effective to reduce energy use and the emissions for producing WMA mixtures at the plant.

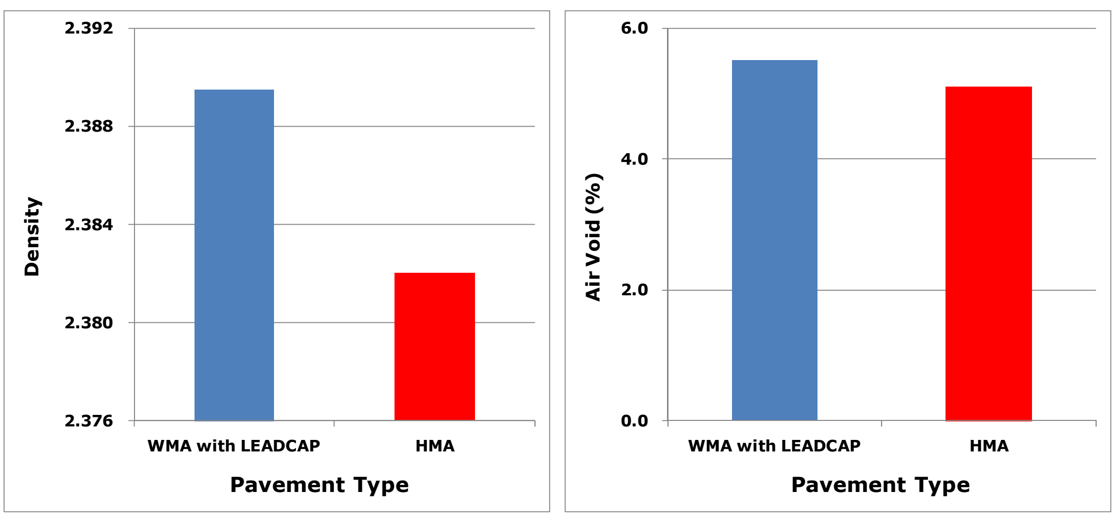
FIG. 6. Measurement of use of bunker C oil (left) and pollutants (right)

Table 1. Collections of Emissions and Fuel Consumption during the Production of WMA and HMA Mixtures in the Plant

Content	Asphalt Mixture		Reduction Ratio
	WMA with LEADCAP	Control HMA	
Fuel use (liter/ton)	6.3	9.3	32%
CO_2 (kg/ton)	19	28	32%
CO (ppm)	850	1040	18%
SO_2 (ppm)	160	210	24%
NO_X (ppm)	20	30	33%

MEASUREMENTS OF FIELD DENSITY AND AIR VOID

To compare compatibility between WMA and HAM pavements in the test section, two samples were cored to measure the field density and air void from both pavements, respectively. The field density and air void were calculated following the AASHTO T 166 (2001). As shown in Figure 7 (a) and (b), the average field density and air void of WMA and HMA pavements were not significantly different. Overall, the WMA pavement section achieved a comparable density and air void as the control HMA pavement section at a significantly lower temperature. No significant distresses were observed in both WMA and HMA test sections for the first year in service.



(a) Density (b) Air void

FIG. 7. Field densities and air voids measured from cored WMA and HMA specimens

SUMMARY AND CONCLUSIONS

A number of warm mix asphalt (WMA) technology has been developed and successfully implemented in the world. Recently, Korea Institute of Construction Technology (KICT) and Kumho Petrochemical have jointly developed an eco-friendly warm mix asphalt (WMA) additive. It is named low energy and low carbon-dioxide asphalt pavement (LEADCAP), which is an organic additive of a wax-based composition including crystal controller and artificial materials.

The performance grade of warm asphalt using LEADCAP additive increased two grades at the high temperature. It is postulated that LEADCAP additive would be effective to increase the performance grade at the high temperature and, it helps improving rutting resistance of WMA mixtures. The tensile strength ratio and dynamic stability values of warm mix asphalt (WMA) specimens were higher than those of hot mix asphalt (HMA) specimens. This result indicates that WMA mixture using LEADCAP additive is superior to HMA mixtures in the moisture sensitivity and rutting resistance. Given the limited field trials of WMA pavement, it is concluded that the WMA pavement achieved a comparable density and air void as the HMA pavement at a significantly lower temperature. The energy savings and the air quality improvements by using WMA mixture using LEADCAP additive were observed but long-term performance and durability of WMA pavement should be researched further.

ACKNOWLEDGMENTS

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REFERENCES

ASTM. (2006). “Standard test method for Marshall Stability and Flow of Bituminous mixtures.” *American Society for Testing and Materials*, ASTM D 6927.

AASHTO. (2001). “Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.” *American Association of State Highway and Transportation Officials,* AASHTO T 166, Washington D.C.

AAHSTO. (2007). “Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-induced Damage.” *American Association of State Highway and Transportation Officials*, AASHTO T 283, Washington D.C.

Anderson, R. M., Baumgardner, G., May, R. and Reinke, G. (2008). “Engineering Properties, Emissions, and Field Performance of Warm Mix Asphalt Technologies.” *NCHRP 9-47, Interim Report*, National Cooperation Highway Research Program, Washington D.C.

NAPA (2008) “Warm-Mix Asphalt: Contractors' Experiences” *IS-134, National Asphalt Pavement Association*, Lanham, Maryland.

Laboratory Investigation of Recycling for Aged SBS Modified Asphalt Cement

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ABSTRACT: This research focused on the recycling of aged SBS modified asphalt cement. The physical properties and rheological properties of aged SBS modified asphalt cement were evaluated based on force-ductility test and SHRP binder tests. Based on the aging characterization of SBS modified asphalt cement, the recycling properties of aged SBS modified asphalt cement, by utilizing a recycling agent in common use for unmodified asphalt binder rejuvenation and a new modifying additive for asphalt mixture performance modification, were evaluated based on SHRP tests. The results showed that aging caused efficacity lose of SBS modifier in the SBS modified asphalt cement and finally led to harden and brittle asphalt cement. However, the recycling agent in common use currently doesn't completely apply to the aged SBS modified asphalt cement recycling. The rejuvenation of aged SBS modified asphalt cement requires new modifying additive. The recycling agent together with new modifying additive were proved to be able to restore and improve the desired road performance and durability of aged SBS-modified asphalt cement.

INTRODUCTION

The polymer modified asphalt cement has better road performances, such as higher rutting resistance and moisture damage resistance, than conventional unmodified asphalt cement. Therefore, the using of polymer modified asphalt cement increased steadily within the last decade. The highway agencies in China recommend that it is prior to use polymer modified asphalt cement in new highway construction especially for surface layer or open grade friction course (OGFC) layer. Among those polymer modified asphalt cements, the styrene-butadiene-styrene block copolymers (SBS) modified asphalt cement is the most commonly used around the world currently.

However, many of the asphalt pavements with SBS modified asphalt cement are reaching the end of their lifetimes and resurfacing must be scheduled. With the increase of construction price (raw materials like asphalt and aggregates) and especially the awareness of the environmental hazards of aged polymer modified asphalt cement, recycling of pavements with polymer modified asphalt cement has become more and more important. Unfortunately, little researches have been conducted on recycling of polymer modified asphalt cement because there was not an urgent need for this topic. Besides, the studies on characterizatioins of aged polymer modified asphalt cement for recycling purposes have not been reported in many publications. As more and more pavements with polymer modified asphalt cement are being constructed, there is an urgent need to investigate the properties of recycled polymer modified asphalt cement before using the recycling mixtures with recycled polymer modified asphalt mixture.

MATERIALS AND TESTS

Materials

A standard cross link SBS modified asphalt cement was selected. Two types of rejuvenators were used for aged SBS-modified asphalt rejuvenation: a fluid recycling agent which is in common use for aged unmodified asphalt cement recycling and a new-type modifying additive which can be used to modify asphalt cement and mixture during asphalt mixture producing process directly instead of having to be mixed with asphalt by specified shearing mixer before asphalt mixture production.

The aged SBS modified asphalt cement was prepared by carrying out laboratory short-term aging process and long-term aging process: rolling thin film oven test (RTFOT, standard ASTM D2872) and pressure aging vessel (PAV, standard ASTM D6521). The recycling asphalt cement was obtained by using the recycling agent to rejuvenate the previous lab-aged SBS-modified asphalt cement. And then the modified recycling asphalt cement was obtained by using the new modifying additive to modify the recycling asphalt cement.

Testing methods

Two conventional tests, rolling thin film oven test (RTFOT, standard ASTM D2872) and pressure aging vessel (PAV, standard ASTM D6521), were used to simulate the field aging for asphalt cements. The RTFOT aging procedure was used to age asphalts for 85mins at 163℃ in fixed air flow to simulate the short-term aging of asphalt cement taking place during asphalt mixture production and pavement construction phase. The PAV test was used to age asphalt cements for 20h at 100℃ under 2.1 MPa of air pressure to simulate the long-term aging of asphalt cement taking place during the in-service life of asphalt pavements.

Force-ductility test and SHRP binder tests including Dynamic Shear Rheometor (DSR) test, Bending Beam Rheometer (BBR) test and Direct Tensile Test (DTT) were used to evaluate the physical properties and rheological properties of asphalt cements.

RESULTS AND DISCUSSION

Aging Behavior of SBS Modified Asphalt Cement

SHRP binder tests

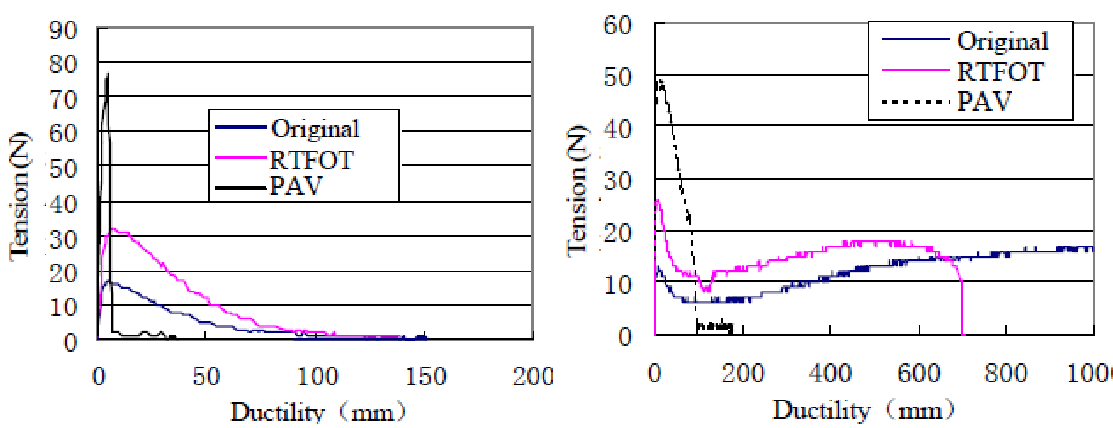
RTFOT-PAV aging combination was conducted on SBS modified asphalt cement to get aged SBS modified asphalt cement. The influences of aging on the rheologcial behavior of the SBS modified asphalt cement are shown in Table 1.

Table 1. Properties of SBS Modified Asphalt Cement Before and After Aging

Asphalt Cement	*G*/sinδ* (64℃, kPa)	*S* (-12 , Mpa)	*m* (-12℃	Failure Strain (-12℃)
Original	6.5	53	0.468	6.11
Aged	25.9	118	0.369	0

In the DSR test, The rutting factor *G*/sinδ,* as a comprehensive rheological parameter, is often used to express the contribution of the asphalt cement to permanent deformation. With increasing *G*/sinδ*, the high-temperature performance of the asphalt cement will be improved. In the BBR test, the creep stiffness *S* and creep rate *m* can reveal the flexibility of asphalt cement at low temperature. Low *S* as well as high *m* represent good flexibility at low temperature. In the DDT test, the failuare strain was also used to express the contribution of asphalt cement to the low-temperature flexibility. From Table 1, it clearly shows that the *G*/sinδ* and *S* increase, while the m-value and failure strain decrease with the increasing aging. Therefore, aging results in harden and more asphalt cement with improved high-temperature performance and degraded low-temperature performance, which is indicated by evidently higher *G*/sinδ* and *S* as well as lower *m* and failure strain after ageing.

Force-ductility test



(a) Unmodified asphalt cement (b) SBS modified asphalt cement

FIG. 1. Force-ductility test results for asphalt cements before and after aging.

The force-ductility test results for the original, RTFOT aged and PAV aged unmodified asphalt cements are shown in FIG. 1 (a). The force-ductility test results for the original, RTFOT aged and PAV aged SBS modified asphalt cements are shown in FIG. 1(b). Compared to the original unmodified asphalt cement, the original SBS modified asphalt cement has persistent tension and much bigger ductility, which represent the contribution of the SBS modifier in the SBS modified asphalt cement. However, after RTFOT-PAV combination aging, the force-ductility testing curve of the aged SBS modified asphalt cement is very similar to that of the aged unmodified asphalt cement. And compared to the original cements, the aged cements have much worse deformability. Therefore, the SBS modified asphalt cement becomes more brittle due to the aging weathering and the aging can cause the degradation of SBS modifier in the SBS modified asphalt cement.

Recycling Characterization of Aged SBS Modified Asphalt Cement

Properties of recycling cements

Six test samples of recycling cements were prepared with lab-aged SBS modified asphalt cement and fluid recycling agent (RA). Each one has different RA contents. The concentrations of RA are 2, 4, 6, 8, 10 and 12% respectively. SHRP binder tests were conducted to evaluate the recycling performance. The test results for the original and aged SBS modified asphalt cements as well as the recycling cement are shown in Table.2.

Table. 2 Test Results for Original, Aged and Recycling Cements

Asphalt Cement	RA Content (%)	DSR, G*/sinδ (kPa)	BBR, S (MPa)	BBR, m-value	DDT, Failure Strain
Original	0	6.5	53	0.468	6.11
Aged	0	25.9	118	0.369	0
Recycling	2	22.3	91	0.379	0.796
	4	16.4	79	0.405	1.775
	6	14	70	0.422	2.874
	8	9.9	55	0.44	3.75
	10	6.8	44	0.475	5.697
	12	5.8	31	0.488	7.805