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Research Article

Investigation of binder aging level in short-term-aged PMA mixture with different anti-stripping additives

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ABSTRACT

As an anti-stripping additive (ASA) of hot-mix asphalt (HMA) mixture, the hydrated lime (HL) has been widely used for many years. Conversely, many brands of liquid anti-stripping additive (LA), which properly provide the anti-stripping function, are also used. HL is known to provide anti-aging functions by retarding age-hardening of the binder in addition to ASA functions. However, the LA was not much evaluated or reported regarding anti-aging function. Since the retardation of binder age-hardening is the foundation of many other beneficial functions of asphalt pavements, it is important to investigate whether the anti-aging function is provided by the LA as well. Therefore, this study investigated the anti-aging effects of HL and two liquid additives in SBS-modified SMA mixes in terms of absolute viscosity estimated from large molecular size (LMS) measured by the gel-permeation chromatography (GPC). It was found that two LAs did not provide any retardation of age hardening effects in polymer-modified asphalt mixes, compared with the binder of the mixes with HL and without any ASA. The PMA in one of the LAs showed a significantly higher age-hardening than the one without any ASA. While HL reacted as a significant age-hardening retarder of PMA in SMA mixes. Therefore, it was concluded that there was significant difference in oxidation level due to the use of different ASAs used in this study.

Keywords: Asphalt oxidation, Age retardation, SMA, Hydrated lime, Liquid anti-stripping additives, LMS, Absolute viscosity

1. Introduction

The binder in HMA is oxidized by heat during short-term aging (STA) time while in truck for hauling and queuing before being paved. If the HMA is produced using a polymer modified asphalt (PMA), a higher temperature is needed to maintain compaction quality. If temperature is higher than normal, the binder is becoming further oxidized in a relatively short time period.

It has been known to retard the binder age-hardening if hydrated lime (HL) is used in asphalt mixture. In Utah (Chachas et al., 1971), the asphalt binder recovered form the field asphalt pavement with HL in an existing highway for many years was found to be aged less than the binder recovered from normal asphalt mixture without HL. Since then, many proofs of age-retardation due to the use of HL were observed and reported (Ahn et al., 2015; Jeong et al., 2017; Kim et al., 2018a; Kwon et al., 2016; Lesueur et al., 2013). Therefore, HL is now known to be a proven age-retarder of asphalt binder in asphalt pavement (Hydrated lime... 2011; Kim et al., 2017; Lesueur, 2010; Little et al., 2006).

However, in spite of this benefit, many types of liquid ASA (LA) are developed and used in asphalt plants due to the simplicity of usage. The age-retardation effect of LA is not well known and a late study showed that the LA did not show any effect on age retardation in normal (unmodified) asphalt mixtures (Kim et al., 2018b). The oxidation chemistry of PMA is different from normal asphalt without polymer, and it is not well known how much oxidation is occurring in PMA binder when different ASA was used.

Since the oxidation mechanism of asphalt and polymer is complex, it is difficult to find out the PMA oxidation mechanism. Therefore, this study evaluated oxidation level of PMA binder in SMA mixture with HL or LA, which was STA conditioned at 185°C, using the estimated absolute viscosity (AV) from large-molecular size (LMS) obtained by gel-permeation chromatography (GPC).

The LMS measured from the dissolution of asphalt mix particles was proved to have very high correlation with AV of the binder (Ahn et al., 2002; Han et al., 2015; Kim and Burati, 1993; Kim et al., 2015). Since LMS is not a familiar to most engineers, however, it may be difficult to visualize the actual aging level by simply comparing LMS itself. Therefore, the typical physical property, AV, was utilized as an index for the oxidation comparison in this study. The estimated AV (EAV) was computed from each LMS value and used for oxidation analysis. The objective of this study was to analyze aging level of SBS (styrene-butadiene- styrene) modified asphalt binder in SMA mixtures which was prepared with HL and two LAs, and to show the reality of oxidation difference in terms of the absolute viscosity estimated from the LMS.

2. Materials and Methods

A 10 mm nominal maximum size of granite aggregate, screenings passing #4 sieve and limestone powder were used for coarse aggregate, fine aggregate and mineral filler, respectively, for stone mastic asphalt (SMA) mixture. The gradation used in this study was set forth by Korea Expressway Corps. A SBS-modified PMA with PG76-22 was used SMA mixture. Three anti-strip additives were used for stripping control of asphalt mixtures, including a hydrated lime (HL) and two liquid-type ASA (LAa and LAb).

Table 1. Materials used, optimum asphalt content (OAC) and STA condition

Binder PG	OAC (%)	Polymer modifier	Original AV (poise)	Anti-stripping additive			STA	
				Name	Dosage (kg/ton of mix)	Application	Temp (°C)	Time (h)
76-22	7.0	SBS	12,575	No	0	-	185	1, 2 and 4
				HL	15	Into agg.		
				LAa	0.345	Pre-mixed		
				LAb				

The mix design for SMA mixture was performed based on Korea Expressway Corps guide and the mixture prepared using the optimum asphalt content (OAC) was used for STA. The SMA mix at optimum PMA content was short-term aged at 185°C, which was suggested to be average temperature of SMA in truck by the Korea Expressway Corps. The mixture blended in a paddle mix for each specimen was short-term aged in a canister, as shown in Fig. 1, which is placed in a drying oven without forced air draft. Since haul-and-queue of mixture takes several hours in a worst case due to severe traffic jams and operation problem in a metropolitan area job sites, the three STA times were investigated as shown in Table 1. One hour (1-h) was considered the optimistic time, 2-h the most likely time, and 4-h the pessimistic (poorest) time for STA (Kim et al., 2018a).

Fig. 1. Short-term aging samples in canister in a drying oven

The asphalt mixture sample was dissolved into tetra-hydro-furan (THF), as shown in Fig. 2. The sample concentration was adjusted to be 0.25% by weight based on asphalt content of the mix. The GPC sample solution was extracted from the dissolution using a syringe through a mounted 0.45 *mm* syringe filter. A 50 ㎕ of the sample was then injected into the GPC injector (Fig. 3). The LMS is the front portion of a chromatogram.

Three LMS values were measured from each sample and the average was used for analysis. Detailed procedures for GPC test is given elsewhere (Han et al., 2015; Kim and Burati, 1993; Kim et al., 2018a)

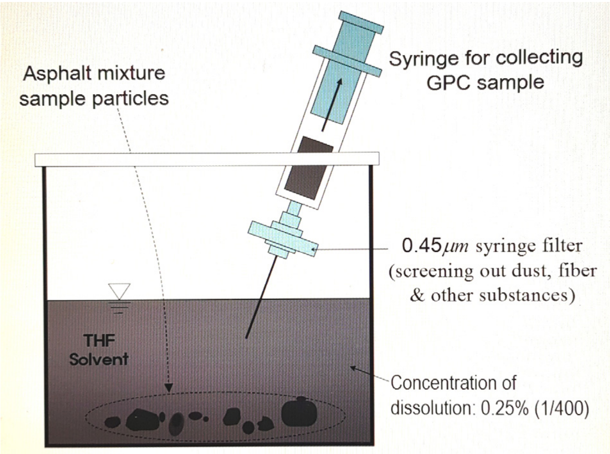

Fig. 2. Schematic illustration of GPC sampling from dissolution of asphalt binder and asphalt mixture in THF

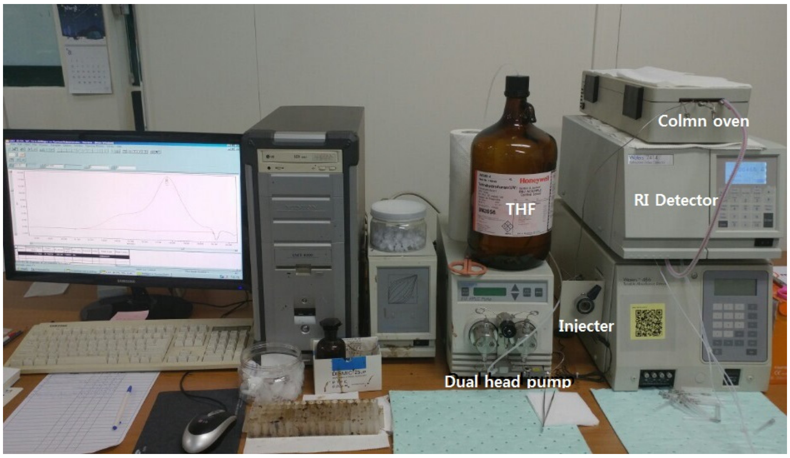

Fig. 3. Picture of GPC system used in this study

In this study, since recovering binder from mix is a troubleshooting and time consuming process, instead of recovering binders from all mixes, a half of them were randomly selected for recovering. The absolute viscosity (AV) of binder is measured at 60°C in accordance with ASTM D2171M-10 (2016) from the binder, which was recovered by Abson method (ASTM D1856, 2016) from the randomly selected mix after each STA. All samples were used for GPC test without recovery to obtain LMS values. A regression analysis was performed between the measured AV from half of the mixes and corresponding LMS values. The best-fit regression models was selected, and AV values were then estimated from LMS using the best-fit regression model.

3. Results and Discussions

Table 2 shows measured absolute viscosity (MAV) from randomly selected mixes and LMS from all samples. Since the asphalt recovery from mix is a troublesome process, only 1/2 of the mixes were randomly selected for Abson recovery for AV test. That is why 1/2 of spaces in MAV column are open without data as shown in Table 2. Using 8 SMA mixes, which were randomly collected, the AV was measured from recovered binders.

The regression analysis result is shown in Fig. 4, in which MAV and LMS displayed very high correlations between each other (R^2 >0.98) by an exponential function model. Using the regression equation in Fig. 3 ($EAV = 1.2488e^{0.3816(LMS)}$), the EAV was computed for each binder, as shown in Table 2. Fig. 5 shows a very high correlation (R^2>0.99) between EAV and MAV. The EAV values were therefore used for further aging analyses throughout the study.

Table 2. Measured absolute viscosity (MAV), LMS and EAV

Material	PG	Polymer	ASA	Time (h)	MAV (p)	LMS (%)	Estimated absolute viscosity (EAV) (p)
Binder	76-22	SBS	No	0	12,575	23.98	11,766
SMA mix (STA at 185C)	76-22	LDPE	HL	1	3,418	21.35	4,313
				2	-	23.12	8,474
				4	15,305	25.8	23,564
		SBS	No	1	14,086	25.41	20,305
				2	-	25.98	25,239
				4	72,989	28.98	79,297
			HL	1	9,898	23.24	8,871
				2	-	24.88	16,587
				4	-	27.12	38,994
			LAa	1	25,032	25.77	23,295
				2	-	27.32	42,087
				4	-	28.86	75,747
			LAb	1	82,494	28.56	67,554
				2	-	31.82	234,379
				4	437,843	33.47	439,914

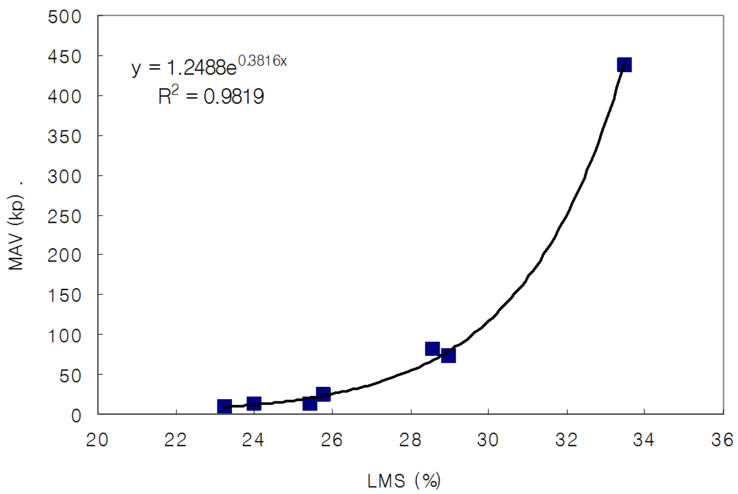

Fig. 4. Relation of measured AV and LMS

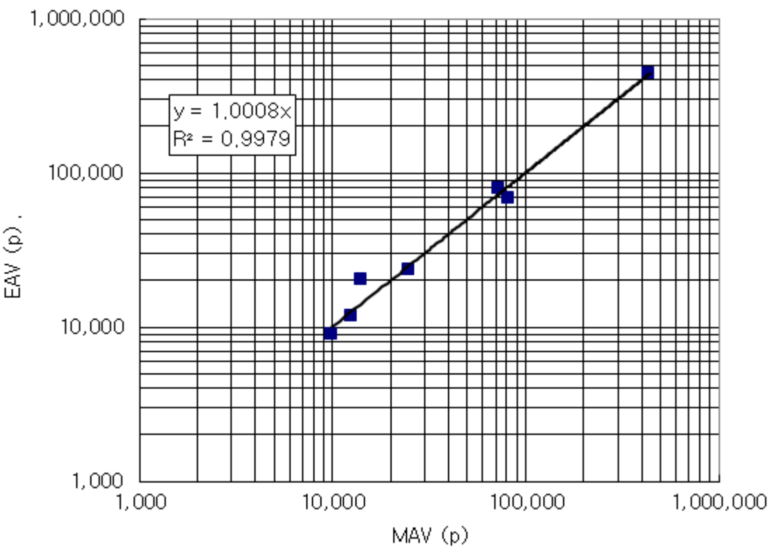

Fig. 5. Relation of estimated AV (EAV) and measured AV (MAV).

The LMS value and LMS ratio were compared in Fig. 6, in which, the LMS ratio was computed based on the LMS value (23.98) of original SBS PMA. HL showed lower LMS and LMS ratio values than any other materials in all 3 STA times. However, LAb showed the highest LMS and LMS ratio, and LAa showed similar to those of No ASA mix. Therefore, HL was aged less than normal binder (No) without ASA and the binders with liquid additives in SMA mixes.

As mentioned earlier, since LMS is not a familiar to engineers, the AV estimated from LMS was used as an index of aging comparison. The estimated absolute viscosity (EAV) and EAV ratio were compared in Fig. 7, in which the EAV ratio was computed based on the EAV (11.77 kp) of original SBS PMA.

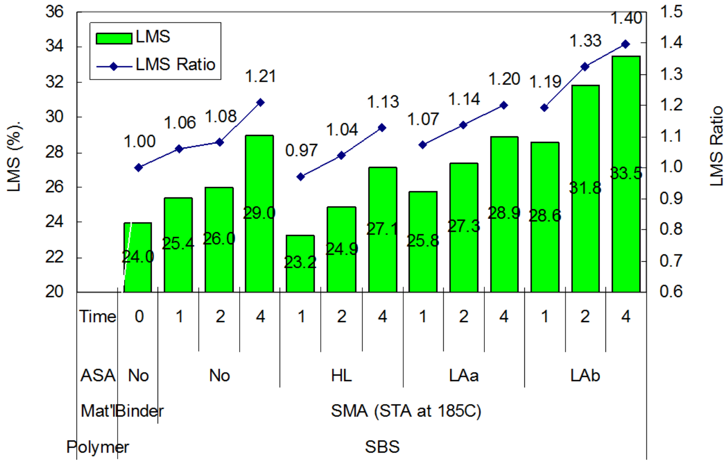

Fig. 6. Comparison of LMS and LMS ratio beaed on original binder LMS (No)

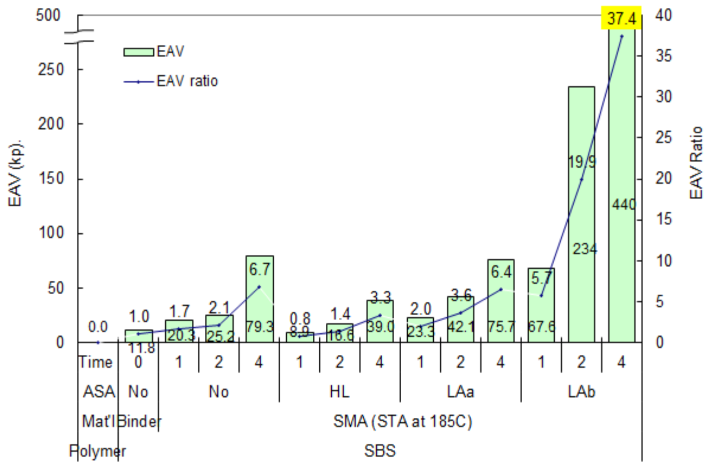

Fig. 7. Comparison of EAV and EAV ratio based on original binder EAV (No)

HL showed lower LMS and LMS ratio values than No in all 3 STA times. This means the HL reacted as a significant agent for reducing age hardening of SBS PMA in SMA mixes. However, LAa showed higher EAV and EAV ratios than those of No in 1-h and 2-h, but similar to that of No in 4-h. The LAb showed extremely high EAV values in all 3 STA times. It might be the result of an expedited oxidation reaction of catalytic substance, which might be contained in the LAb.

From the LMS and estimated absolute viscosity analyses results, it was found that the aging level of SBS PMA was significantly different due to the use of different ASA material in the mix. In other words, both LAs did not show any better age-retardation effect than the mix without using any ASA (No). Therefore, there should be an action for retarding aging of PMA mixes when the liquid ASA is used for stripping control.

4. Conclusions

This study evaluated the retardation effect of binder age-hardening in SBS-modified stone mastic asphalt (SMA) mixes due to the use of different anti-strip additive (ASA); hydrated lime (HL) and two liquid ASAs (LAa and LAb). The mixes were artificially aged by short- term aging (STA) for 1-h, 2-h and 4-h at 185°C. The large molecular size (LMS) after each STA was measured by GPC, and the estimated absolute viscosity (EAV) from LMS was used for aging level comparison.

Based on the analysis results, it was concluded that, after all STA conditioning, there were significant differences in binder aging level due to the use of different ASA in SBS-modified SMA mixes. The HL in SMA mix showed the lower aging level than any other additives, including normal PMA without ASA, revealing strongest age-retardation effect in the hot-mix SMA when LMS and EAV were compared.

As opposed to HL, two liquid additives did not show any age-retardation effect when compared with the normal PMA without ASA and HL. Since the liquid additives used in this study seem to have no effective age-retardation function in PMA binders, the short-term aging level must be investigated before paving when LA is to be used for stripping control.

However, since this study was used a limited number of material, the conclusion reached is tentative and further investigations are required using other mixes; more LAs, binders and aggregates to reach a generalized conclusion.

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