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Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

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PREDICTION OF SHORT-TERM AGING LEVEL BY AGING QUANTITY MODEL USING TIME AND TEMPERATURE OF HOT-MIX ASPHALT

Yeongsam Kim, Baeseon Dong, Sungun Kim, Jaewon Jo, Kwang W. Kim
Kangwon National University, Department of Regional Infrastructures Engineering, Republic of Korea

Abstract

The aging level of asphalt mix due to short-term aging (STA) during delivery was analyzed using aging quantity (AQ) model based on temperature (T) and time (t) of STA. AQ values for various STA conditions were computed and used for estimating absolute viscosity (AV) of the binder as aging index. The estimated AV (EAV) and measured AV from recovered binder showed an excellent correlation ($R^2 > 0.9$). Raising T of mix to maintain compaction T in cold weather was found to be a significant cause of expedited aging. Extended STA t due to traffic delay was another significant cause of aging. The AV of HMA binder for 1 h STA at 160 °C was 400 Pa.s, which is identical to RTFO-run level. The AV was 801 Pa.s when the mix was kept for 1 h at 180 °C, and AVs were 2,024 and 4,436 Pa.s when the mix was kept for 2 and 3 h at 180 °C, respectively. The AV levels are much higher than the AV (1,108 Pa.s) of PAV-run binder. Therefore, if T of mix is elevated to 180 °C, the STA time should not be over 1 h before paving. Since the result of over aging by STA is detrimental, the t and T should be controled to prevent premature service life reduction.

Keywords: Asphalt, short-term aging, absolute viscosity, aging quantity model

1 Introduction

The binder in hot-mix asphalt (HMA) is aged (oxidized) during the short-term aging (STA) period while in truck for haul and queue. Since there is no way of cutting back to the fresh condition once the mixture was paved, the aging level of STA is very important for later pavement service life. For the same mix, the STA level depends mainly on the time (t) length and temperature (T) at which it was kept in truck, even though many other factors are related to the aging. The accelerated aging is often observed when the T is elevated at the production plant due to concerns about cooling down [1]. Jeong et al. [2, 3] showed that the increasing rate of absolute viscosity (AV), which was measured from the binder recovered from the aged mix, followed the form of exponential function of t and T.

It was found that the AV of HMA binder (PG64-22) was increased by 4 and 20 times the RTFO-run AV of the same binder when the mix was kept for 2 hour (h) and 4 h at 180 °C, respectively [1, 2]. For the HMA kept in a haul truck for 2 h at 180 °C in December [1], the AV was found to increase to approximately 2,000 Pa.s [1]. In this case, it can be said that the newly produced HMA is no longer in fresh condition because the AV of recovered binder from cores of 6-7 year-old pavement was found to be approximately 1,500 Pa.s for the similar types of surface mixes [4, 5]. Since the AV increases exponentially, the T and t of STA should be controlled properly to maintain aging level below a certain limit.

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To measure the AV of paved mix, a series of field and lab works are required. However, if the aging level is properly quantified by the model, it will be possible to judge aging level based on the estimated AV (EAV). Since the EAV by this model was found to fit well to the measured AV, this study was designed to emphasize the aging level prediction issue which has been ignored. Therefore, the objective of this study was to show the significance of severe aging predicted by t and T using aging quantity (AQ) model for normal dense-graded HMA mix.

2 Materials and Methods

2.1 Materials

A PG 64-22 was used as the base asphalt with granite aggregate. The absolute viscosity (AV) values by condition are given in Table 1. A granite-based 13 mm aggregate, screenings passing #8 sieve, and limestone powder were used as the coarse aggregate, fine aggregate and mineral filler, respectively. The aggregate was prepared to confirm the WC-1 dense-graded asphalt (DGA) gradation, which was specified for surface course asphalt mix by the Korean Guide [9].

2.2 Methods

A mix-design by the Korean Guide [9] was performed for normal DGA surface mix using a gyratory compactor. The optimum asphalt content (OAC) was determined based on four properties; air void ratio (AVR) strength against deformation (S_D), voids filled with asphalt (VFA), and voids in mineral aggregates (VMA). The specification limit of AVR, S_D, VFA and VMA is 4 %, $\geq$3.2 MPa, 65 %~80 % and $\geq$14 %, respectively, for surface mix for secondary roadway pavement.
The HMA mix at OAC was prepared using a paddle mixer. The loose mix was kept in an open canister for short-term aging (STA) for each mix. The temperature (T) and time (t) for STA in a drying oven without forced air draft are shown in Table 1. After each STA, the binder was recovered from the aged mix using Abson method (ASTM D 1856) with Rota vapor (Figure 1(a)). The AV was measured using the equipment and AI Viscometer (Figure 1(b) and 1(c)).

Table 1 Material property, STA temperature (T) and time (t)

Binder AV [Pa.s]			**Asphalt mix**		**Material temp. [°C]**		**STA**	
Original	RTFO	PAV	Type	OAC	Binder	Agg.	T [°C]	t [h]
195.4	424	1,108	13 mm DGA	4.7 %	160 160	165 185	160 180	1, 2, 4 and 8

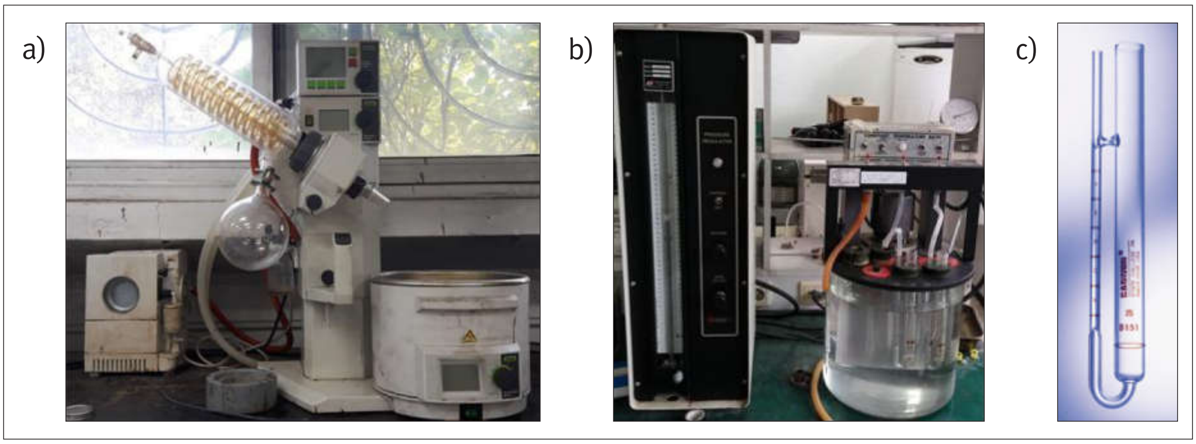

Figure 1 a) Rota vapor for recovery, b) AV tester and c) Asphalt Institute viscometer

The delivery time of field mix, which should be considered as t of STA for lab mix, was assumed to range from 1 h to 4 h [7]. The three times were investigated for normal paving mix STA; one h as the optimistic time, 2 h the most likely time, and 4 h the worst time for STA. However, 8 h was also selected for the carry-on mix in an insulated container for repair work.

3 Results and Discussion

3.1 AQ Modelling

Table 2 shows measured absolute viscosity (MAV) values from the binder recovered from dense-graded asphalt (DGA) mixes after STA. The AV of 412 Pa.s after 1 h STA at 160 °C is identical level (424 Pa.s) to the RTFO-run binder in Table 1. Therefore, the 1 h STA at 160 °C was considered as the desired time for haul and queue of the normal HMA mix in the field, and therefore designated as the reference STA (RSTA) [1]. Figure 2 was drawn using the ratio of AV increase in order, compared with the AV of RSTA by temperature (T) and time (t) for STA. It was noticeable that, by doubling the time from 1 to 2 hours at 160 °C, the AV of 412 Pa.s was increased to 625 Pa.s, the AV ratio of 1.5. But by doubling the time from 4 to 8 hours, the ratio was tripled; from 3.1 to 9.2. However, the same t step increase at 180 °C induced much more significant increasing trend. Therefore, the trend of increase appeared to follow a typical exponential function, $y = ae^{bx}$, as shown in Figure 2.

Table 2 Measured AV (MAV) of normal mixtures

Binder & mix	STA temp. [°C]	Measured AV [Pa.s] by STA time [h]			
		1	2	4	8
PG 64-22 DGA	160	412.3	625.4	1,273.9	3,791.8
	180	574.3	1,944.7	9,720.0	100,000*
AV ratio (180 °C / 160 °C)		1.39	3.11	7.63	26.37

** Test terminated when passing 100,000 Pa.s time*

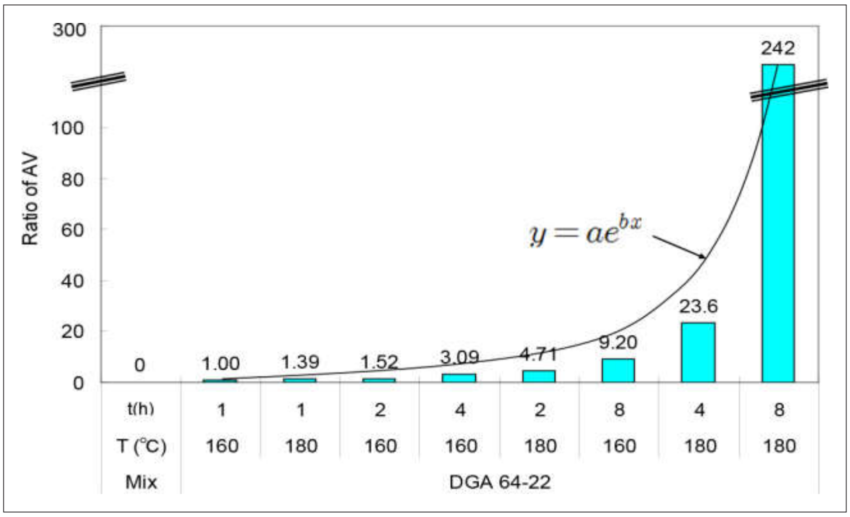

Figure 2 Ratio of AV due to various STA conditions compared with RSTA

Since the pattern in Figure 2 implies that an exponential function can be used if the value in the x axis is managed to be used as aging quantity (AQ). Therefore, the AQ was quantified with aging t in minutes (min) and T in Celsius (°C) for developing a model [2]. The AQ model was expressed as AQ = f(t, T). In the form of an exponential model, $AQ = Ae^{B}$, constant A was found to be related more to t, and B related more to T. The developed model is given by Eq. (1), which was determined based on R^2 between the AV and estimated AQ.

$$AQ = 10t^{0.6848} \cdot e^{0.03486T} \tag{1}$$

in which, AQ = aging quantity (min°C), t = STA time (min), and T = STA temperature (°C). The AQ by Eq. (1) for each STA condition in Table 2 was computed and shown in Table 3.

A regression analysis was performed to examine if the aging level in terms of AV can be predicted by AQ. Figure 3 shows the correlation between AV in Table 2 and AQ in Table 3 with $R^2 > 0.99$. Therefore, Eq. (1) can be used to compute the AQ for any condition of STA if the t and T are known. This AQ value can be used to estimate AV by the regression model ($y = 166.23e^{0.0002x}$, in which y = AV and x = AQ) in Figure 3. The model was further refined by using more field data, making Eq. (2). Therefore, this study used Eq. (2) for aging analyses, because this model was verified using field mix data [7].

$$EAV = 17.4358e^{0.0000174(AQ)} \tag{2}$$

in which, EAV= estimated AV (Pa.s) and AQ = aging quantity (min°C) by Eq. (1).

The EAVs were computed using the AQ in Table 4 for each STA condition given in Table 3. The regression between EAV vs. measured AV (MAV) in Table 4 shows an excellent correlation ($R^2 > 0.99$ in Figure 4). MAV and EAV computed by AQ were identically increased as T and t increase. Therefore, it is possible to state that the EAV by AQ is another way of judging STA level of asphalt mixes.

Table 3 Aging quantity (AQ) values obtained by using Eq. (1)

T [°C]	160				180			
t [min]	60	120	240	480	60	120	240	480
AQ [min°C]	43,651	70,169	112,795	181,315	87,657	140,908	226,506	364,104

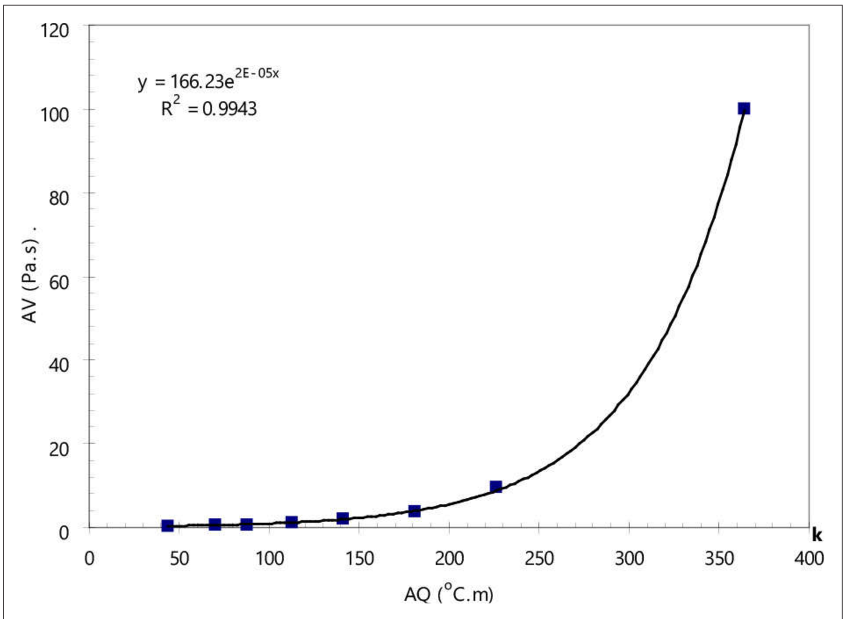

Figure 3 Relation of AV with aging quantity (AQ) given by Eq. (1)

Table 4 The EAV computed by AQ and MAV by T and t

T [°C]	160				180			
t [min]	60	120	240	480	60	120	240	480
AQ [m°C]	43,651	70,169	112,795	181,315	87,657	140,908	226,506	364,104
EAV [Pa.s]	372.7	591.1	1,241.1	4,088.8	801.4	2,024.1	8,976	98,372
MAV [Pa.s]	412.3	625.4	1,273.9	3,791.8	574.3	1,934.7	9,720	100,000

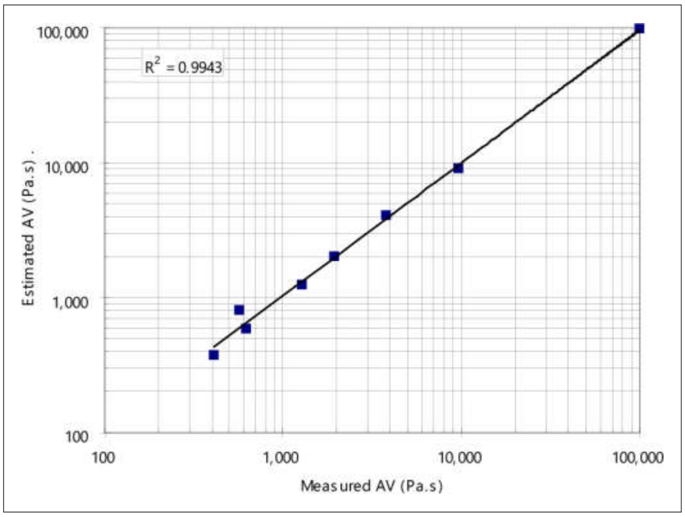

Figure 4 Relation of estimated AV (EAV) and measured AV

3.2 Estimation of STA Level

Before examining field mix STA, the T and t for inducing RTFO level of aging (424 Pa.s in Table 1) was sought using the AQ model for illustration purposes. The proper t for three times within acceptable T range of HMA was selected when the EAV was nearest to 424 Pa.s, as shown in Table 5. According to this analysis, the proper t for HMA mix at T of 155 °C, 160 °C and 165 °C is 97 min, 75 min, and 58 min, respectively, to obtain identical aging level to RTFO aging.

Table 5 Proper t inducing AV of RTFO-run aging level for 3 HMA temperatures

T [°C]	155			160			165		
t [min]	80	97	120	60	75	90	50	58	70
AQ [m°C]	44,654	50,952	58,945	43,651	50,858	57,622	45,864	50,771	57,749
EAV [Pa.s]	379.2	423.1	486.3	372.7	422.4	475.2	387.3	421.8	476.2
Computed	423.1 in 97 min			422.4 in 75 min			421.8 in 58 min		

The mixture T in the early winter season is elevated at the plant to maintain the compaction temperature due to fast T dropping during delivery and paving. If the average mixture T in truck is 10, 20, or 30 °C higher than the normal T (160 °C), the AV of the binder in those mixes can be estimated by AQ model. Table 6 shows that EAV values due to STA for 133 min at 170 °C, 80 min at 180 °C and 48 min at 190 °C were just over 1,108 Pa.s, which is the PAV-run AV (Table 1) of the same binder. Since the PAV is a simulation procedure making binder aged by long-term service in the field for 5 to 7 years [11], the EAV over 1,108 means the mix is already old as much as the PAV by mixture STA only. If the T is 180 °C, for example, it takes only 80 min to reach the PAV level. It is surprising to notice that if the T is 190 °C, it will take only 48 min to become oxidized to the PAV level.

Table 6 AQ and EAV by T and t

T [°C]	170			180			190		
t [min]	60	133	240	60	80	240	48	120	240
AQ [m°C]	61,858	106,691	159,840	87,657	106,745	226,506	106,615	199,678	320,978
EAV [Pa.s]	5,11.5	1,116.0	2,813.9	801.4	1,117.1	8,976.0	1,114.6	5,6,28.0	46,449.5

Figure 5 shows the EAV ratio based on the EAV of 160 °C for the same t. The EAV ratio (R) of 170 °C/160 °C is less than 2.5 by t increase up to 240 min (4 h), but the ratio of 180 °C/160 °C was continuously increased by t, reaching 7.2 at 240 min. The ratios of 185 °C/160 °C, and 190 °C/160 °C was more than double and quintuple of 180 °C/160 °C, respectively, at 240 min. The R of 185 °C/160 °C at 180 min or longer, and 190 °C/160 °C at 120 min or longer was 10 or higher. From those points, the R was exponentially increased and AV levels will have to be over 5,900 Pa.s, which is a rare case of field pavement in 10 years in service [2, 4]. The potential over-aging damage will be irrecoverable unless an antioxidant such as hydrated lime and other polymer stabilizer are used when producing the overheated HMA mixes [3, 7, 8, 9].

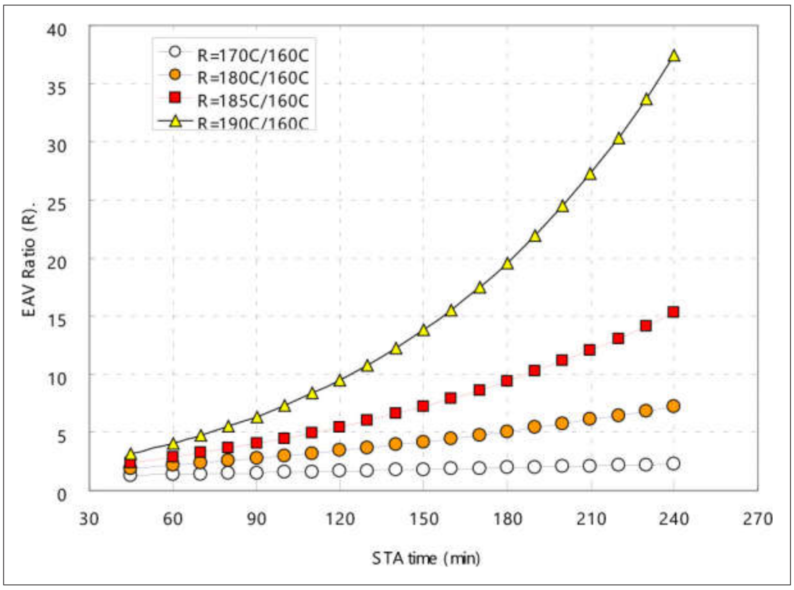

Figure 5 EAV ratio based on 160 °C EAV for the same t

4 Conclusions

The aging level of HMA mix after short-term aging (STA) was analyzed based on aging quantity (AQ) model developed using only temperature (T) of mix, and time (t) length of STA. Using the model, AQ values for various STA conditions were computed and used for estimating absolute viscosity (AV) as an aging index.
The aging quantity, given by AQ = f(t,T), was computed using time and temperature of any STA, and estimated AV (EAV) was obtained as aging level index. Since the estimated AV and the measured AV were found to show an excellent correlation, it was possible to use the estimated AV, given by $EAV = ae^{b(AQ)}$, for judging aging level of asphalt mixes.
According to estimated AV analysis, the mix temperature elevation was found to be a significant cause of expedited aging. Since the estimated AV level due to only severe STA is surprisingly high, significant care must be exercised to control the HMA time and temperature for preventing potential over-aging damages.
Since this study used a PG64-22 asphalt and only dense-graded HMA mixes, further study using many other binders and mixes may be needed for more generalized conclusion.

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References

[1] Lee, S., Han, J., Kim, Y., Kim, S., Kim, K. W.: Significance of short-term aging due to high asphalt mixture temperature. Journal of Advanced Mineral aggregate Composites, 19(1), 2014, pp. 11-20.

[2] Jeong, S., Kim, Y., Dong, B., Kim, K. W.: Quantifying model for short-term aging of hot-mix asphalt mixture. Proceedings, 10th International Conference on Road and Air field Pavement Technology, (10th ICPT 2017), Hong Kong, 8-10 Aug. 2017.

[3] Jeong, S., Xiao, F., Kim, Y., Kim, K. W.: Evaluation of age retardation effect of antioxidant in dense-graded asphalt (DGA) mixture using large molecular size. Construction and Building Materials 149, 2017, pp. 459-466.

[4] Kim, S., Lee, S. H., Kwon, O., Han, J. Y., Kim, Y. S., Kim, K. W.: Estimation of service life reduction of asphalt pavement due to short-term ageing measured by GPC from of asphalt mixture. Road Materials and Pavement Design, 17(1), 2016, pp. 153-167.

[5] Kim, S., Yun, Y., Kwon, O., Kim, K. W.: Aging properties of asphalt concrete by performance period. Journal of Korean Asphalt Society, 5(2), Dec. 2015, pp. 62-67.

[6] Kim, Y., Lee, S. J., Ahn, K, Yun, J., Kim, K. W.: Effect of hydrated lime for age-retardation of asphalt mixture with severe short-term aging. Paper submitted to ICPT Aug. 2017, Hong Kong.

[7] Kim, Y., Lee, S., Dong, B., Choi, C., Kim, K. W.: Age retardation effect of hydrated lime in comparison with liquid anti-stripping agents in asphalt mixtures. Paper submitted to TRB for 2018 TRB Meeting.

[8] Ahn,K., Kim, Y. S., Yun, J. H., Han, J. H., Kim, S., Kim, K. W.: Analysis of antioxidant effect on retardation of asphalt aging using GPC. Journal of Korean Asphalt Society, 5(1), June 2015, pp. 12-17.

[9] Production and construction of asphalt mixtures: 2015. Ministry of Land, Infrastructure and Transport, Sejong City, Republic of Korea.

[10] Kim, Y., Yun, J., Jeong, S., Kim, K. W.: Analysis of binder aging levels in asphalt mixture caused by short-term aging conditions using the GPC technique. International Journal of Highway Engineering, 18(3), June 2016, pp. 1-9.

[11] Performance graded asphalt binder specification and testing, Superpave Series No. 1, (SP-1), Lexington, KY, USA, 2002.