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Simulating Laboratory Short Term Aging to Suit Malaysian Field Conditions

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***Abstract*—**This paper characterizes the effects of artificial short term aging in the laboratory on the rheological properties of virgin 80/100 penetration grade asphalt binder. After several years in service, asphalt mixture started to deteriorate due to aging. Aging is a complex physico-chemical phenomenon that influences asphalt binder rheological properties causing a deterioration in asphalt mixture performance. To ascertain asphalt binder aging effects, the virgin, artificially aged and extracted asphalt binder were tested via the Rolling Thin film Oven (RTFO), Dynamic Shear Rheometer (DSR) and Rotational Viscometer (RV). A comparative study between laboratory and field aging conditions were also carried out. The results showed that the specimens conditioned for 85 minutes inside the RTFO was insufficient to simulate the actual short term aging caused that took place in the field under Malaysian field conditions.

***Keywords*—**Asphalt binder, Short term aging, Rheological properties, Viscosity, Temperature susceptibility.

I. Introduction

ASPHALT binder is a common material that has been used largely in the road construction industries. However, binder aging is among the factors that caused shorter pavement life span. Aging can be divided into several stages. The initial stage takes place during transportation, storage, and handling; followed by asphalt mix production and construction. The final stage occurs while the pavement is in service over extended time. Aging is quite nominal during the initial stage. The second stage refers to short-term ageing, simulated using the Rolling Thin Film Oven (RTFO) in the laboratory. The final stage refers to the long-term ageing and simulated in the laboratory using a Pressure Aging Vessel (PAV) on the RTFO test residue [1]. The properties of asphalt binder coating the aggregates changed during mixing, transporting, construction and during service life [2]. Volatilization of asphalt binder and reaction with oxygen from the environment (oxidation) were two different mechanisms that caused property changes and led to aging of asphalt binders [3]. During the mixing process, binders aged due to elevated temperatures and continuous air flow throughout the process. Over an extended period of time and due to oxidation process, it was postulated that binder aging in the mix is getting more severe, caused by greater variations in air temperature [1]. Short and long term aging increased asphalt binder viscosity and resulted in stiffer mixtures. Molecular re-structuring over time and actinic light (primarily ultraviolet radiation, particularly in desert conditions, were among the contributing factors that promoted binder aging. Oxidation, volatile loss and thixotropic effects were universally accepted as the three dominant factors affecting asphalt binder's hardening [4].

In countries with temperate climate, aging is considered as a seasonal process and generally more severe in summer than in winter [1]. A more rapid aging process happened in tropical countries such as Malaysia as compared to temperate countries. Located near the equator, Malaysia's climate is categorized as equatorial, being hot and humid mostly throughout the year. This research was conducted to evaluate and simulate the effects of ambient conditions on short-term aging for the asphalt binder during a typical road construction in Malaysia. The findings imply the need to specify a suitable laboratory short term conditioning procedure to simulate Malaysian field conditions especially the weather.

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II. Materials And Methods

A. Materials

A conventional penetration grade bitumen 80/100 (PG 64) supplied by PETRONAS was used. The basic properties of the 80/100 bitumen used are summarized in Table I.

TABLE I
Properties of Bitumen Used

Properties	Results
Specific gravity (g/cm^3)	1.020
Penetration at 25 °C (dmm)	81
Softening point (°C)	46
Ductility at 25 °C (cm)	>100

B. Methods

The rheological properties of the binder were investigated. The rheological tests were performed on virgin, artificially aged, and extracted asphalt binders. Bitumen is a visco-elastic material that exhibits a more viscous behavior when being conditioned at extended aging period at high temperatures; that is. more than 100˚C. In this study, the differences between virgin and aged asphalt binder viscosities were considered as the aging effects on asphalt binder physical properties. The aging process increased the asphalt binder viscosity, making it more brittle and stiffer. To ascertain the effects of short-term aging on asphalt binder physical properties, the Dynamic Shear Rheometer (DSR) and Rotational Viscometer (RV) tests were conducted. The DSR was used to characterize the visco-elastic properties of asphalt binder at intermediate temperatures, while the RV was used to determine the properties of the asphalt binder at elevated temperatures [1]. The Rolling Thin Film Oven (RTFO) was used to produce an artificial short-term-aged asphalt binder. The RTFO test measures the effects of air and heat on a moving film of semi-solid asphaltic binder [5]. The aging duration of 85 minutes in the RTFO that simulated aging effects was postulated to have similar effects of aging at an ambient field condition although the variables causing binder aging in the field were different from the aging process simulated in the RTFO [6].

On the other hand, the extracted binder demonstrates the aging effects of ambient field conditions on an asphalt binder. Binder extraction was carried out according to ASTM D6847-02 procedures [7]. The extracted binder was used for further physical and rheological tests. To extract the asphalt binder, asphalt mixture was repeatedly washed using a chemical solvent using a laboratory extractor. Then, the solvent was evaporated using a vacuum rotary evaporator. Fig. 1 describes experimental design used in this study.

The RTFO was used to simulate the asphalt binder aging in laboratory. Table II summaries the RTFO test parameters. For this test, 35 g of the asphalt binder was placed inside the RTFO bottles. The bottles were placed in a vertical rotating carriage, where the bottle hole faced the air jet. The samples were kept for 0, 85, 105, 125, 145, 165 and 185 minutes in the oven at 163°C. The rotating carriage rotated at a rate of 15 rev/min. This aging process was conducted to simulate the aging conditions experienced by a film of asphalt binder during hot mix asphalt production and construction.

TABLE II
RTFO TEST PARAMETERS

Parameters	RTFO
Sample placement	Glass bottle
Sample size	35 g per bottle
Rolling action	15 rev/min
Forced air	Heated air jet
Test duration	85, 105, 125, 145, 165 and 185 min
Test temperature	163°C

The DSR and RV were respectively used to determine asphalt binder viscosity and elasticity properties. The complex shear modulus (G*) and phase angle (δ) were determined using the DSR, where G* is a measure of the total resistance of a material to deformation and δ is an indicator of the relative amounts of recoverable and non-recoverable deformations [1], under specific temperature and loading frequency. G* is the resultant of two vectors, G' and G" where G' represents the elastic components and G" represents the viscous components

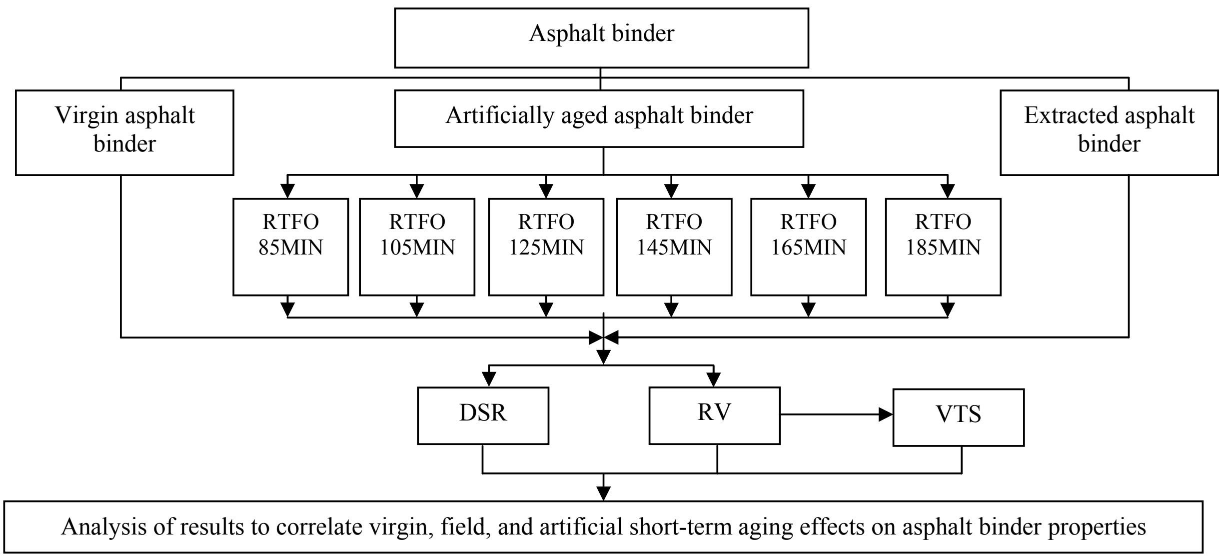

Fig. 1 Experimental Design

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as depicted in Fig. 2. According to Superpave™ asphalt binder test protocol; this test was conducted at 10 rad/s at high temperature range of 46-82°C. The asphalt binder film thickness was 1 mm and 25 mm in diameter. The sample was placed between oscillating spindle and a fixed base plate. To prepare the sample, hot asphalt binder was poured into a mold to produce a 1-mm-thick film of asphalt binder. Upon cooling and became more solid, the sample was placed properly between the spindle and fixed plate for further G* and δ measurements.

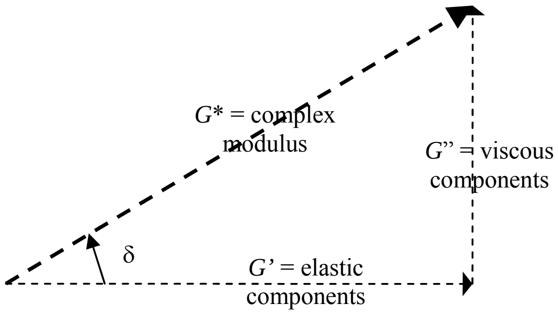

Fig. 2 Vectorial Relationship between G*, G', and G"

The RV was used to determine the viscosity and torque of asphalt binder at high temperatures. The tests were conducted at 120, 130, 140, 150 and 160°C. The waiting period for each temperature was 1½ hours to allow the torque and viscosity to become constant. For this test, spindle No. 27 was chosen and the spindle speed was set at 20 rpm. Almost 14 g of fluidic asphalt binder was poured into the sample chamber, placed in the thermo container and was ready to be tested when the temperature became stable.

In addition, the Viscosity Temperature Susceptibility (VTS) method was used to determine the effects of temperature susceptibility on the asphalt binder viscosity. Asphalt researchers have been using the viscosity-temperature susceptibility (VTS) method in binder temperature susceptibility classification for years [8]. VTS method was used to figure out the relationship between temperature susceptibility and viscosity. The basic definition of VTS is shown in Equation 1.

$$\mathrm{VTS} = \frac{[\log[\log(\eta_{T2})] - \log[\log(\eta_{T1})]]}{[\log(T_2) - \log(T_1)]} \quad (1)$$

where T1 and T2 are temperatures at two known points (degree Celsius), while η_{T1} and η_{T2} are viscosities of the binder at the same two points (cP) [9].

The VTS method was conducted at 120, 130, 140, 150 and 160°C for the virgin, artificially aged, and extracted asphalt binders. The viscosity-temperature dependency was obtained from the RV test results.

III. Result and Discussion

Fig. 3 illustrates G* and δ temperature dependency for the virgin, short-term-aged, and extracted asphalt binder. It can be seen that increasing the aging time during sample preparation has significant effects on G* and δ. Fig. 3 also shows that at elevated temperatures, the value of G* decreases, while δ increases, irrespective of δ for the virgin binder that decreases at 76°C and 82°C. Moreover, Fig. 3 shows that G* drops drastically from 46°C until 58°C, however, the decrement at higher temperatures, is very small. The relationships between G* and temperature as well as δ and temperature, follows the power and polynomial trends, respectively, as indicated in Tables III and IV.

From Fig. 3, Table III and Table IV, the results reveal that the aging duration in the RTFO has significant effects on the asphalt binder, to simulate ambient field conditions in the laboratory. According to ASTM D 2872, it was postulated that 85 minutes aging time in the RTFO would be sufficient to simulate the aging field condition [5]. The extracted asphalt binder represents the result of actual short-term aging, which was induced by the field weather and environment conditions. Fig. 3 shows aging time that simulates the actual field condition in the RTFO which is approximately 125 minutes, not 85 minutes.

TABLE III
G* Equation and R-Square Value from DSR Test

Binder	Equation	R-square value
Virgin	G*= 1E+17(T)-7.765	R^2= 0.9997
RTFO 85 min	G*= 1E+18(T)-8.08	R^2= 0.9992
RTFO 105 min	G*= 3E+18(T)-8.204	R^2= 0.9998
RTFO 125 min	G*= 3E+18(T)-8.158	R^2= 0.9995
RTFO 145 min	G*= 4E+18(T)-8.212	R^2= 0.9992
RTFO 165 min	G*= 5E+18(T)-8.268	R^2= 0.9995
RTFO 185 min	G*= 3E+18(T)-8.147	R^2= 0.9990
Extracted	G*= 2E+18(T)-8.064	R^2= 0.9994

T = Test temperature.

TABLE IV
Δ Equation and R-Square Value from DSR Test

Binder	Equation	R-square value
Virgin	δ=-0.0113(T)2+1.5535(T)+35.867	R^2=0.9997
RTFO 85 min	δ=-0.0087(T)2+1.4224(T)+31.682	R^2=0.9817
RTFO 105 min	δ=-0.0079(T)2+1.3384(T)+33.234	R^2=0.9973
RTFO 125 min	δ=-0.0064(T)2+1.2070(T)+33.972	R^2=0.9922
RTFO 145 min	δ=-0.0081(T)2+1.4249(T)+27.007	R^2=0.9946
RTFO 165 min	δ=-0.0065(T)2+1.2573(T)+30.259	R^2=0.9985
RTFO 185 min	δ=-0.0067(T)2+1.2218(T)+32.762	R^2=0.9986
Extracted	δ=-0.0081(T)2+1.3580(T)+32.733	R^2=0.9885

T = Test temperature.

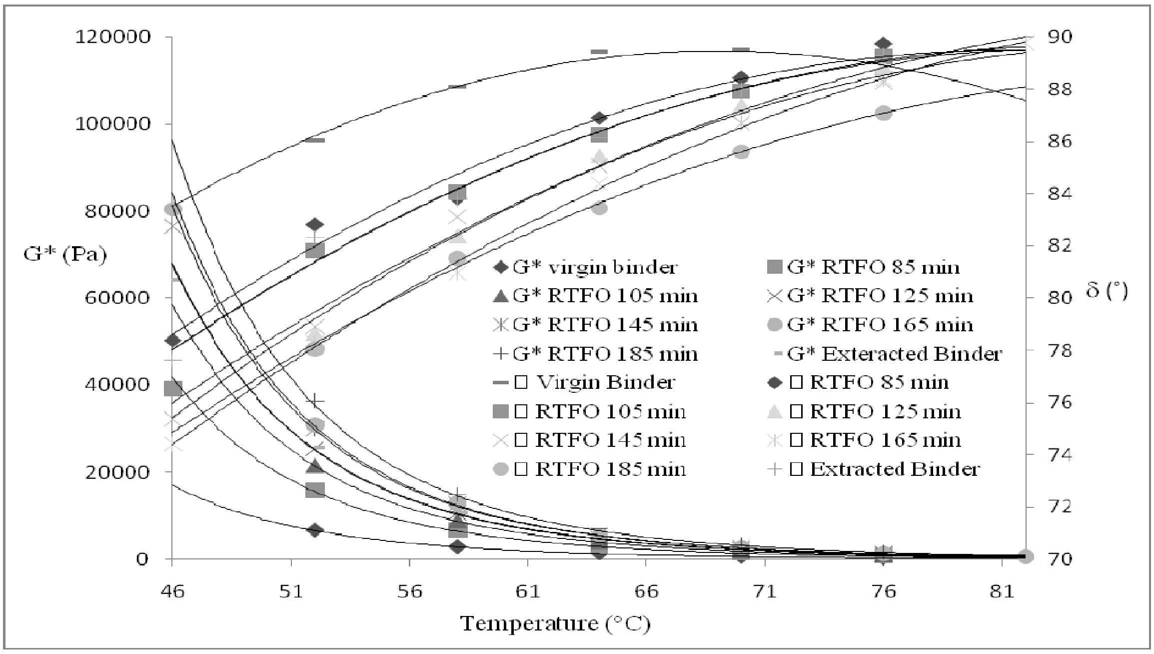

Fig. 3 Rheological Behavior of Asphalt Binder from DSR Test

The effects of the aging on the RV are shown in Fig. 4. The results show a linear relationship between aging time and viscosity. As expected, viscosity increases along with the increment of aging duration at stipulated test temperature.

Fig. 4 also depicts the viscosity differences among virgin, artificial aging and extracted asphalt binders. The results show that viscosity decreases rapidly at 120°C until 140°C, but decreases at a slower rate at 150ºC and 160ºC. It can be infer that 125 and 145 minutes of aging simulate the short term aging based on field condition in terms of viscosity.

The viscosity-temperature susceptibility (VTS) results are shown in Table V. Higher VTS values indicate that binder viscosity is more susceptible to temperature. The results show the VTS values change due to temperature increment. However, there appears to be no significant correlation between temperature and VTS for all samples tested under different conditions, and this applies to virgin, artificially aged and extracted binders. In addition, it is found that VTS values are higher at lower temperatures and vice versa. Furthermore, average VTS values for each test temperature range, that is, 120-130, 130-140, 140,-150 and 150-160°C, are very close to the VTS value range for 120-160°C as indicated in the last row of Table V.

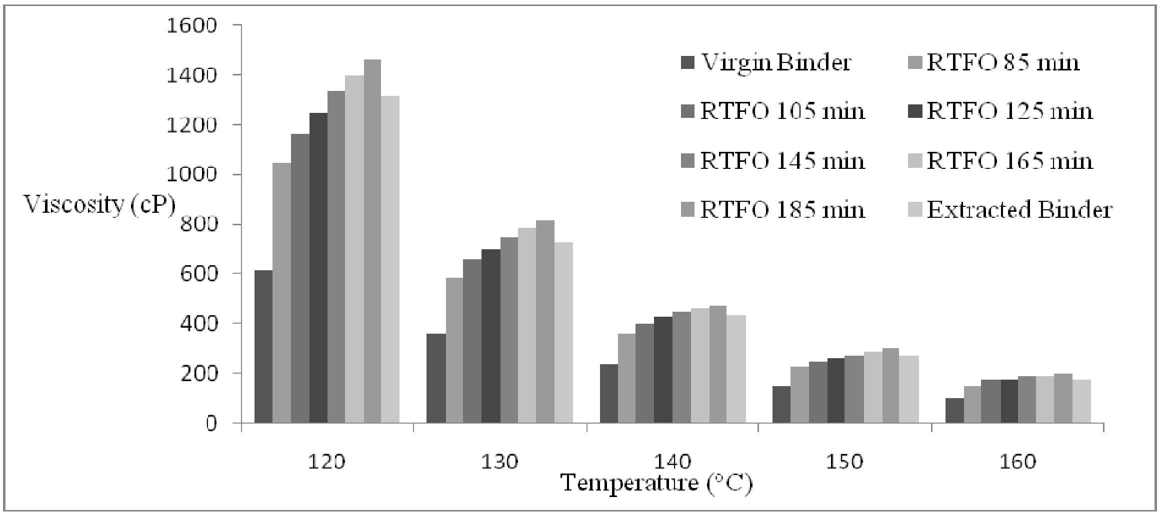

Fig. 4 Viscosity Behavior of Asphalt Binder from RV Test

TABLE V
VTS RESULTS FOR DIFFERENT CONDITIONS

		Binder							
		Virgin binder	**RTFO 85 min**	**RTFO 105 min**	**RTFO 125 min**	**RTFO 145 min**	**RTFO 165 min**	**RTFO 185 min**	**Extracted binder**
VTS	VTS 120-130	-1.065	-1.089	-1.038	-1.06	-1.046	-1.034	-1.05	-1.079
	VTS 130-140	-1.005	-1.063	-1.091	-1.069	-1.084	-1.122	-1.127	-1.077
	VTS 140-150	-1.272	-1.223	-1.184	-1.202	-1.218	-1.169	-1.123	-1.151
	VTS 150-160	-1.307	-1.206	-1.035	-1.171	-1.094	-1.216	-1.143	-1.300
	VTS 120-160	-1.154	-1.141	-1.086	-1.121	-1.108	-1.13	-1.108	-1.145
	Average	**-1.162**	**-1.145**	**-1.087**	**-1.126**	**-1.111**	**-1.135**	**-1.111**	**-1.152**

Average of VTS values for each test temperature range except VTS 120-160.

IV. CONCLUSION

The findings indicate that the aging time in the RTFO exhibit a linear relationship with asphalt binder viscosity. It is observed that longer aging duration in the RTFO had a significant effect on the DSR, RV and VTS results. Aging the mix for 85 minutes was insufficient to simulate the real aging that took place under prevailing site conditions and weather in Malaysia. Therefore, from the DSR results (G^* and δ) it is recommended that the aging time is extended to 125 minutes. According to the VTS and RV results, reductions in asphalt binder viscosity significantly took place at 120°C to 140°C, compared to that of 150°C to 160°C, for all tested asphalt binder samples.

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