EFFECT OF AGING ON VISCOELASTIC PERFORMANCE OF ASPHALT BINDER

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ABSTRACT

The aging of asphalt binder is an important factor to asphalt pavement service property. In this paper, rolling thin film oven (RTFO) is used to simulate the short-term age of asphalt binder during construction, then pressure aging vessel (PAV) is used to age the RTFO test residues for different hours. The authors studied the effects of aging on viscoelastic performance of asphalt binder by using bending beam rheometer and dynamic shear rheometer. The results indicate that the aging of asphalt binder will decline its viscous performance and enhance its elastic performance, so its resistance to deformation will be enhanced while its anti-fatigue cracking capacity will decrease.

Keywords: asphalt binder, aging, viscoelasticity, bending beam rheometer (BBR), dynamic shear rheometer (DSR)

1. INTRODUCTION

The aging of asphalt binder is an important factor in asphalt pavement service performance. In asphalt mixture, asphalt binder functions as bonding agent to glue aggregate together and undergoes deformation when the pavement is stressed during service. A series of physics and chemical changes (such as volatilization, oxidation, etc.) will take place duo to the influence of temperature, light and oxygen during mixing, laying and service period, which will decline its properties. The macro representation of aging is to make its softening point higher, penetration lower, viscosity higher and ductility lower.

Strategic Highway Research Program (SHRP) researcher found that rotation thin-film oven (RTFO) could be used to simulate asphalt binder aging during construction period, and that aging in pressure aging vessel (PAV) for 20 hours on RTFOT residues could simulate asphalt binder aging during 5 years service. The authors aged asphalt by using RTFO at 160C for 85 minutes, then aged the residues in PAV at 100C, 2MPa condition for different periods. Then bending beam rheometer (BBR) test and dynamic shearing rheometer (DSR) test on these residues are performed to assess the influence of aging on asphalt binder viscoelastic performance and index.

2. PERFORMANCE OF ORIGINAL ASPHALT BINDER

Asphalt binder used in this study is Shell-70, whose fundamental characteristics are shown in Table 1.

Table 1. Technical index of original asphalt binder.

Index		Units	Values
Penetration（100g, 5s）	5ºC	0.1mm	9.63
	15ºC	0.1mm	28.57
	25ºC	0.1mm	68.8
Penetration Index		ºC	-0.43
Softening point		ºC	46.5
Ductility (5cm/min)	5ºC	Cm	5.5
	15ºC	Cm	>100
	25ºC	Cm	>100

3. INFLUENCE OF AGING ON CREEP STIFFNESS AND CREEP RATE

The creep stiffness and creep rate on low temperature condition denote the low temperature crack resistance of asphalt binder. The paper measured the performance of asphalt, aged for different PAV aging periods, on different low temperature condition with BBR. The results are listed in Tables 2 and 3.

Table 2. Creep stiffness S of asphalt after different PAV aging periods (MPa).

Temperature（°C）	Aged period in PAV (hr)				
	0	5	10	15	20
-30	382	456	600	958	1191
-20	135	220	269	374	406
-18	120	185	216	300	325
-15	71	140	178	179	224
-10	43	62	85	94	106
-8	42	47	70	74	77

Table 3. Creep stiffness change rate (m) of asphalt after different PAV aging periods.

Temperature（°C）	Aged period in PAV (hr)				
	0	5	10	15	20
-30	0.174	0.169	0.152	0.144	0.137
-20	0.266	0.274	0.248	0.212	0.190
-18	0.310	0.290	0.274	0.240	0.201
-15	0.330	0.320	0.282	0.263	0.268
-10	0.385	0.369	0.337	0.314	0.310
-8	0.401	0.387	0.351	0.327	0.318

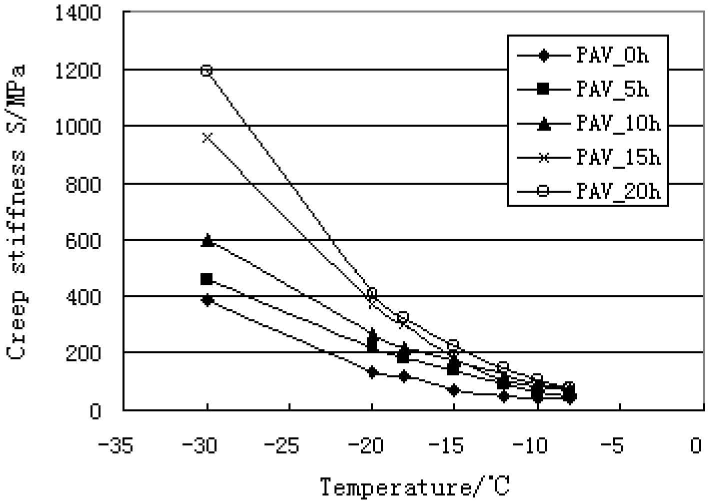

Figure 1. The rules of creep stiffness(S) varying with temperature after different PAV aging periods.

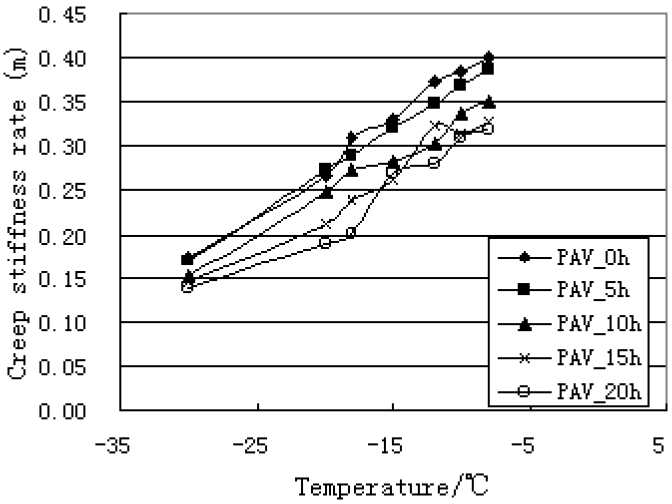

Figure 2. The rules of creep stiffness change rate (m) varying with temperature after different PAV aging periods.

As is shown in Tables 2 and 3 and Figures 1 and 2, creep stiffness (S) of asphalt binder becomes lower, while the change rate of creep stiffness (m) becomes higher with the rise of temperature. Aging of asphalt binder in PAV exerts major influence on its creep stiffness S and m in that creep stiffness becomes higher and m will becomes lower with the prolonging of PAV aging period, which indicates that the viscosity performance of asphalt residue will decrease gradually and its elastic performance distinct increasingly along with the prolonging of PAV aging process.

4. THE INFLUENCE OF AGING ON CREEP COMPLIANCE J OF ASPHALT BINDER

BBR is performed to measure the variation law of mid-span deflection creep deformation in simply-supported asphalt beam under constant load with time. It is known from viscoelastic theory that viscoelastic solution could be derived easily from the solution of elasticity problem according to elasticity-viscoelasticity correspondence principle (Correspondence principle, for short). As is known in mechanics of materials, when mid-span of simply-supported elastic beam is under a constant load q_0, deflection at mid-span is:

$$v = \frac{-q_0 \cdot L^3}{48E \cdot I} \tag{1}$$

Where： q_0 is the constant load applied;

L is the distance between two bearings of simply-supported beam;

E is elastic modulus;

I is the flexural rigidity of the beam.

According to correspondence principle, the deflection response of simply-supported viscoelastic beam is:

$$\overline{v(s)} = \frac{-\left(\frac{q_0}{s}\right)\cdot L^3}{48I\cdot s\overline{E}} = -\frac{q_0L^3}{48I\cdot s^2\overline{E}} = -\frac{q_0L^3}{48I}\cdot\overline{J\left(s\right)} \tag{2}$$

So：

$$v\left(t\right) = -\frac{q_0L^3}{48I}J\left(t\right) \tag{3}$$

V(t) is the mid-span deflection value of simply-supported viscoelastic beam undergoing permanent load at different instances. So,

$$J\left(t\right) = -\frac{-48I\cdot v\left(t\right)}{q_0L^3} \tag{4}$$

As for the BBR sample, the supporting distance L is 102mm, width 12.5mm and thickness 6.25mm. so:

$$J\left(t\right) = -0.0115029\frac{v\left(t\right)}{q_0} \tag{5}$$

So, the creep compliance J(t) of asphalt beam can be figured out easily from BBR test result. The creep compliance J(t) of asphalt residues, aged for different PAV aging time, derive from BBR test result at -20C are shown in Figure 3.

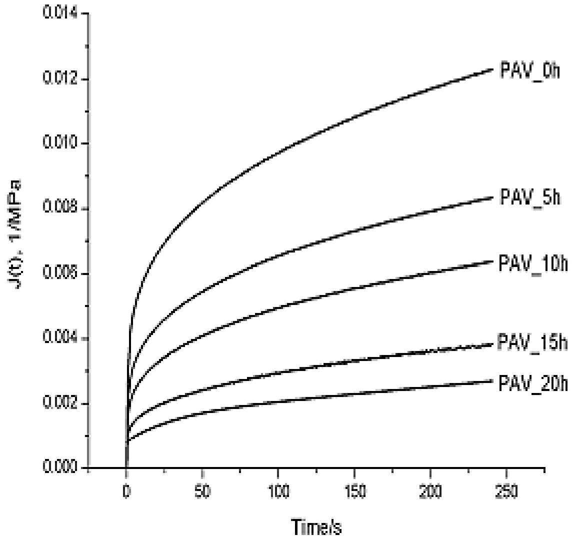

Figure 3. Creep compliance J(t) of asphalt after different PAV aging periods.

It can be observed from Figure 3 that asphalt creep compliance will decrease after PAV aging. The longer the aging time, the more its creep compliance decreased. The slope of creep compliance J(t) will decrease in response to the prolonging of PAV aging time. For instance, the creep compliance curve of asphalt residue aged for 20 hours with PAV already tends to be horizontal. This indicates that the creep property and viscous performance of asphalt residue reduce gradually, and its elastic properties will emerge gradually with increasing of PAV aging time.

5. INFLUENCE OF AGING ON DYNAMIC VISCOELASTIC PARAMETERS OF ASPHALT BINDER

SHRP researchers use DSR to measure viscoelastic performance of asphalt binder (dynamic shear modulus G^* and phase angle δ), and control permanent deformation by restricting $G^*/\sin\delta$ and control fatigue cracking by restricting $G^* * \sin\delta$. In this paper, DSR is applied to perform on the PAV aged asphalt residues at different temperatures. The results are shown in Table 4 and Figure 4~Figure 6.

Table 4. DSR test results of asphalt binder after different PAV aging periods.

Aged periods with PAV（h）	Viscoelastic index	Temperature（°C）					
		5	10	15	20	25	30
0	G^* （KPa）	19600	14000	7590	3480	1290	375
	δ (°)	40.7	43.2	48.3	54.3	60.8	67.1
	G^**sinδ（MPa）	12.8	9.61	5.67	2.82	1.13	0.345
5	G^* （KPa）	22900	15900	8940	4340	1900	814
	δ (°)	40.7	43.2	48.3	54.3	60.8	67.1
	G^**sinδ（MPa）	14.93	10.88	6.67	3.52	1.66	0.75
10	G^* （KPa）	29200	18000	9930	4710	2150	865
	δ (°)	37.5	43.4	48.2	53.8	60	65.7
	G^**sinδ（MPa）	17.78	12.37	7.40	3.80	1.86	0.79
15	G^* （KPa）	34800	20500	11300	5600	2370	986
	δ (°)	33.2	39.7	43.5	49.6	55	61.7
	G^**sinδ（MPa）	19.06	13.09	7.78	4.26	1.94	0.87
20	G^* （KPa）	50400	30600	16100	7670	3790	1490
	δ (°)	34.7	37.8	42.6	48.8	54.4	60.9
	G^**sinδ（MPa）	28.69	18.75	10.90	5.77	3.08	1.30

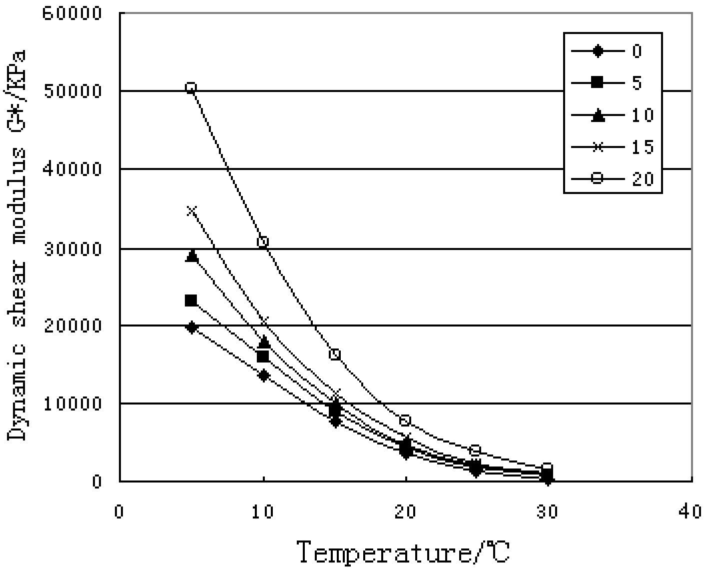

Figure 4. The rules of asphalt complex stiffness modulus G^* varying with temperature after different PAV aging periods.

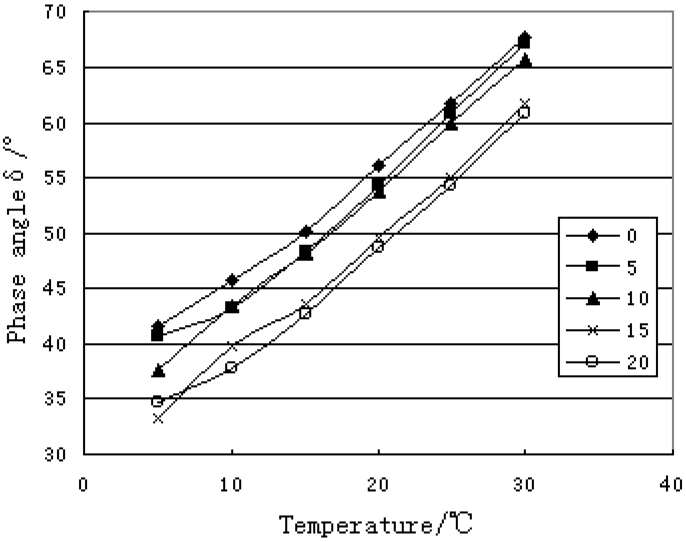

Figure 5. The rules of asphalt phase angle δ varying with temperature after different PAV aging periods.

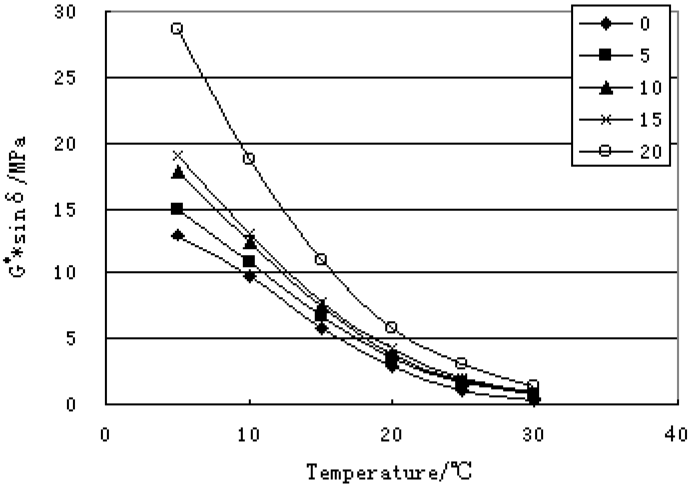

Figure 6. The rules of G^**sinδ varying with temperature after different PAV aging periods.

It can be seen from Figures 4 and 5 that with the increasing of PAV aging time, the complex shear modulus G^* of asphalt residue increases, while its phase angle δ decrease gradually, which indicates that aging will make asphalt elicit obvious elastic properties, and enhance its anti-deformation capacity, which is favorable to decrease the permanent deformation of asphalt pavement. But it can also be seen from Figure 6 that the G^**sinδ of asphalt residue increases with the increase of PAV aging period, which indicates that its anti-fatigue cracking capacity declined.

6. SUMMARY

In this paper, rolling thin film oven (RTFO) is used to simulate the short-term age of asphalt binder during construction, then pressure aging vessel (PAV) is used to age the RTFO test residues for different hours. The authors studied the effects of aging on viscoelastic performance of asphalt binder by using bending beam rheometer and dynamic shear rheometer.

The following rules are obtained after systemic testing and analyzing.

1. PAV aging has major influence on creep stiffness S, creep stiffness change rate m, creep compliance J(t). Creep stiffness increases with aging time, while m and J(t) decline with the aging time. This indicate that the viscosity performance of asphalt residue decrease gradually, and elastic behavior distinct increasingly with the increasing of PAV aging time.

2. With the prolonging of PAV aging time, elastic behavior of asphalt residue will increase and viscous behavior will decrease gradually. This is favorable to decrease the permanent deformation, but unfavorable to anti-fatigue cracking of asphalt pavement.

7. ACKNOWLEDGMENTS

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