

Evaluation of Fatigue Performance of Asphalt Based on Constant Strain DSR Test

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Abstract. Asphalt performance has important effect on the fatigue resistance performance of asphalt mixture. This research based on the DSR time scanning mode, investigated the constant strain performance of 70 # matrix asphalt and SBS modified asphalt. Based on 50% G^*_0 to simulate the fatigue performance of two kinds of the asphalt.

1. Introduction

Fatigue cracking is one of the major failure mode of asphalt pavement and considered as the main factors of asphalt pavement structure design. Fatigue resistance of asphalt mixture is one of the important factors affecting the service life of the asphalt pavement. In recent years, researchers at home and abroad adopt the phenomenological method to study the factors affecting the fatigue performance of asphalt mixture. In the same time, different fatigue model of asphalt mixture is put forward, and some scholars also explore the fatigue mechanism of asphalt mixture in terms of damage perspective.

In asphalt mixture, asphalt binder bonds the aggregate together to form the structure of pavement. Under the loads, asphalt and asphalt mortar is the principal part to endure tensile stress and tensile strain of asphalt pavement, so the fatigue performance of asphalt directly affect the fatigue performance of asphalt mixture. In recent years Fatigue performance of asphalt were studied at home and abroad. Tan with the aid of dynamic shear rheometer, study the normal fatigue characteristic of asphalt through the stress mode of continuous loading fatigue test [1]. By the continuous load fatigue test of strain mode, Li Xiaomin analyzed the mechanical response of asphalt mortar under repeated load [2]. Shenoy A studied the influence of temperature on the fatigue test performance of the asphalt [3]. Yuan Yan study the fatigue properties of modified asphalt by stress and the strain mode of continuous load fatigue test [4]. K.S. Bonnetti chose two kinds of common asphalt and five kinds of modified asphalt as the research object, discussed the load mode, loading frequency, test temperature and initial dissipation can affect the performance of asphalt fatigue [5].

This paper used phenomenology method, based on the DSR time scanning mode, carried out strain fatigue test on 70 # ordinary asphalt and SBS modified asphalt, got the fatigue equation of different asphalt. Using based on 50% G^*_0 to evaluate the two kinds of the fatigue performance of asphalt, which can provide reference for the design of the asphalt mixture.

2. Experiment materials and method



2.1. Materials

In our country 70 # matrix asphalt and SBS modified asphalt used mostly in asphalt pavement, so this paper used this two kinds of bitumen as the research object. In accordance with the Highway Engineering Asphalt and Asphalt Mixture Test Procedures (JTG E20-2011), the provisions of the related technical indexes were tested. 70 # matrix asphalt technical index test results are shown in table 1, meet the heavy traffic road asphalt quality requirements; SBS modified asphalt technology index test results are shown in table 2, conform to the requirements of the quality of modified asphalt.

Table 1. 70 # matrix asphalt technical indicators.

Test project	Technical requirements	Test results	Test method
Penetration (100g 5s 25°C) (0.1mm)	40~60	68	T0604
Softening point (°C)	≤60	48.5	T0604
Ductility (5cm/min, 5°C) (cm)	≤20	28	T0605
Flash point (°C)	≤230	—	T0611
Solubility (%)	≤99	—	T0607
elastic recovery 25°C (%)	≤75	81	T0662
separation	≥2.5	0.4	T0661
kinematic viscosity (135°C) (Pa·s)	≥3	2.3	T0625

Table 2. SBS modified asphalt technical indicators.

Test project	Technical requirements	Test results	Test method
penetration (100g 5s 25°C) (0.1mm)	40~60	57	T0604
Softening point (°C)	≤60	67	T0604
Ductility (5cm/min, 5°C) (cm)	≤20	28	T0605
Flash point (°C)	≤230	—	T0611
Solubility (%)	≤99	—	T0607
elastic recovery 25°C (%)	≤75	81	T0662
separation	≥2.5	0.4	T0661
kinematic viscosity (135°C) (Pa·s)	≥3	2.3	T0625

2.2. Experiment theory and method

2.2.1. DSR theory. In the late 1980s, the SHRP project introduced Dynamic Shear Rheometer (DSR) from material field into civil engineering, solving formlessness issue during asphalt fatigue experiment, which made high-speed development in asphalt fatigue property realized. Until now, the main study on asphalt fatigue property is implemented by DSR parallel plate. In this paper, asphalt samples are time swept via DSR, and are forced by sinusoidal dynamic shear stress or strain at the same time. The load effect is shown in Figure 1. Before the test, asphalt samples are places on the lower plate, which is fixed, and the distance between parallel plates is adjusted by shifting upper plate. After loading, one cycle begins with upper plate moving from point A to B, and then back to point C before finally reaching A.

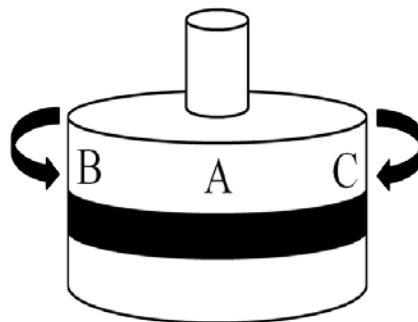


Figure 1. Illustrates the DSR loads.

Dynamic mechanical response rules of material associated with its own viscoelastic properties. Assumptions on the material according to the sine law of change of dynamic shear strain, angular frequency ω , as shown in type 1:

$$\gamma(t) = \gamma_0 \sin(\omega \cdot t) \quad (1)$$

Type, γ_0 — Strain amplitude;

ω — The angular frequency, rad/s.

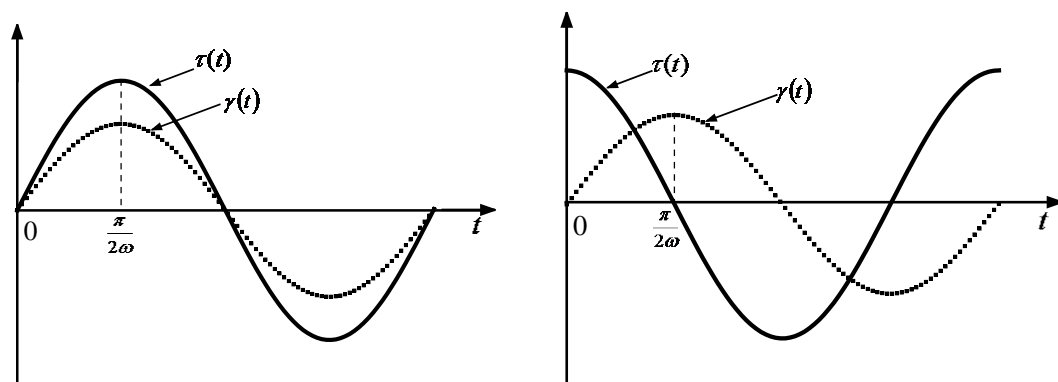
For line elastomer, stress and strain is in building a balanced instantaneous, so

$$\tau(t) = G\gamma(t) = \gamma_0 G \sin(\omega \cdot t) \quad (2)$$

That is to say, the stress and strain with the same phase and frequency, amplitude $\sigma_0 = \gamma_0 G$, as shown in figure 2 (a). For the linear viscous fluid, according to the Newton's law:

$$\tau(t) = \eta \dot{\gamma} = \eta d\gamma(t)/dt = \gamma_0 \eta \omega \cos(\omega \cdot t) = \gamma_0 \eta \omega \sin(\omega \cdot t + \frac{\pi}{2}) \quad (3)$$

The stress and strain of the linear viscous fluid with the same frequency, the phase difference $\pi/2$, stress and strain lagging behind amplitude for $\pi/2$, and the size of the frequency, as shown in figure 2 (b).



(a) Elastic material stress strain relationship (b) Viscous material stress-strain relationship

Figure 2. Material stress-strain diagram.

Under the effect of a certain amount of stress or strain, the mechanical behavior of materials with the environment temperature and load on the role of time, and the effect of loading history is closely linked. Under usually pavement temperature and traffic load, asphalt for viscoelastic body material can be sold and turned into money. When the asphalt applied by sinusoidal variation of strain and the stress is also changes according to the sine function. The same frequency, but the phase lag in the stress strain δ ($0 < \delta < \pi/2$), as shown in figure 3, the stress function can be expressed as:

$$\tau(t) = \tau_0 \sin(\omega \cdot t + \delta) \quad (4)$$

Type τ_0 — Stress amplitude (Pa)
 ω — The angular frequency ; rad/s
 δ — Phase Angle , °

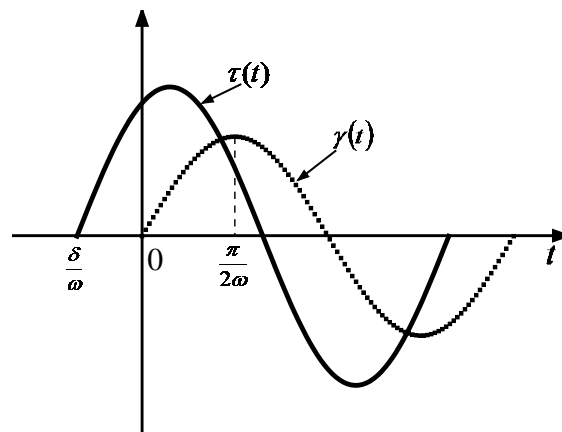


Figure 3. Asphalt stress-strain diagram.

In general, use the plural form description of alternating to physical quantities can simplify the calculation, so the alternating stress and cyclic strain can be represented as:

$$\gamma^* = \gamma_0 e^{i\omega t} \quad (5)$$

$$\sigma^* = \sigma_0 e^{i(\omega t + \delta)} \quad (6)$$

Define the complex shear modulus as:

$$G^*(\omega) = \frac{\sigma^*}{\gamma^*} = \frac{\sigma_0}{\gamma_0} e^{i\delta} = \frac{\sigma_0}{\gamma_0} (\cos \delta + i \sin \delta) = G'(\omega) + iG''(\omega) \quad (7)$$

Type, $G'(\omega)$ — storage modulus, said the elastic and viscoelastic body shows that the size of the linear viscoelastic body stored energy (Pa);

$G''(\omega)$ — loss modulus and viscoelastic body of viscous, shows that the size of the loss of linear viscoelastic body energy (Pa).

According to the type 7, $G'(\omega)$ and $G''(\omega)$ can be expressed as:

$$G'(\omega) = \frac{\sigma_0}{\gamma_0} \cos \delta \quad (8)$$

$$G''(\omega) = \frac{\sigma_0}{\gamma_0} \sin \delta \quad (9)$$

The mode of complex shear modulus $G^*(\omega)$ is the dynamic modulus:

$$|G^*(\omega)| = G(\omega) = \left\{ [G'(\omega)]^2 + [G''(\omega)]^2 \right\}^{\frac{1}{2}} \quad (10)$$

Similarly follow the general definition of viscosity, define the plural shear viscosity for:

$$\eta^*(\omega) = \frac{\sigma^*}{\dot{\gamma}} = \frac{\sigma_0}{\omega \gamma_0} e^{i(\delta - \frac{\pi}{2})} = -\frac{i \sigma_0}{\omega \gamma_0} (\sin \delta - i \cos \delta) = \eta'(\omega) - i \eta''(\omega) \quad (11)$$

2.2.2. *Testing scheme.* Using DSR time scanning mode, selection of diameter of 8 mm parallel powder, control test temperature of 30°C, load frequency of 10 Hz, at 5%, 8%, 10%, 12% strain condition, the two often repeated strain loading fatigue test of asphalt for continuous scanning test (time).

3. Test results and analysis

3.1. fatigue damage standard

Complex shear modulus attenuation for the initial value of 50% is the most widely used definition of asphalt fatigue damage one of the methods and the definition of asphalt mixture fatigue damage of the most commonly used method for stiffness modulus attenuation to the initial value is less than 50% of the (S). As a result, the definition of asphalt fatigue damage way makes the research of asphalt and mixture. Studies have shown that under the same strain level and the test temperature, according to determine the fatigue life of asphalt and 50% G^* and 50% S for determine the fatigue life of asphalt mixture in good correlation, the correlation coefficient is 0.7 ~ 0.9.

3.2. Different asphalt damage process

Figures 4 and 5 are respectively the DSR time scanning experiment, under the condition of different strain, 70 # asphalt and SBS modified asphalt complex shear modulus changing with the load times.

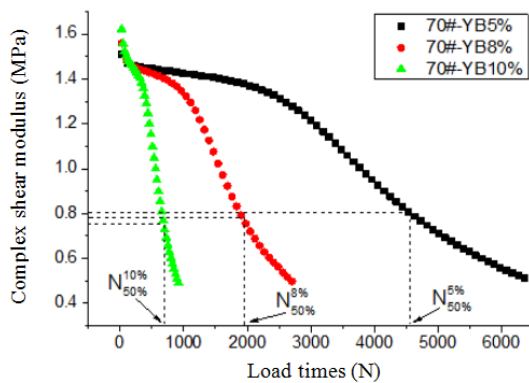


Figure 4. # 70 common asphalt curve.

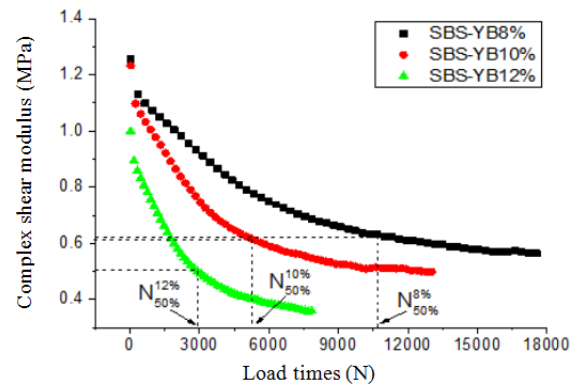


Figure 5. the curve of the SBS modified asphalt.

Can be seen from the graph:

1) under the condition of different strain levels, the plural of 70 # ordinary asphalt and SBS modified asphalt shear modulus with the increase of the number of loading and gradually decreases, but the two kinds of bitumen is obviously different from the shape of the curve. 70 # ordinary asphalt is roughly s-shaped curve shape, but in the late loading, plural shear modulus decay gradually slow down and stable. So the curve of the strain mode 70 # ordinary asphalt can be subdivided into four stages, namely initial stage, stable stage, accelerating phase and stable phase. And the curve shape of the SBS modified asphalt is roughly C (arc), not like a 70 # ordinary asphalt has half a stable stage.

2) with the increase of the strain level, the initial complex shear modulus of asphalt are reduced, and the plural shear modulus attenuation speed, specimen damage can bear before the loading times and complex shear modulus decay to 50% when the corresponding loading times were significantly reduced.

3.3. Different fatigue equation of asphalt

Related studies have shown [6,7] that asphalt or fatigue life of asphalt rubber paste DSR fatigue test and loading strain obey power relations, usually can use the type 12 said.

$$N_f = K\gamma^{-b} \quad (12)$$

Type: N_f — the fatigue life of asphalt;

γ — test applied strain size;

K 、 b regression coefficient, K associated with the shear strength of the material, b the fatigue life of asphalt strain sensitivity.

According to the test data, can return to get two constant strain fatigue equation of asphalt is as follows:

70 # ordinary asphalt:

$$N = 1.473059 \cdot \gamma^{-2.72894} \quad (13)$$

SBS modified asphalt:

$$N = 3.361244 \cdot \gamma^{-3.19648} \quad (14)$$

It can be seen that the SBS modified asphalt fatigue performance is better than that of 70 # ordinary asphalt, but compared with the ordinary asphalt, SBS modified asphalt fatigue life more sensitive to the strain level.

4. Conclusions

This paper based on the DSR time scanning mode, investigated constant strain fatigue test for different type of asphalt. Analyzing the often strain fatigue process and its fatigue life, main conclusions are as follows:

1) Under the condition of different strain levels, the complex shear modulus of 70 # ordinary asphalt and SBS modified asphalt was increased when the number of loading was gradually decreased, but the shape of the curve $G^* - N$ of two kinds of bitumen is obviously different.

2) The curve $G^* - N$ of the 70 # ordinary asphalt can be subdivided into four stages, namely initial stage, half stable stage, accelerating stage and stable stage. However, the SBS modified asphalt does not exist a half stable stage.

3) Constant strain fatigue equation of the 70 # ordinary of asphalt and SBS modified asphalt was obtained respectively, and the fatigue performance of SBS modified asphalt is better than that of 70 #

ordinary asphalt. However, compared with the ordinary asphalt, the fatigue life of SBS modified asphalt is more sensitive to the strain level.

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