SDUDY OF THE CREEP DAMAGE PROPERTIES OF ASPHALT MIXTURE UNDER STATIC LOAD

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Abstract: Asphalt concrete AC-13 and SMA-13 are designed to study their viscoelastic and damage properties under uniaxial pressure. The results indicate that the flow deformation of viscosity of asphalt mixture doesn't unlimitly increase with the loading time. As time goes by, the increment of flow deformation of viscosity decreases gradually and causes the flow deformation of viscosity to incline a stable value ultimately, which is so-called 'consolidation effect'. Moreover, under the same conditions, SMA has a stronger anti-deformation ability than AC. According to the flow characteristics of asphalt mixture, it is proposed a comparatively desirable and useful creep compliance model and visco-elastic-plastic creep model. Based on the static creep test results, the parameters concerned of the models are determined by using a constrained optimization method.

Key words: Asphalt mixture; Creep; Viscoelasticity; Damage; Model

Introduction

Asphalt mixture is thermoviscoelastic material with flow characteristics, the physical and mechanical properties is closely related to the effects of temperature and loading time. The load conditions often exhibit obvious nonlinear viscoelastic properties. The mechanical analysis generally focused on the linear viscoelastic category. In practical applications, using asphalt mixture is in non-compliance with infinitesimal deformation of the linear theory assumptions, when the deformation exceeds a certain range; linear superposition is no longer effective, so nonlinear viscoelastic theory of more universal. In recent years, road researchers have made some studies on the general nonlinear, elastic-plastic, creep, viscoelasticity of asphalt mixture [1]-[13]. As the two branch of the viscoelastic theory, liner viscoelastic theory is already quite mature, nonlinear viscoelastic theory also made a series of research results, but because of its difficulties in testing and mathematical theory, is still in development and perfected.

Damage mechanics as a subject branches is nearly 20 years. The classic nonlinear viscoelastic material constitutive theory does not consider initial defect and in actual engineering, creep failure of various loads and environmental conditions, may belong to the creep damage, more likely to be the initial defect evolution and the crack initiation and propagation. The study for the establishment of asphalt mixture viscoelastic damage constitutive model and its engineering applications is still small [14]-[25].

Therefore, based on the contrast test of AC-13 and SMA-13 two kinds of asphalt mixture road performance, focus on them under uniaxial pressure static creep damage behavior. Through the static creep test of different temperature, pressure, study the creep deformation of the characteristics and the law of variation. To reflect the creep deformation characteristics of the asphalt mixture creep deformation, establish nonlinear viscoelastic creep model and the creep damage model as the permanent deformation analysis and the high temperature stability of asphalt mixture and pavement which provides theoretical and experimental basis for evaluation.

1 Asphalt mixture design and road performance

1.1 Raw materials performance and mixture ratio design

Raw material of the test is modified asphalt, stone, mineral powder and fiber. The technical Specifications refer to references [27], which meet the technical specification for construction of highway asphalt pavement [27] requirements. Through the results of Marshall test, based on the method of technical specification for construction of highway asphalt pavements [27], AC-13 and SMA-13 asphalt mixture optimum asphalt content is 4.8%, 5.95%.

1.2 Pavement performance of asphalt mixture

The result of high temperature stability, low temperature crack resistance and water stability of two kinds of asphalt mixture according to the high-temperature rutting test, low-temperature bending test, freeze-thaw splitting test and immersion Marshall test are shown in Table 1. the results are shown in Table 2 when carried out fatigue tests under the control of stress.

Table 1 The test results of two kinds of asphalt mixture high temperature stability, low temperature crack resistance and water stability

Material type	High temperature stability	Low temperature crack resistance	Water stability	
	Dynamic stability （times/mm）	Bending limit strain(10-6)	Freeze-thaw cleavage strength (%)	Residual stability (%)
AC-13	4624	2478	87.1	90.9
Regulatory requirements [27]	⩾1000	⩾2000	⩾75	⩾80
SMA-13	5886	2645	91.0	92.1
Regulatory requirements [27]	⩾2800	⩾2500	⩾80	⩾85

Table 2 The test results of Asphalt mixture fatigue

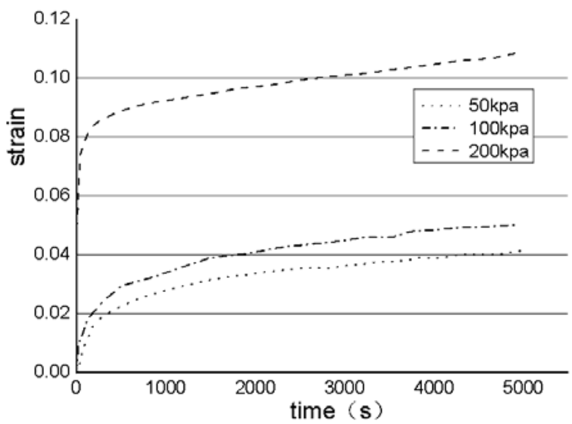
Mixture	Temperature （℃）	Stress level σ0（MPa）	Fatigue Fracture Life Ncr（time）
AC-13	25	0.1	2986
		0.2	1836
		0.3	1248
		0.7	654
SMA-13	25	0.1	3628

	0.2	2156
	0.3	1452
	0.7	800

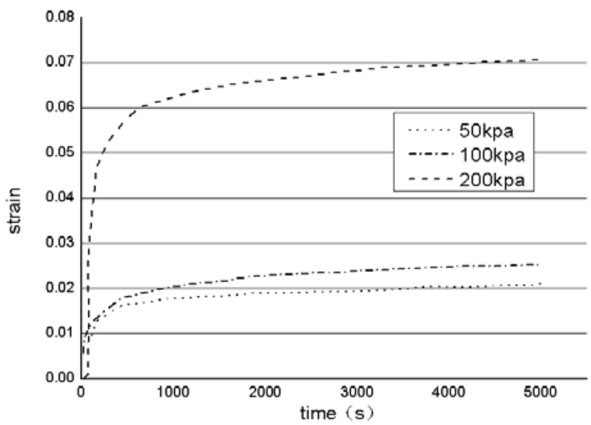
As the results shown, the high temperature stability and low temperature crack resistance and water stability of two kinds of mixture meet the technical standard value, and the performance of SMA-13 asphalt mixture is significantly better than ordinary asphalt mixture AC-13.

2 Creep test and analysis of static load of asphalt mixture

According to the standard test methods of bitumen and bituminous mixtures for highway engineering, the cylinder specimen for the static pressure method is controlled by the density of the Marshall test. The specimen size: diameter 100mm, height 100mm. Considering the performance of the high-temperature creep tests reflect asphalt mixture, select the test temperature is 25 ° C, 40 ° C, 60 ° C; applied three stress levels: 0.05, 0.1 and 0.2 MPa; loading time 5000s in order to facilitate the deformation full recovery. Put the sample in the environmental case for 4 hours before the test, and then after installing the servo-hydraulic materials testing machine HYD-25 applied preload 0.002Mpa, preload three minutes to prevent eccentric compression. Then loaded on specimen and the time data collected every 2 seconds. Static creep test results are shown in Figure 1 to Figure 3.

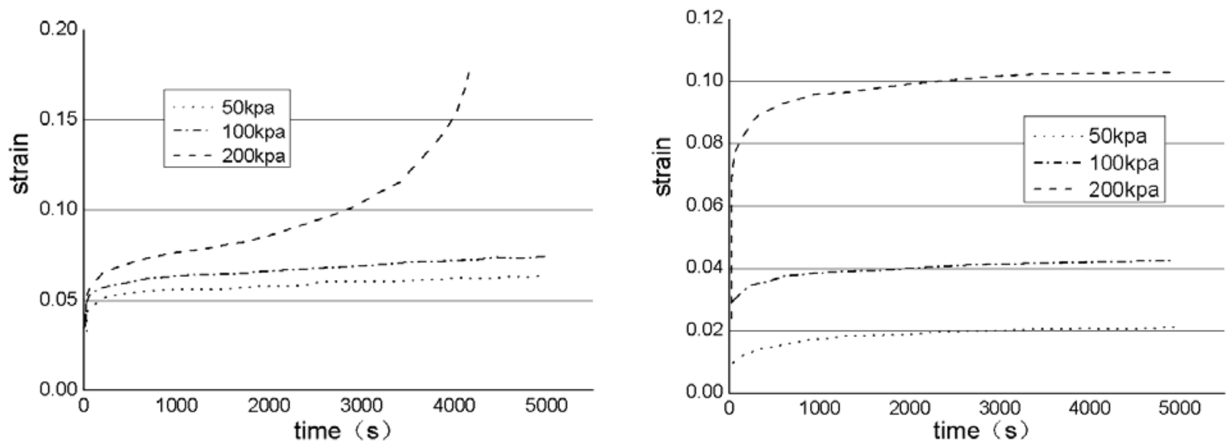


AC-13



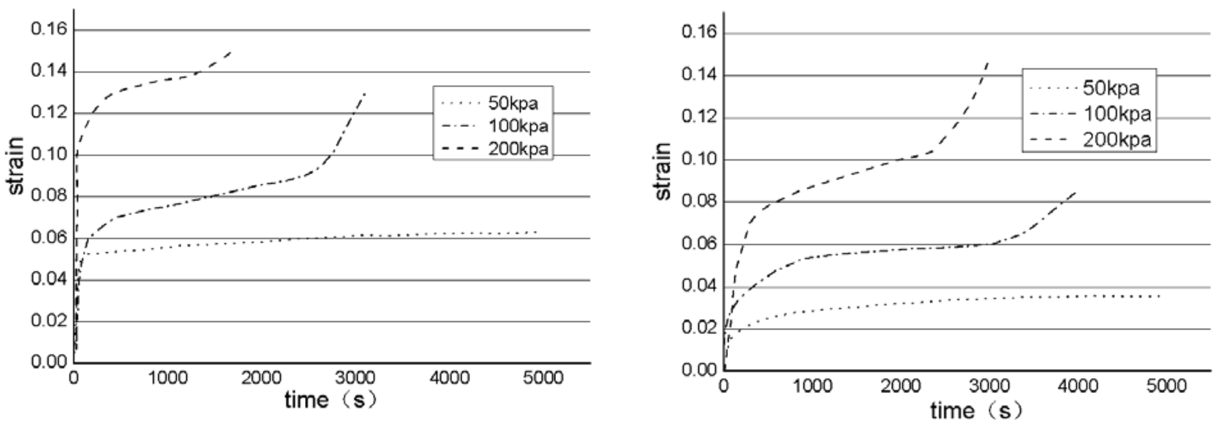
SMA-13

Fig 1 The static creep curves at 25 ℃



AC-13 SMA-13

Fig 2 The static creep curves at 40 ℃



AC-13 SMA-13

Fig 3 The static creep curves at 60 ℃

Contrast Figures 1 to 3 static creep curves:

①Asphalt mixture at low stress levels, with the loading time, creep curve slope from large to small gradually stabilized, which shows that asphalt mixture increases the deformation resistance, resulting in further deformation is more difficult, the viscous flow of asphalt mixture with the load deformation does not affect the extension of time with load and increase infinitely, the increment decreases, finally tends to a stable value, is called the‘consolidation effect’.

②At the same temperature, high stress levels, the asphalt is too late to produce viscous and flow along with the mineral aggregate elastic deformation, with time goes on ,the start of viscous flow, VMA further reduce ,the mineral aggregate embedded squeeze more and more obvious, strain rate tend to stable, mineral aggregate porosity is further reduced, the viscous flow decreases with increasing time. But with time goes by, because of greater stress, mineral aggregate begin to slip, viscous flow of asphalt also been further extended. Therefore, the specimen is not immediately destroyed and to produce an accelerated deformation rate, which has a direct relationship with the load and temperature. Then specimen’s void ratio and clearance rate increased with increasing time and then continue to increase as the deformation, the specimen eventually completely destroyed.

③Under the same conditions, SMA has stronger deformation resistance than ordinary asphalt concrete(AC). Because the composition of SMA, coarse aggregate accounted for more than

70%,there is a lot of the mutual contact surface between coarse aggregate, and part of the stone mastic asphalt fill the gap among the coarse aggregate,. In high temperatures and loads, the coarse aggregate mutual good interlocking role, so that the mixture has better resistance to deformation. Under the condition of high temperature, stone mastic asphalt viscosity decrease which reduces the impact of the ability of resistance to deformation.

④The temperature of asphalt mixture has a great effect on deformation resistance ability, the higher the temperature, deformation resistance decreased more quickly, 2 times the deformation of high temperature of 60 ℃ to 40 ℃.Because the asphalt and asphalt mixture is a typical viscoelastic materials, these materials exhibit mechanical behavior of deformation is obviously dependent on temperature.

3 Representation to rheological model analysis of asphalt mixture viscoelastic properties

3.1 Representation to rheological model of asphalt mixture viscoelastic properties

In order to fully describe the rheological properties of the asphalt mixture under complex stress state, it is necessary to re-establish a better creep model. The first analysis of a plurality of Kelvin composite model units (as shown in Figure 4), the creep compliance is [29]

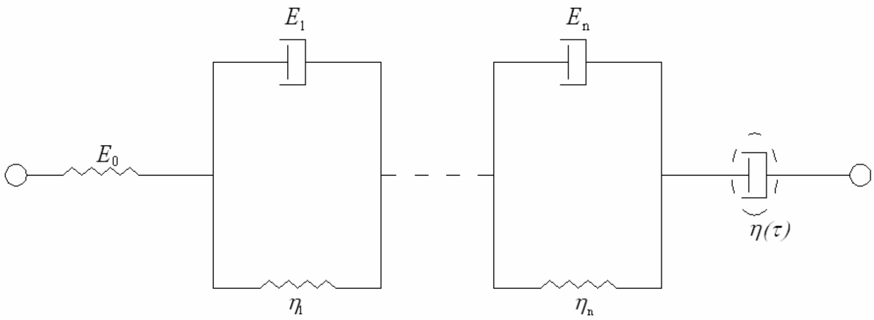


Fig 4 Several Kelvin unit composite models

$$J(t-t^{'}) = \frac{1}{E_0} + \sum_{i=1}^{n} q_i[1-e^{-\lambda_i(t-t^{'})}] \qquad (1)$$

Where: $q_i = 1/E_i$, $\lambda_i = E_i/\eta_i$, $t^{'}$ is the starting moment loads. The model reflects the instantaneous elastic deformation, recoverable viscoelastic deformation and “consolidation effect", but does not reflect the unrecoverable viscous flow deformation. Therefore, the equation (1) is suitably supplemented as follows:

$$J(t-t^{'}) = \frac{1}{E_0} + \sum_{i=1}^{n} q_i[1-e^{-\lambda_i(t-t^{'})}] + \sum_{i=1}^{m} p_i e^{-\gamma_i t^{'}}[1-e^{-\gamma_i(t-t^{'})}] \qquad (2)$$

Eq. (2) in the third term on the right side means that the viscous flow deformation, while it does not destroy the Eq. (1) with “consolidation effect" characteristic. Eq. (2) there is two summations. The more number of terms in summation, the more accurately express the stress and deformation characteristics of materials. But it involves too many parameters; the actual application is not conducive to the model. A simple model only considered here, each sum of only one, so the Eq. (2)

is simplified as:

$$J(t-t^{'})=\frac{1}{E_0}+q[1-e^{-\lambda(t-t^{'})}]+pe^{-\gamma t^{'}}[1-e^{-\gamma(t-t^{'})}] \tag{3}$$

There are five parameters in Eq (3), which can be determined by creep test curve.

3.2 Determination of asphalt mixture rheological model parameters

According to the creep test curves（Figure 1 to Figure 3）, the five parameters in the asphalt mixture rheological model of Eq. (3) can be constrainer optimization method (Levenberg-Marqurdt global optimization method) to determine. The model parameter values obtained at three different temperatures as shown in Table 3 below.

Table 3-1 Model parameters simulation results under 0.05MPa pressure

Types of asphalt mixture	Test temperature（℃）	E0（MPa）	q（10-4MPa）	λ（10-4s）	p（10-4s）	γ（10-4s）	Correlation coefficient R2
SMA-13	25	1620	6.86(1458)	8.44	8.46	8.12	0.9456
AC-13		1260	9.48	12.85	12.86	6.20	0.9686
SMA-13	40	1300(0.20)	11.20(893)	13.06	13.70	5.85	0.9861
AC-13		1010	13.52	19.80	19.53	5.76	0.9675
SMA-13	60	760(0.53)	14.80(676)	28.46	27.82	4.53	0.9770
AC-13		600	18.45	37.40	32.20	4.08	0.9687

Table 3-2 Model parameters simulation results under 0.1MPa pressure

Types of asphalt mixture	Test temperature（℃）	E0（MPa）	q（10-4MPa）	λ（10-4s）	p（10-4s）	γ（10-4s）	Correlation coefficient R2
SMA-13	25	1780	6.96	7.86	8.24	7.80	0.9566
AC-13		1360	8.60	12.84	12.45	5.68	0.9642
SMA-13	40	1380(0.22)	9.80	13.08	13.80	4.94	0.9712
AC-13		1120	10.67	16.50	18.46	5.12	0.9513
SMA-13	60	820(0.54)	13.90	26.45	26.48	4.40	0.9824
AC-13		680	16.88	35.81	31.80	3.96	0.9780

As we can see from table 3-3:

①Under the same condition, E0 of SMA-13 is bigger than AC-13’s, and with the higher the temperature , the relative proportions of the tendency is to diminish. Under the conditions of 25℃, 40℃, 60℃ with 0.2MPa，E0 of SMA-13 are respectively higher by 29.23%, 25.71% 23.44% than AC-13's.

②In different stress but the same other conditions, the parameters variation of Model 5 is small.

4 Analysis to Nonlinear viscoelastic creep damage model for asphalt mixture

The static creep deformation reflected in Figure 1~Figure 3 usually can be divided into three stages: migration period, strain increases rapidly, but the strain rate gradually decreases with time increasing; stable period, strain steady growth, but the strain rate is essentially unchanged; Period of destruction, strain, and strain rate increases rapidly until failure increases with time. In the deformation of asphalt mixture, the modulus of the existence of a first increased and then decreased with the process, is also a first strengthened after the weakening of the process, the creep strain of asphalt mixture can be used as a nonlinear spring and a viscoplastic unit series, namely:

$$\varepsilon = \varepsilon_e + \varepsilon_{vp} \tag{4}$$

For the total strain where non-destructive condition can be expressed as:

$$\varepsilon = \frac{\sigma}{at^2 + bt + c} + [\frac{B}{A}(n+1)]^{\frac{1}{n+1}} \sigma^{\frac{m}{n+1}} t^{\frac{1}{n+1}} \tag{5}$$

In the one-dimensional problem, effective stress can be expressed as:

$$\sigma = \frac{\sigma_0}{1-\omega} (\sigma \geq 0) \tag{6}$$

Where: ω is damage factor.

Kachanov [31] uses the Norton formula obtained law of creep damage Kachanov:

$$\dot{\omega} = [\frac{\sigma_0}{C(1-\omega)}]^k \tag{7}$$

Where: C, k are material parameters.

Using the fully coupled method to consider the coupling effect of creep and damage of asphalt mixture, can be obtained by the constant stress damage of asphalt mixture under creep deformation equation.

$$\varepsilon = \frac{\sigma_0}{(1-\frac{t}{t_r})^{\frac{1}{K+1}} (at^2 + bt + c)} + [\frac{B}{A}(n+1)]^{\frac{1}{n+1}} (1-\frac{t}{t_r})^{-\frac{m}{(K+1)(n+1)}} \sigma^{\frac{m}{n+1}} t^{\frac{1}{n+1}} \tag{8}$$

$$t_r = \frac{1}{K+1} (\frac{\sigma_0}{C})^{-K} \tag{9}$$

Where: $\frac{B}{A}(n+1) = O$, $\frac{1}{n+1} = P$, $\frac{m}{n+1} = Q$.

Fitting of Figure2,the AC-13 at 40℃,0.2MPa under load data manipulation the Levenberg-Marqurdt and the global optimization method, can obtain a creep damage model parameters, such as shown in Table 4.The comparison between creep test values calculated and creep damage model is shown in

Figure 5. The result shows, the creep damage model proposed (Eq. (9)) with high precision, can well simulate the creep damage of asphalt mixing material.

Table 4 Values of parameters in creep damage model of asphalt concrete AC-13

a(MPa)	b(MPa)	c(MPa)	t_r(s)	K	O	P	Q
3764.57	1511.66	258.66	4399.98	6.18	4.61	0.07	2.03

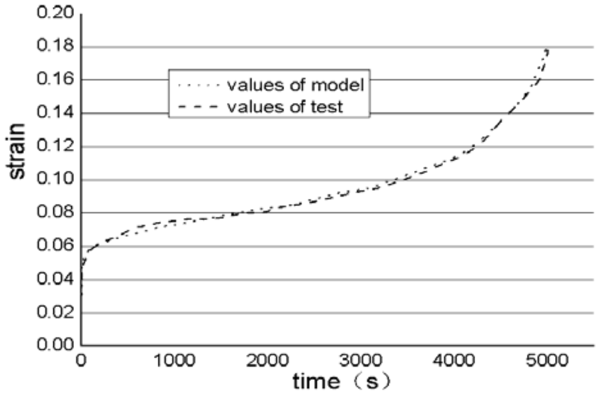


Figure 5 The AC-13 asphalt mixture creep test and creep damage model comparison under 40 ℃, 0.2MPa

5 Conclusions

（1）The results of test show that , the high temperature stability, water stability and low temperature crack resistance of the asphalt mixture of AC-13 and SMA-13 which this paper designed can meet the requirement of the construction technology, various performance indicators of SMA-13’s are better than AC-13 .

（2）A creep test is implemented on the two kinds of asphalt mixture under different temperatures and uniaxial pressure load ,and the result show that: ①The viscous flow deformation tends to a stable value after long period of loading at low stress levels which call this phenomenon as ‘consolidation effect’. ②under the same level of temperature and high stress, the strain rate tends to be stable as time goes on, there will be accelerated distortion, and the rate of deformation has a direct bearing on the load and temperature. With the increase of deformation, the specimen will be destroyed completely. ③The temperature of asphalt mixture has a great effect on deformation resistance ability, the higher the temperature, the more quickly the deformation resistance decrease. ④SMA has a stronger ability to resist deformation than AC under the same conditions.

（3）A relatively ideal and practical creep model was established according to the rheological characteristics of asphalt mixture, which can express the asphalt mixture ‘consolidation effect’, and can reflect the permanent deformation of asphalt mixture after unloading, and also can represent rheological characteristics such as the instantaneous elastic deformation, And the effectiveness of this model was verify by comparing with the test results.

（4）A model about asphalt mixture viscoelasticity creep damage was established, and the asphalt mixture creep damage was analyzed and simulated via global coupled and the parameters of the model were determined.

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