Research Article

Short-Term Creep Experiment of Cement Asphalt Mortar and Its Numerical Simulation

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In order to investigate the creep performance of cement asphalt mortar (CA mortar), the field sampling of CA mortar cylinder samples was produced, and all samples were tested on WDW series electric universal testing machine by using uniaxial static creep test at 25°C, and the load stress levels were 0.05 MPa, 0.1 MPa, 0.3 MPa, and 0.5 MPa. The greater the load is, the bigger the creep deformation is. The creep performance was simulated by using Burgers model, and the correlation coefficients between fitting results of Burgers model and experimental results are all greater than 0.9. Based on the requirements of finite element software, the Prony series of Burgers model was obtained, and the short-term creep process of CA mortar was simulated by the finite element software ANSYS. The relative error between simulation results and experimental data is not more than 2.5%, which indicates that the short-term creep process of CA mortar can be simulated by ANSYS software. The study results can improve the structural design theory of slab track.

1. Introduction

The nonballast slab track consists of concrete roadbed, reinforced concrete track slab, and cement asphalt mortar (CA mortar) injected between the roadbed and track slab [1]. With the rapid development of high-speed railway, cement and asphalt mortar (CA mortar) which is the key material of the cushion layer of ballastless slab track is widely used in high-speed railways in Japan [2, 3], Germany, France, and China [4], and it consists of cement, emulsified asphalt, fine aggregates, water, and admixtures and is an organic-inorganic composite material formed by mechanical mixing, whose main functions are supporting and adjustment, buffer and load transfer, blocking cracking, and providing elasticity and resistance for track structure [5]. CA mortar is very important for the safety, stability, and comfortable degree of high-speed railway [6].

As a viscoelastic material and in order to meet its service environment and construction conditions, the physical and chemical properties of CA mortar and mechanical properties have been studied extensively [7–13]. Wang et al. [7] investigated the compressive strength developing process and the microstructure of CA mortar. Yutaka et al. [8] introduce

the CA mortar used in cold weather, and Kazuyosi and Yosio [9] and Wang et al. [10] studied the compressive strength of CA mortar and its temperature susceptibility. Liu et al. [11] studied the static and dynamic mechanical properties of CA mortar. Qiu et al. [12] studied the fatigue behavior of CA mortar and proposed the fatigue equation. Xu et al. [13] investigated the dynamic compression damage properties of CA mortar under different strain rates. These research results play a useful guiding role in actual projects. Creep property is an important index for evaluating the viscoelastic behavior of CA mortar, and according to survey, after the high-speed railway has been operated for 3–5 years, the CA mortar layer will have unrecoverable deformation. Therefore, the study on the creep properties of CA mortar is very necessary.

Creep is the case that the deformation of material increases with the growth of time at constant load. Uniaxial static load creep test is one of the principal methods of studying material viscoelastic properties. Xie et al. [5] studied the long-term deformation properties and creep properties of CA mortar. Li and Jiang [14] conducted uniaxial creep test of asphaltic sand under 6 loading stresses at 20°C, and the results showed that the Burgers model can reflect asphaltic sand's viscoelasticity well. Guo and Zhao [15] studied the effects of fiber

FIGURE 1: Sampling process and part specimens.

content on the creep performance of fiber reinforced asphalt concrete by using uniaxial creep test, and the reasonable fiber content is 0.2%.

As the buffer, damping structural layer of slab track, CA mortar is mainly under the vertical load and in dynamic loading process [16], so the short-term creep properties are also needed to be researched. In this work, the relationship between deformation of CA mortar and time was measured under uniaxial static load through uniaxial compression creep test. The creep properties of CA mortar under different stress level were studied, and the test curve was fitted, which could provide an experimental basis for the optimization of CA mortar and design of slab track.

2. Experimental

2.1. Raw Materials and Specimen Fabricating. In order to reflect the mechanical properties of CA mortar in field CRTS I type slab track, the CA mortar specimens used in this experiment were sampled in the construction field. The lift plate test of field CA mortar layer of CRTS I type slab track was conducted firstly. And then, core samples were taken on the CA mortar layer. Specimens are cylinder specimens with the size of $\phi 50 \times 50$ mm. Sampling process and part specimens of CA mortar layer are shown in Figure 1.

The raw materials of CA mortar field specimens come from Anhui Engineering Material Technology Co., Ltd., of CTCE Group. The 24 h volume expansion rate of these cement emulsified asphalt mortar special dry ingredients is 2.1%, whose 7 d line expansion rate is 0.1% and the 1 d compressive strength is 6.89 MPa. The asphalt emulsion is the special emulsified asphalt of CA mortar on CRTS I type slab ballastless track, whose solid mass fraction is 62.1%. Average strength of CA mortar specimens is 2.63 MPa and the elasticity modulus is 269.58 MPa. Other properties meet the Chinese regulation [17] put in references. The mix proportion of CA mortar is $m(\text{dry ingredients}) : m(\text{asphalt}) : m(\text{water}) = 1000 : 500 : 60$. Mixing water is tap water. The age of CA mortar used in the creep test is 180 d.

2.2. Experimental Method. The experiment was conducted by WDW series microcomputer electronic universal testing machine, and this machine was controlled by computer, driven by a servomotor, and loaded by precision ball screw

machine. There is load sensor in the compressive direction. The displacement was measured by high precision displacement sensor. The accuracy of this experiment machine can reach to 10^{-3} mm. This machine has the advantages of stable loading, accurate measurement, and the machine can collect load and displacement data automatically.

The creep test of CA mortar is conducted by uniaxial compressive creep test. According to the stress of CA mortar in actual engineering which is 0.1 MPa [18], considering the deterioration of track irregularity and the disease of CA mortar, when the debonding length of CA mortar varies from 0.0 m to 1.0 m, the stress of CA mortar varies from 0.057 MPa to 0.53 MPa [19]. Short-creep properties of CRTS I type slab ballastless track were studied, respectively, at 4 load levels (0.05 MPa, 0.1 MPa, 0.3 MPa, and 0.5 MPa). The experimental temperature was controlled in $23 \pm 2^\circ\text{C}$. The experimental process is first preload (0.005 MPa) 10 min and then applied to the required load moment and kept in 60 min, and then the experiment is ended. The deformation measurement is the key point in a creep test. The creep deformation was collected automatically by the electronic universal testing machine, which can ensure the reliability and accuracy of data to measure. There were 3 specimens in each group, and the final result was the average deformation of 3 specimens. Two loading surfaces were coated with French chalk to reduce the surface restraint effect and three samples were used for each test as duplication. If test results are discrete, the number of specimens should be increased in order to ensure the validity of test data.

3. Results and Analysis

According to test results, the average values of the test results are listed in the same coordinate system. Creep curves of CA mortar under different load level are shown in Figure 2.

As shown in Figure 2, the shapes of creep curves of CA mortar are similar under different load level. CA mortar can be seen as three-phase system: asphalt, cement gel, and fine aggregates. In the beginning of the three-phase system of CA mortar bearing the load together, with the passage of time, the asphalt gradually unloads due to viscous flow, and the cement gel and fine aggregates bear more load and have elastic deformation [5]. Under the action of instantaneous load, CA mortar produces the instantaneous deformation, and

FIGURE 2: Creep curves of CA mortar under different load level.

FIGURE 3: Schematic diagram of Burgers model.

the deformation increases sharply. With the sustaining action of a constant load, the deformation of CA mortar increases, and the final incremental deformation is gradually stabilized. This stage of deformation is called delayed elastic deformation, and then CA mortar shows a viscous flow gradually. The higher the load level is, the larger the creep deformation of CA mortar is. When the load stress is 0.05 MPa, the creep deformation of CA mortar is 0.074 mm. When the load stress is 0.5 MPa, the creep deformation is 0.431 mm. The creep deformation of CA mortar increases by 5.82 times when the load stress varies from 0.05 MPa to 0.5 MPa.

4. Creep Model

Viscoelasticity material can be described by an appropriate mathematical model, and the basic components used to describe the viscoelastic properties are hook springs and Newton sticky pot. There are viscoelastic models: Maxwell model, Kelvin model, Burgers model, and generalized Maxwell model used in engineering, and the Burgers model could reflect the creep and relaxation properties. In this paper, the Burgers model was selected to describe the creep property of CA mortar.

4.1. Creep Model and Constitutive Equations. Burgers model consists of two hook springs and two Newton sticky pots. The Burgers model was shown in Figure 3.

FIGURE 4: Fitting curves of Burgers model and experimental curves of CA mortar.

Burgers model is four-parameter fluid model and its constitutive relation can be expressed as

$$\sigma + p_1 \dot{\sigma} + p_2 \ddot{\sigma} = q_1 \dot{\epsilon} + q_2 \ddot{\epsilon}. \quad (1)$$

Here, $p_1 = \eta_1/E_1 + (\eta_1 + \eta_2)/E_2$, $p_2 = \eta_1\eta_2/E_1E_2$, $q_1 = \eta_1$, and $q_2 = \eta_1\eta_2/E_2$.

The creep compliance can be obtained by formula (1), which can be expressed as

$$J(t) = \frac{1}{E_1} + \frac{t}{\eta_1} + \frac{1}{E_2} \left(1 - e^{-E_2 t / \eta_2}\right). \quad (2)$$

For the Burgers model, the total deformation of CA mortar under stress of $\sigma = \sigma_0 H(t)$ is

$$\epsilon(t) = \sigma_0 \left[\frac{1}{E_1} + \frac{t}{\eta_1} + \frac{1}{E_2} \left(1 - e^{-E_2 t / \eta_2}\right) \right]. \quad (3)$$

Here, E_1 , η_1 , η_2 , and E_2 are model parameters, t is the experiment time, and σ_0 is the loading stress.

4.2. Parameters Calculation of Creep Model. The viscoelastic parameters of the model are determined by mathematical iteration method. According to the creep test data, the nonlinear fitting method was provided by Origin software. The initial parameters are assumed and the parameters of the model are obtained by the given function expression.

It is assumed that the initial values of Burgers model parameters E_1 , η_1 , E_2 , and η_2 are 120, $5e^5$, 60, and $7e^3$, the fitted parameters of CA mortar under different stress level are shown in Table 1, and the fitted results are shown in Figure 4.

As shown in Table 1 and Figure 4, the Burgers model can effectively predict the short-term creep of CA mortar under different load level.

For the Burgers model, elastic parameter E_1 determines the initial position in the creep process, which reflects

TABLE 1: Parameters of Burgers model.

Load level/MPa	Model parameters				Correlation coefficient
	E_1/MPa	$\eta_1/(10^5 \text{ MPa}\cdot\text{s})$	E_2/MPa	$\eta_2/(10^4 \text{ MPa}\cdot\text{s})$	
0.05	31.957	9.289	163.123	1.782	0.981
0.1	33.326	13.68	172.126	1.958	0.974
0.3	58.862	13.295	168.315	1.638	0.987
0.5	84.549	16.691	215.809	2.09	0.989

TABLE 2: The Prony series of Burgers model parameters.

Load stress/MPa	Prony series of Burgers model			
	g_1	g_2	τ_1	τ_2
0.1	0.1628	0.8371	95.303	49016.136

the ability to resist deformation of CA mortar. Elastic parameter E_2 determines the value of delayed elastic deformation of CA mortar, viscosity parameter η_1 influences the curve slope of viscous flow deformation, and viscosity parameter η_2 controls the bending extent of the delayed elastic deformation curve.

4.3. Simulation of CA Mortar Creep Process. The mechanical parameters of material are required by the Prony series when calculating the viscoelastic mechanics using the ANSYS finite element software. According to [20], the shear modulus of the Burgers model can be expressed as Prony series as follows:

$$G(t) = G_\infty + G_0 \left(g_1 e^{-t/\tau_1} + g_2 e^{-t/\tau_2} \right). \quad (4)$$

Here, $G_\infty = 0$, $G_0 = G_1$, $g_1 = (1/(\alpha - \beta))(G_2/n_2 - \beta)$, $g_2 = (1/(\alpha - \beta))(\alpha - G_2/n_2)$, $\tau_1 = 1/\beta$, $\tau_2 = 1/\alpha$, and $n_2 = \eta_2/3$, where g_1 , g_2 , τ_1 , and τ_2 are the coefficients needed to be entered, which correspond to the ANSYS software in the specified Prony series, respectively. And E_1 , μ are the initial elastic modulus and Poisson's ratio.

Since the stress of CA mortar is 0.1 MPa in actual engineering [18], the Burgers model parameters under 0.1 MPa were put into the formula above, and the Prony series g_1 , g_2 , τ_1 , and τ_2 of Burgers model needed to be entered in ANSYS software are shown in Table 2.

In order to calculate simply, the model is a rectangle with size $1 \text{ m} \times 2 \text{ m} \times 1 \text{ m}$, and the size of an element is $1 \text{ m} \times 1 \text{ m} \times 1 \text{ m}$. The calculation model of ANSYS software is shown in Figure 5. The calculation model was simulated by solid 185, which has the properties of super elasticity, stress toughened, creep, large deformation, and large strain. The model has two elements, and the axial uniformly distributed load $p = 100 \text{ kN/m}^2$. According to the element area, the stress of each unit is 0.1 MPa, and the load time is 3600 s. The axial strain of unit 1 was chosen as a comparative data. Creep test data, fitting data, and ANSYS calculation results are compared in Table 3.

As shown in Table 3, the relative error of creep experimental data of CA mortar and fitting data is less than 1.7%, and the relative error and ANSYS calculation results are below 2.5%. The short-term creep process of viscoelastic material

FIGURE 5: Calculation model of ANSYS.

can be simulated using ANSYS software. The differences between test data, fitting data, and ANSYS calculation results are mainly due to the error of fitting and viscoelastic parameters transform to Prony series.

5. Conclusions

The short-term creep properties of CA mortar were studied by the independently uniaxial static creep experiment, the creep properties of CA mortar were fitted by Burgers model, and the short-term creep process was simulated by ANSYS software. The following conclusions can be drawn:

- (1) CA mortar as a typical viscoelastic material has obvious creep characteristics, the shapes of creep curves of CA mortar are similar under different load level, and the higher the load level is, the larger the creep deformation of CA mortar is. When the load level reaches 0.5 MPa, the creep deformation is 0.431 mm; compared to the creep deformation under the load level 0.05 MPa, the creep deformation of CA mortar increases by 5.82 times.
- (2) A creep constitutive model of CA mortar based on the Burgers model is established. The model has a simple form and can predict the short-term creep deformation of CA mortar, and the correlation coefficients of

TABLE 3: Compared with the result of creep test, fitting data, and ANSYS calculated.

Time/s	Test data (strain)	Fitting data of Burgers model		Calculation results of ANSYS	
		Total strain	Relative error	Total strain	Relative error
10	0.00307	0.00305	0.651%	0.00308	−0.326%
20	0.00314	0.003096	1.40%	0.00312	0.637%
30	0.00319	0.003137	1.66%	0.00315	1.25%
40	0.00323	0.003176	1.67%	0.00319	1.24%
50	0.00326	0.003211	1.50%	0.00322	1.22%
100	0.00337	0.003348	0.653%	0.00333	1.18%
150	0.00342	0.003437	−0.497%	0.00341	0.292%
200	0.00347	0.003496	−0.749%	0.00345	0.576%
500	0.00359	0.003611	−0.585%	0.00355	1.11%
1000	0.00367	0.003655	0.408%	0.00359	2.18%
1500	0.0037	0.003691	0.243%	0.00362	2.16%
2000	0.00374	0.003728	0.321%	0.00365	2.40%
2600	0.00377	0.003772	0.053%	0.00369	2.12%
3600	0.0038	0.003801	0.026%	0.00375	1.31%

the creep constitutive model of CA mortar are more than 0.9.

- (3) The short-term creep process of viscoelastic material can be simulated using ANSYS software. And the differences between test data, fitting data, and ANSYS calculation results are mainly due to the error of fitting and viscoelastic parameters transformed to the Prony series. Meanwhile, the application of the creep model to describe the creep properties of CA mortar under high-speed vehicle load needs to be further studied.

Competing Interests

The authors declare that they have no competing interests regarding the publication of this paper.

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