Construction and Building Materials 171 (2018) 303–311

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Establishment and verification of prediction models of creep instability points of asphalt mixtures at high temperatures

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HIGHLIGHTS

- Prediction model of the creep instability points of mixtures was established.
- The instability points of the same gradation mixtures can be predicted.
- Method for establishing models can study high-temperature performances of mixtures.

ARTICLE INFO

Article history:
Received 5 March 2017
Received in revised form 9 March 2018
Accepted 10 March 2018
Available online 26 March 2018

Keywords:
Asphalt mixture
Creep instability point
Prediction model
Dynamic triaxial creep test

ABSTRACT

This study established and verified prediction models of the creep instability points of two densely graded asphalt mixtures at high temperatures. First, AC-13 and AC-20 asphalt mixtures were selected and prepared. Their compressive strength values under different confining pressures and shear strength parameters were obtained through triaxial compression tests at 60 °C. Second, multiple repeated pressure values, which were less than the compressive strength values under the same confining pressure, were applied in dynamic triaxial creep tests at 60 °C, and the rheological numbers (F_N) corresponding to the creep instability points of the asphalt mixtures were obtained. Third, prediction models of the different asphalt mixtures were established by analyzing the change law of F_N under different confining and cyclic loading pressures. Finally, the F_N values of the different additive mixtures were forecasted using the models. The reliability of the prediction results was successfully verified by the test results. The predicted F_N values of the two asphalt mixtures were consistent with the experimental results at 60 °C. The proposed prediction models and the model establishment method can be of great significance in investigating the properties of asphalt mixtures at high temperatures and asphalt pavement rutting.

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1. Introduction

In high-temperature environments, distresses, such as rutting, pushing, waves, and upheaval, easily develop on asphalt concrete pavements. Rutting is one of the main failure types [1,2]. Asphalt mixtures undergo this permanent deformation because of material compaction in the initial stage of deformation development and rheological deformation under repeated shear loading, which increases distress [3–5]. Asphalt concrete pavements with semi-rigid bases are extensively designed in China. These bases possess high strength; therefore, rutting of liquidity type mainly occurs on the surface layers of asphalt concrete. Several studies [6,7] have shown that low material shear strength results in instability rutting, which in turn causes road safety problems. Therefore, investigating the development law of permanent deformation and analyzing the formation of rutting are important in combatting rut diseases and ensuring vehicle safety.

Researchers have constantly improved research methods for investigating high-temperature deformation in asphalt pavements and have established evaluation indices for the shear strength of asphalt mixtures to understand the development of cumulative deformation in asphalt concrete pavements in high temperature environments and reduce instability rutting in flexible pavements. Static, dynamic, uniaxial, and triaxial creep tests have often been used to explore the cumulative deformation law of asphalt mixtures at high temperatures [8–10]. Sun et al. [11–13] proposed new tests, with the uniaxial penetration test being a typical method. These test methods have been used to obtain shear strength parameters for the judgment and prediction of rutting and investigation of the creep law and deformation extent of asphalt mixtures under repeated load [14,15]. Numerous

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https://doi.org/10.1016/j.conbuildmat.2018.03.087
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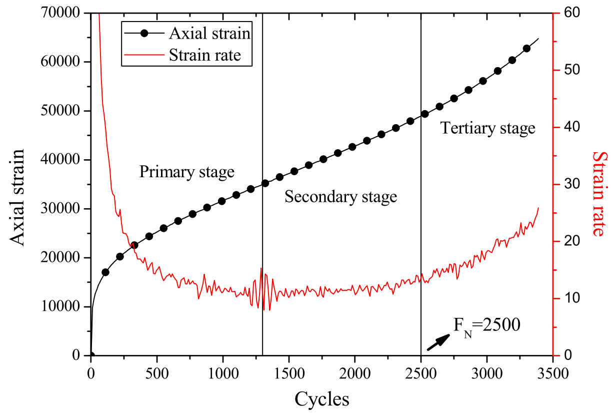

Fig. 1. Three stages of creep development and the corresponding rheological number (F_N).

prediction methods and models for rutting have also been proposed. Deacon et al. [16] implemented an analytically based (mechanistic–empirical) procedure to estimate the development of rutting in asphalt pavements as a function of traffic loading and environment as defined by pavement temperatures. Fwa et al. [17] illustrated the usefulness of the c-φ-based approach by developing a rutting prediction model based on the c-φ model and estimated rut depths in in-service pavements. These methods mainly predict deformation, that is, the depth and development of asphalt pavement rutting. However, the occurrence time of the instability of asphalt pavement materials has been ignored. Gandomi et al. [18] investigated and predicted the flow number of dense asphalt–aggregate mixtures by using gene expression programming (GEP), but the underlying assumption that the input parameters are reliable is not always the case.

According to existing research results, creep development of asphalt mixtures has three distinct strain stages [18]: (1) primary stage, in which the strain rate decreases; (2) secondary stage, in which the strain rate is constant; and (3) tertiary stage, in which the strain rate increases. The rheological number (F_N), which is the starting cycle number of creep development or the minimal strain rate in the third stage, is commonly used as an indicator to evaluate the stability of asphalt mixtures at high temperatures. Fig. 1 shows an example of a creep curve and the corresponding rheological number (F_N).

The instability of asphalt mixtures is induced by many factors, including temperature and the value and duration of the load. Thus, material constitutive models are complex, and establishing an accurate model for predicting the instability point of asphalt mixtures is difficult. According to creep tests on asphalt mixtures, under a certain load and temperature, instability is essentially caused by the creep of asphalt mixtures and shear fatigue under long-term repeated loading. Thus, research can be performed by using the theory of shear fatigue.

2. Objectives

This study presents and verifies a prediction model of creep instability points of asphalt mixtures. Specifically, a triaxial compression test is used to obtain the shear strength parameters of asphalt mixtures, and dynamic triaxial creep tests (DTCT) are performed under different confining pressures and repeated loads to determine the rheological numbers (F_N) corresponding to the instability points of the asphalt mixtures. The fatigue life equation is established by using the rheological number (F_N) and shear stress values to predict the creep development processes and instability points of asphalt mixtures. The prediction models are verified using different asphalt–additive mixtures that include an anti-rutting agent or fiber. The models and their establishment method can provide a foundation for further research on asphalt pavement rutting.

3. Materials and test methods

3.1. Materials

SBS modified asphalt (PG76-22) was used as the binder in this study. This binder, which is commonly utilized as a material on modern pavements, is usually selected to increase the stability of asphalt at high temperatures. The AC-13 asphalt mixture included basalt coarse and limestone fine aggregates. The AC-20 asphalt mixture included limestone aggregates only. The particle size of mineral powder was less than 0.075 mm. All of the performance indices of the raw materials meet the JTG E20-2011 standard of China [19]. The gradations of the two types of densely graded asphalt mixtures are described in Table 1. The asphalt–aggregate ratios of the AC-13 and AC-20 asphalt mixtures were 4.9% and 4.4%, respectively.

3.2. Test methods

Cylindrical specimens of the asphalt mixtures were fabricated by gyratory compaction. The diameter and height of the specimens were 150 and 170 mm, respectively. The specimens were cut into small sizes with a diameter and height of 100 and 150 mm, respectively.

A triaxial compressive test was applied to obtain the shear strength parameters of the asphalt mixture. DTCT was used to evaluate the dynamic compressive creep performance and predict the creep instability points of the asphalt mixtures at high temperatures. The load frequency was set to 1 Hz, and a loading cycle comprised 0.1 s of loading and 0.9 s of intermittent time [30,31]. The triaxial test is suitable for this study because the force conditions of the specimens are relatively similar to the state of the actual pavement. Moreover, this test allows for investigation of the change laws of the parameters under different confining pressures. All tests were performed with a UTM-25 tester in a loading chamber of 60 °C. The test loading device is shown in Fig. 4.

4. Shear strength theory and parameters

4.1. Fundamental theory

According to the Mohr–Coulomb failure criterion, soil under principal stress loading is destroyed when the ratio of shear stress on a certain surface to normal stress reaches a specific value. The position of the surface is related only to the properties of the soil,

Table 1
Gradations of the asphalt mixtures.

Sieve (mm)	26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
AC-13	–	–	100.0	98.2	78.1	46.8	35.2	26.2	18.4	12.9	10.2	7.9
AC-20	100.0	96.9	86.5	76.3	65.0	37.8	28.5	21.1	14.7	10.3	8.2	6.3

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