Construction and Building Materials 79 (2015) 136–144

Contents lists available at ScienceDirect

Construction and Building Materials

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

Characterization of mechanical behavior of asphalt mixtures under partial triaxial compression test

Jiantong Zhang [a], Jun Yang [a,*], Y. Richard Kim [b]

[a] School of Transportation, Southeast University, 2#Sipailou, Nanjing, Jiangsu 210096, PR China
[b] Department of Civil, Construction, & Environmental Engineering, North Carolina State University, Raleigh, NC 27695-7908, United States

HIGHLIGHTS

- The principle and testing procedures of PTCT were introduced.
- The reasonable sizes of specimen and platen were determined for PTCT requirement.
- The PTCT was conducted to characterize the deformation of asphalt mixtures.
- Testing results were sensitive with the sizes of specimen and platen for PTCT.
- Compared with other test method, the advantages of PTCT were explained.

ARTICLE INFO

Article history:
Received 24 April 2014
Received in revised form 13 November 2014
Accepted 27 December 2014
Available online 22 January 2015

Keywords:
Asphalt mixture
Partial triaxial compression test
Finite element modeling
High-temperature performance
Stress–strain relationship

ABSTRACT

The principle and procedures of partial triaxial compression test (PTCT) was introduced. The appropriate diameter and height of specimen and platen were determined for PTCT requirement. Three types of mixtures were tested by PTCT at a temperature of 60 °C. Stress–strain results indicate that the response of asphalt mixtures to various test conditions by PTCT is in accordance with that of typical triaxial compression tests. Also, both PTCT and traditional triaxial compression test represent the similar deformation characteristics of asphalt mixtures. The PTCT inherits many advantages possessed by the triaxial test, and is easier to be carried out considering the simplicity of experimental equipment, specimen preparation, and test operation.

1. Introduction

Rutting is one of the major distresses of asphalt pavements especially when the ambient temperature is high, for instance, in tropic areas or during summer period of temperate regions [1]. The rutting problem could be more significant under extreme conditions such as overloading, low-speed trucks, and long and steep slopes. A growing number of researchers have been convinced that rutting occurs when the shear stress in asphalt surface exceeds the shear strength of mixes, and therefore shear strength could be used to evaluate the rut resistance of materials [2–4]. The conventional method of asphalt mix design uses the Marshall stability test [5]. The standard Marshall mixture design method was revised to prepare specimens satisfying the minimum size and aspect ratio requirement in uniaxial testing [6]. The main drawback of the Marshall stability test lies in the fact that its results cannot be used directly to guide pavement thickness design or to predict the performance of the designed mixture during service. On the contrary, the triaxial test apparatus as standard equipment in typical geotechnical engineering laboratories has been used to evaluate the shearing resistance, stress–strain characteristics, and strength properties of soil specimens under different conditions by varying axial loading, confining pressure, and drainage condition. Asphalt mixtures consisting of aggregates, bitumen, and air void are to some extent analogous to soils which are composed of soil solids, water and air. Thus it is reasonable to borrow some test methods and theories developed in soil mechanics for asphalt concrete mixtures. The idea of applying the concept of cohesion and angle of friction to asphalt mix design was carefully studied by a number of pavement researchers [7–10]. However, the use of the triaxial test for testing asphalt mixtures is complicated and time consuming [11].

In order to simplify the simulation work of the stress state in an asphalt pavement, Bi et al. [12] presented a uniaxial penetration

---

* Corresponding author.

E-mail addresses: tongtong01@126.com (J. Zhang), yangjun@seu.edu.cn (J. Yang), kim@ncsu.edu (Y.R. Kim).

http://dx.doi.org/10.1016/j.conbuildmat.2014.12.085
0950-0618/

test method to evaluate the material shearing properties [13,14], but it is difficult to obtain the cohesion and angle of friction of asphalt mixture. Chen et al. [15] used the uniaxial penetration test to characterize the shear resistance of HMA mixtures at elevated temperatures. And the uniaxial penetration test was conducted to evaluate the deformation of asphalt mixtures considering the confinement and temperature condition in actual pavement [16]. Zhang [17] and Huang et al. [18] studied the deformation of asphalt mixtures using the partially repeated loaded triaxial test (PRLT). Parameters of PRLT are stable and accurate. Based on PRLT, this paper studied a special test method, that is, the partial triaxial compression test (PTCT), to evaluate mechanical characteristics of asphalt mixtures at high temperature (60 °C).

2. Test methods and specimen preparation

2.1. Materials

Rut resistance of asphalt mixtures is affected by the shape and interlock of aggregates [19]. Therefore, clean, hard, wear-resistant, crushed and non-acidic aggregates were selected in this study to achieve high rutting resistance of asphalt mixtures. Limestone was employed as filler. Three types of asphalt mixtures known as AC13, SMA13 and PA13, which are the most commonly used mix types for wearing course in China, were studied. Mix design and gradations are shown in Table 1.

Table 1
Mix composition and gradation of asphalt mixtures.

Type of mix (mm)	AC13	SMA13	PA13
Sieve size (mm)	% Passing by weight		
16	100	100	100
13.2	98.1	96.7	97.7
9.5	76.7	59.1	70.2
4.75	52.8	25.5	21.2
2.36	36.7	22.0	16.4
1.18	26.7	18.3	12.6
0.6	17.9	14.9	9.1
0.3	12.6	12.8	6.9
0.15	9.9	11.7	5.8
0.075	8.4	10.5	5.1
Aggregate type	Granite	Granite	Granite
Type of asphalt	SBS	SBS	High-viscosity asphalt
Optimum binder content (%)	5.36	5.9	4.85

Note: The number of each mix represents the nominal maximum aggregate size.

2.2. Specimen preparation

The Superpave gyratory compactor is used to prepare cylindrical specimens [20,21] with different gyratory numbers. Thus, two air void contents of specimen for AC13, SMA13 gradations can be obtained corresponding to the varied gyratory numbers. The air void content of AC13 specimen was tested as 3.1% and 5.7%, and 2.9% and 4.0% for SMA13 specimen. To characterize the porous asphalt mixture, the PA13 mixtures was used. And the air void content of PA13 specimen was determined as 18.5%. To make sure the aspect ratio (height to diameter ratio) being similar to the specimen in a typical triaxial test, the tested specimens were obtained by sawing the two ends of original specimens to a height of 90, 100 and 105 mm, respectively.

2.3. Test principles and methods

The PTCT was put forward based on the theories of triaxial test and uniaxial penetration test. Fig. 1 shows the principles of the evolution of PTCT. It can be seen from this figure that the stress-state at one point of the asphalt pavement (in (a)) can be simulated by uniaxial compression test (in (b)) and triaxial test (in (c)). Triaxial test is more commonly used to calculate the strength of asphalt materials than uniaxial compression test by simulating the actual stress state more closely. Although the triaxial test is widely accepted by the geotechnical and pavement engineers, this test method has its own flaws such as operational complexity, time consuming, and artificial confining pressure. In order to avoid using the artificial confining pressure, PTCT is used to simulate the actual confining pressure provided by asphalt mixtures, as shown in Fig. 1(d). The PTCT inherits the advantages of triaxial test and uniaxial penetration test, e.g. by considering different test temperatures and ratio of loading. At the same time, it also models the actual lateral confinement of asphalt pavement.

It can be seen from Fig. 1(d) that there are two pedestals of a smaller diameter than the specimen. Loading is applied upon the upper pedestal and the stress condition of the specimen is similar to that in a triaxial test. To make sure the specimen can provide enough confining pressure, the diameter ratio of pedestal d over specimen D should be controlled in a reasonable range. The smaller the ratio is, the larger the confining pressure can be provided. However, considering the size effect of aggregate and pedestal, d should not be too small. If the ratio is too small, especially when the pedestal's diameter is close to the nominal maximum aggregate size, the test result will exhibit large variability [17]. In this paper, pedestal's diameter (75 mm) is more than two times of the nominal maximum aggregate size (13.2 mm). There are two conditions that the parameters of d and D should be satisfied for the PTCT. To satisfy the stress and strain uniformity in specimen, the Von Mises stress should attenuate at $r = d/2$ of specimen $S_{\mathrm{Mises}}|_{r=d/2}$. In order to make sure that the specimen can provide enough confining pressure when the pedestal applies load, the radial normal stress shall be close to zero at $r = D/2$ of specimen, that is to say, $\sigma_{33}|_{r=D/2} \to 0$. And $S_{\mathrm{Mises}}|_{r=D/2}$ has the minimum value. Where d and D are the diameters of pedestal and test specimen, respectively. σ_{33} is the radial normal stress. And S_{Mises} is the Von Mises stress.

$$S_{\mathrm{Mises}} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]},$$

where, σ_1, σ_2, and σ_3 are the principal stresses.

3. Test design and test procedures

3.1. Test design

The main purpose of this section is to determine the size of pedestal and test specimen, so that the confining pressure provided by specimen is close to actual asphalt pavement and the aspect ratio (height to diameter ratio) is similar to the specimen in a typical triaxial test. The diameter of pedestal should be three times longer than that of the nominal maximum aggregate size to alleviate size effect as much as possible.

Finite element modeling (see Fig. 2) was introduced to obtain more knowledge of the PTCT to calculate the key parameters as shown in Table 2. Considering that d is at least three times of the nominal maximum aggregate size, it is calculated by ANASYS finite element at a level of in 60, 65, 70, 75, 80 and 85 mm. The reduction of Von Mises stress at $r = d/2$ and $r = D/2$ to maximal stress in specimens can be seen in Table 3.

It can be seen from Fig. 3 and Table 3 that with the increase of pedestal diameter, the Von Mises stress decreases firstly at $r = d/2$, and then increases, while the Von Mises stress attenuates at $r = D/2$. It is obvious that when $d = 75$ mm, the Von Mises stress reduces smaller than other values of d at $r = d/2$. It indicates that specimen