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Failure criterion of an asphalt mixture under three-dimensional stress state

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HIGHLIGHTS

- A self-developed triaxial test method was adopted.
- The failure criterions under three-dimensional stress states were established.
- A new method to carry out the strength design of asphalt pavement was given.

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ABSTRACT

A self-developed triaxial test method was adopted to characterize mechanical behavior of the asphalt mixture under three-dimensional stress states in this study. The conventional uniaxial tests and triaxial tests were conducted in the laboratory to verify the triaxial test results obtained using the technique developed. It is shown that the three dimensional stress states affect significantly the ultimate failure strength of AC-13 asphalt mixture and the failure modes are mainly represented both for the tensile failure and shear failure. The nonlinear strength criterions, as well as a linear engineering model of asphalt mixture under three-dimensional stress states in $\sigma_{oct} - \tau_{oct}$ space, were established based on the triaxial compressive/tensile tests, the plane tensile and compressive/axial tensile tests. In addition, a new method to carry out the strength design of asphalt pavement under the three-dimensional stress state was given to consider the failure effect of each stress component to the asphalt pavements.

1. Introduction

At present, 136 thousands kilometers expressway has been built in China, in which more than 90% uses the asphalt pavement structure. In addition, 40–50 thousands kilometers expressway with the asphalt pavement will be constructed by 2030. The design method of the asphalt pavement in China belongs to the mechanical-empirical method and the elastic layered half-space is modeled to calculate the mechanical responses of pavements. The theories of strength with the maximum tensile stress and maximum tensile strain are used as the failure criterions for asphalt pavements.

In general, the pavement works under complex stress states subjected to the traffic loading and thermal effects [1,2,3]. The ordinary strength test such as the uniaxial tensile test [4,5], uniaxial compression test [6,7], bending test [8,9,10] and indirect tensile test [11,12] under simple stress states cannot be applied to simulate the real multi-axial stress conditions in the pavement structures. Apparently the tensile strength of asphalt materials under one-dimensional or two-dimensional stress state cannot represent the failure characteristics of asphalt pavements. Due to the conventional triaxial test is available only for the triaxial compressive tests with a low confining pressure [13,14,15,16,17], it is difficult to study the failure criterion of asphalt mixtures using this test.

Due to the limits of the test equipment, few researchers carried out the study on the failure criterion of asphalt mixtures under complex stress states. Wang et al. [18] proposed a nonlinear failure envelop in $I_1 - \sqrt{J_2}$ space based on the failure strength results of the dense asphalt concrete. Desai et al. [19] proposed a response surface for asphalt materials and utilized it as the response function of the yield surface. It can be applied both in the stress invariant and strain variant space. Nevertheless, three-dimensional unequal stress state was not established and the failure criterion was not verified by true triaxial results in a three-dimensional stress state, especially at a triaxial tensile stress state. Guan et al.

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[20] carried out three-directional compression strength tests for three kinds of asphalt mixtures at −10 °C with a self-developed simplified triaxial machine, the tested data of strength on the π-plane are close to a twin shear theory contour curve without the triaxial tensile strength consideration. In general, the tensile performance rather than the shear performance should be considered for asphalt mixtures in a low temperature [21]. Therefore, it is necessary to make efforts to establish the strength criterion of asphalt mixtures under three-dimensional stress states, in which the effects of triaxial tensile strength should be considered. So, the main objective of this paper is to establish the failure criterions under three-dimensional stress states. Moreover, a new design method to carry out the strength design of asphalt pavements was presented under three-dimensional stress states.

2. Test methods and specimen preparation

2.1. Materials and specimens

In order to evaluate the mechanical behavior of asphalt mixtures under three dimensional stress states, the representative AC-13C asphalt mixture which were widely used in China were tested. As shown in Fig. 1, the aggregate particles of AC-13C asphalt mixture are continuously graded to form an interlock structure. The performances of mixtures tested extensively can be referred from the results of Huang [22], in which the SBS modified bitumen was used as the binder and the basalt was used as aggregates.

To ensure the consistency of specimen in the triaxial test, the gyratory compactor was used to prepare cylindrical specimens with 102 mm in height and 100 mm in diameter. The bitumen-aggregates weight ratio of 5.2% was selected with the air void content for these specimens of 4.5% ± 0.5%. Moreover, the tested specimens were obtained by sawing the two ends of original specimens in the water with a diamond blade up to the height of 100 mm.

2.2. Test equipment and method

The triaxial test system developed by Zheng and Huang is shown in Fig. 2 [22,23]. For this testing system, a hollow cylinder specimen with an inner radius r_a and outer radius r_b was placed in the triaxial test equipment while the inner and outer surfaces of specimens were loaded by two flexible airbags respectively. Using this airbags, the adjustable radial compressive stress and circumferential tensile stress can be produced consequently. A sketch of hollow cylinder specimen with dimensions and element with principle stresses are shown in Fig. 3.

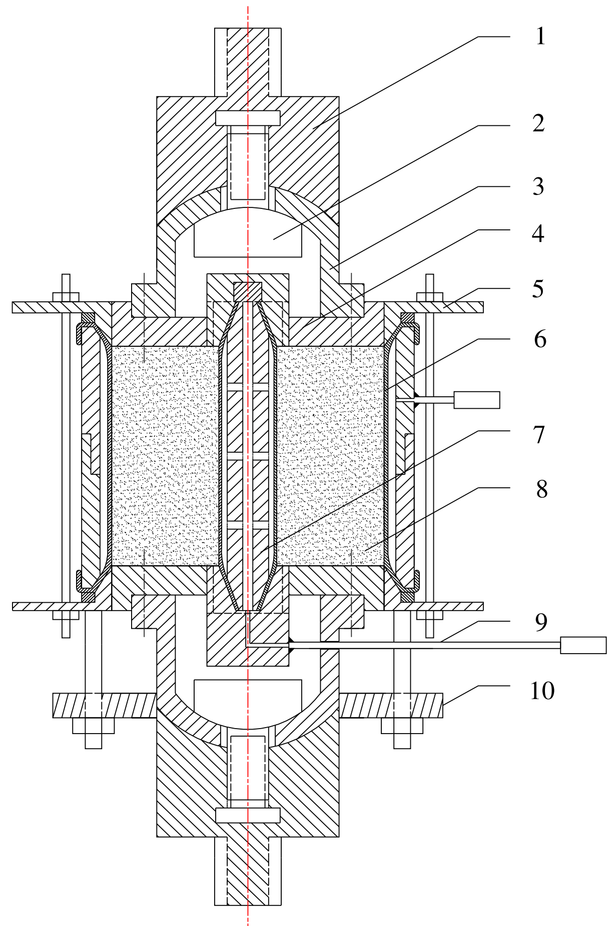

Fig. 2. Loading structure schematic diagram of triaxial testing equipment.

Note: 1-loading rod, 2-ball hinge pin, 3-hemispherical head compressive(tensile)tip, 4-compressive(tensile) plate, 5-outer airbag cover, 6-outer airbag, 7-inner airbag, 8-specimen, 9-trachea, 10-outer airbag tray.

The output from 0 MPa to 6 MPa with the control precision of 0.01 MPa can be obtained by those two airbags connected to the pressure control system, as shown in Fig. 4. When the main switch is open, the air is compressed into the high pressure vessel by the booster pump with a compression proportion of 6:1. In such control system, two passages are designed in order to isolate the pres-

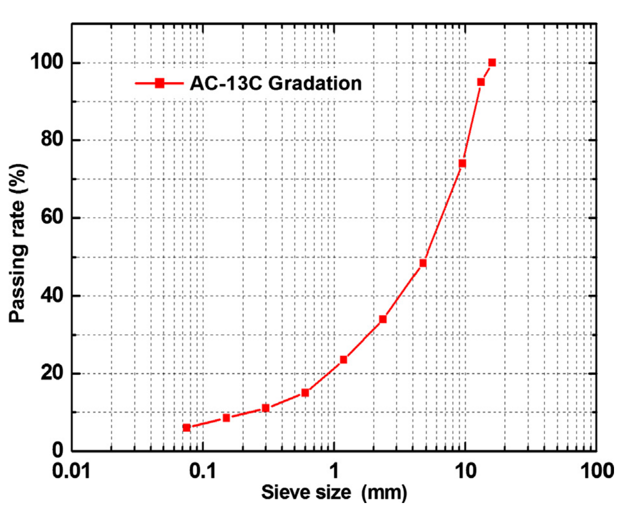

Fig. 1. Gradation curve of AC-13C asphalt mixture.

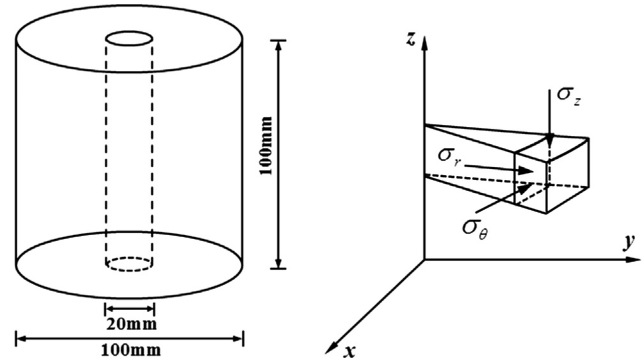

Fig. 3. A sketch of hollow cylinder specimen and the principle stresses with an element.