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Comparisons of synchronous measurement methods on various moduli of asphalt mixtures

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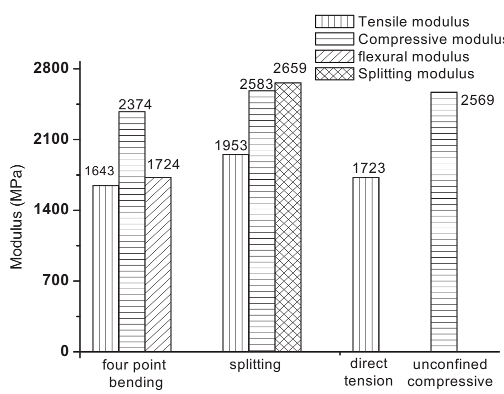
HIGHLIGHTS

- Two synchronous measurement methods of different moduli for asphalt mixture were proposed.
- The effectiveness of two synchronous measurement methods was verified.
- The correlation and difference of moduli obtained by four test methods were analyzed.

GRAPHICAL ABSTRACT



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ABSTRACT

Two new test methods were proposed to measure the different moduli of asphalt mixtures simultaneously based on four-point bending and indirect tensile tests. The new calculating formulas were derived for tensile and compressive moduli of asphalt mixtures under four-point bending loading model, which combining the equilibrium condition and the plane hypothesis in elastic mechanics theory. Meanwhile, on the basis of the test principle of indirect tensile moduli and Hooke's law in two-dimensional stress states, the new calculating formulas were derived in indirect tensile loading model. The moduli tests of four-point bending, indirect tensile, direct tension and unconfined compression were carried out separately to verify effectiveness of the new methods. The results of tensile and compressive moduli from the two new methods were compared with the direct tension moduli tests and unconfined compression moduli tests. The correlations among them were analyzed. The result indicates that the tensile and compression moduli of asphalt mixtures show a significant difference, and can be obtained by two methods simultaneously. The two new methods realize the synchronous measuring of various moduli of asphalt mixtures.

1. Introduction

Multiplayer elastic system theory is the basic theory of asphalt pavement design method in the most countries [1,2]. Practice has proved that more than 100,000 km expressway and millions kilometers ordinary road were built according to the Chinese asphalt pavement design method. It has made an important contribution to the development of Chinese transportation [3]. However, there is no doubt that there remains a lot of in-adaptation, irrational and ineligible problems of the current asphalt pavement design theory and method [4].

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The major problems in design parameter of the current asphalt pavement design method are as follows:

(1) The current asphalt pavement design method of the most parts of the world adopts the multiplayer elastic system theory which on the basis of the hypothesis that the tensile and compressive moduli of the pavement material are equivalent [4,5], and only unconfined compressive moduli are used as design parameter during the structural design. However, lots of experimental results have proved that the tensile and compressive moduli of asphalt mixture material or semi-rigid base course materials are different, and the compressive moduli are usually much larger than the tensile moduli [6,7]. In fact, the actual stress states of pavement structure layers are that the tensile stress and compressive stress coexist in the pavement structure layers [8], and the stress states are upper compression and lower tension [9,10]. Therefore, it will cause large errors in the calculation results of pavement design which leads to overestimation of deformation resistance and resisting power of pavement and makes the design unsafe if only unconfined compressive moduli are used as design parameter during the mechanical calculation of pavement design, equating the tensile and compressive moduli. Those really affect the performance and service life of pavement negatively.

(2) The stress states of asphalt mixture during the experiments of obtaining moduli don't match with the stress states of asphalt pavements [11]. The general moduli test methods of pavement materials are moduli tests of four-point bending, indirect tensile and unconfined compression [12]. However, the stress states into materials are defined as tension, compression and the various combinations of them, without flexural tensile stress state or indirect tensile stress state [13], which means the flexural tensile moduli and indirect tensile moduli obtained by experiments are not corresponding to the stress state of the material. Therefore, it will cause large errors in the calculation results of pavement design if the flexural tensile moduli and indirect tensile moduli which are the macroscopic mechanical response of materials [14,15] were used as design parameters. Furthermore, the calculation models of the flexural tensile and indirect tensile moduli are both deduced on the basis of the hypothesis that the tensile and compressive moduli of the asphalt mixtures are equal, ignoring the dissimilarity between them [16]. And different moduli are obtained via different test methods; it means not only the waste of materials, labors, and capital but the impossibility of comparisons among the moduli obtained respectively. Which parameter could reflect the mechanical properties of asphalt mixture materials is still undetermined.

This paper proposed two new tests and calculation methods to measure the different moduli of asphalt mixtures simultaneously, one for the tensile, compressive and flexural tensile moduli which is based on the four-point bending test, and the calculation formula was derived which combining the equilibrium condition and the plane hypothesis in elastic mechanics theory. Another for the tensile, compressive and indirect tensile moduli of asphalt mixtures, which is based on the indirect tensile test, and the calculation formula was derived on the Hooke's law in two-dimensional stress states. The difference of tensile and compressive moduli were taken account into both two new methods, and the tensile and compressive moduli were obtained not under a simple stress state, the stress states of materials in the moduli tests of four-point bending and indirect tensile are more similar to a real stress states of pavement materials. The moduli tests of four-point bending, indirect tensile, direct tension and unconfined compression were carried out separately with the Material Test System (MTS). The results obtained by new & original methods are compared, and the correlations of them were analyzed. This paper can provide theoretical supports and method basis to optimize the design parameters of asphalt pavement structures.

2. Sample preparations

2.1. Materials

In this paper, the moduli tests of four-point bending, indirect tensile, direct tension and unconfined compression were carried out separately to verify the new methods. In order to reduce the discreteness of experimental results, the asphalt mixtures (fine-grained AC-13C) were taken as research object, which were composed of SBS modified asphalt binders, limestone aggregates, and limestone powders. The performance indexes of SBS modified asphalt are shown in Table 1, the physical and chemical properties of aggregates are shown in Table 2 and the dense skeleton type gradation of aggregate were chosen according to "Specifications for Design of Highway Asphalt Pavement" [5], the detail information is presented in Fig. 2. The optimum asphalt ratio were determined by Marshall Tests, the test results are displayed in Table 3.

The dense skeleton type gradation of aggregate was shown as Fig. 1.

2.2. Specimen manufacture

According to the specifications and test methods of bitumen and bituminous mixtures for highway engineering (JTG E20-2011) [17], samples 400 mm × 300 mm × 80 mm were made through the experiment of vibrating compaction. Then, the beam specimens were cut from block samples to the size of 360 mm × 50 mm × 50 mm for four-point-bending test and directly tensile test, as the Fig. 2(a), (c); the cylindrical specimens were drilled from block samples to the size of Φ100 mm × 80 mm for the unconfined compressive moduli test, as the Fig. 2(b); and the indirect tensile specimens were prepared by sliced the top and bottom surface of the specimens of unconfined compressive moduli test to the size of Φ100 mm × 60 mm, as the Fig. 2(d). All the specimens were preserved in a thermostat of 15 °C after the smoothing of the surface and pasted with strain gauge for the following experiment. There were five parallel tests for each moduli test.

3. Moduli test

3.1. Experiment condition

The static moduli of pavement material is calculated with the loads applied to the material and the corresponding rebound

Table 1
Performance Index of SBS (I-D) modified asphalt.

Technical indexes	Result	Specification
Penetration 25 °C, 100 g, 5 s (0.1 mm)	55.91	30–60
Ductility 5 cm/min, 5 °C (cm)	34.22	≥20
Softening point TR&B (°C)	79.39	≥60

Table 2
Physical and chemical properties of aggregates.

Items	Crushing value	Content of needle-like particles	Content of SiO_2	Apparent density
Value	10.8	7.8	1.79	2.578
Specification	≤26	≤20	/	/

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