Journal of Science and Technology in Civil Engineering NUCE 2019. 13 (1): 60–64

ASPHALT CONCRETE TESTING DEVICE: STUDYING AND DESIGNING BASED ON THE PROPERTIES OF ASPHALT CONCRETE

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Article history:
Received 4 December 2018, Revised 20 December 2018, Accepted 24 January 2019

Abstract

With the purpose of obtaining the shear strength parameters (friction angle, ϕ, and cohesion, c) of asphalt concretes. At the present time, almost the testing devices were designed based on the condition of the vehicle's load when they are moving on the pavement structure. That means, the fatigue resistance of the interfaces was determined through the loads acting at the interfaces between layers are repetitive mechanical action of the moving vehicles. With that view, the ratio of the normal and shear fatigue loads of asphalt concrete was not considered in terms of the nature of the material. An asphalt concrete testing device is proposed based on the modification from AST-2 instrument and Shear Fatigue Test instrument. The main parameters of this device are calculated from the ratio of shear stress and normal stress at the fatigue of the asphalt concrete according to the Mohr-Coulomb failure criterion. Test results with asphalt specimens show that the device is stable, the acting vertical loads were smaller and more stable.

Keywords: normal strength; shear stress; asphalt concrete; fatigue stresses.

https://doi.org/10.31814/stce.nuce2019-13(1)-06

1. Introduction

Asphalt concrete structures are composed of more than one asphalt concrete layers, which are bonded together using a tack coat. Therefore, the life and performance of the pavement depend not only on the properties of each layer (stiffness, modulus and fracture energy) but also on the quality of the bond between the adjacent layers. A strong interlayer bond between the layers is critical in order to dissipate the stress throughout the entire pavement structure. In contrast, a poor interface bond may lead to several types of premature distress, such as slippage cracking, top-down cracking, premature fatigue cracking, and delamination. Delamination or debonding problems are particularly more severe for asphalt pavements that are subjected to heavy vehicle loads, especially horizontal forces that are due to braking and turning of vehicles. The undetected delamination that is due to inadequate bonding at the layer interface can eventually result in localized slippage failure at the surface layer. Furthermore, poor bonding may activate distress mechanisms that can rapidly lead to the total failure of the pavement because the debonded layers can no longer act as a monolithic pavement

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section and therefore cannot provide the intended load-bearing capacity of those layers. Thus, the interface bond between pavement layers is a key factor that affects the performance of any pavement structure [1]. To develop an acceptable design method, a reliable analysis procedure and associated test methods are necessary to determine the shear bond strength between the pavement layers and compaction of asphalt layers. Therefore, several types of direct shear tests with and without normal confinement currently are used to evaluate the interface bond strength of asphalt concrete layers.

Florida DOT Shear Test method is used to determine the interface bond strength between two layers of asphalt pavement in shear mode by the UTEP Pull Off Test, and the Torque Bond Test [2]. Donovan et al. [3] conducted a laboratory testing program name is Virginia shear fatigue test to determine the optimum asphalt binder tack coat application rate that needs to be applied in the field. To accomplish this, a fixture was designed to allow the application of cyclic shear loading at the geocomposite membrane interface when used as an interlayer simulating a concrete bridge deck overlaid with the geocomposite membrane and a hot-mix asphalt (HMA) overlay. A Direct shear Apparatus was developed at the Illinois Center for Transportation [4], it used to investigate the characteristics of the overlays and Portland cement concrete (HMA-PCC) interface and to determine the interface shear strength by applying shear force in the vertical direction and normal force in the horizontal direction. Another direct shear testing device, known as the Louisiana interlayer shear strength tester (LISST) [5], was invented to characterize the interface shear strength. This device can accommodate specimens up to 101.6 mm in diameter. The test can be performed monotonically at a shear rate of 2.54 mm/sec. Chen and Huang [6] analyzed the effects of several surface properties in order to determine the behavior of tack coats. The direct shear device used in the study applies a vertical normal load and a horizontal shear load in order to analyze the behavior at the interface. Constant displacement of 2.5 mm/min is applied in the horizontal plane. Both shear force and displacement measurements are recorded using a data acquisition system. Romanoschi and Metcalf [7] proposed a laboratory test configuration to perform shear fatigue tests on asphalt concrete with interfaces in order to simulate the repetitive load of moving vehicles. The specimens are subjected separately to normal and shear loads. In order to include normal force, this device allows for the longitudinal axis of the test specimen to be at a 25.5° angle to the vertical axis. This angle was chosen because the shear stress at the interface is half the normal pressure at this angle. Adam Zofka et al. [8] developed an advanced shear tester (AST) device to test specimens under constant normal stiffness (CNS) conditions. The CNS conditions are complementary to the constant normal load conditions that are applied in the current shear-mode devices incorporated in testing of asphalt concrete (AC) and pavement interface properties. A dynamic shear testing device was developed in the laboratory of the Road department at the National University of Civil Engineering (NUCE) [9], similar to the shear fatigue test models but they are suitable for conditions of Vietnamese laboratories. It was used to calculate the bonding coefficient (c) and the internal friction angle ($\tan\phi$) of asphalt concrete types.

All of these devices simulate the condition of the vehicle's load when they are moving on the asphalt concrete. That means, under traffic, the pavement structure is subjected to a repetitive mechanical action of the moving vehicles. The loads acting at the interfaces between layers are also repetitive, and therefore it is important to determine the fatigue resistance of the interfaces. Accurate simulation of the stress field at the interface is very difficult if not impossible. The ratio of shear to normal stresses at a point at the interface changes as the vehicle approaches and recedes from that point. Moreover, the different magnitudes of the vertical and horizontal pressures acting on pavement surface change with each vehicle, and therefore the stress field at the interface changes. With that view, the ratio of the normal and shear fatigue loads of asphalt concrete has not been considered in terms of the nature of the material. Particularly with devices using vertical loads to be divided into compressive loads and shearing loads as in [7, 9], they could be made the error during the tests. The primary objective of this research is to make a device base on modified the AST-2 instrument following the relationship between the normal and shear fatigue loads of asphalt concrete.

2. Modelling of the device

The object of study in the present development is rational of main geometry parameters of the testing device for asphalt concrete specimens that were created in accordance with the Marshall standard. With the purpose of obtaining the shear strength parameters (friction angle, ϕ, and cohesion, c) of asphalt concretes.

The schematic of the test configuration proposed for the fatigue tests of the asphalt concrete layer interfaces is presented in Figs. 1 and 3. The asphalt specimens are placed in two metal split cups. The cups are fixed onto two sets of metal angle pieces welded to base plates so that the longitudinal axis of the specimen makes an angle α to the vertical. The bottom base plate (2) is fixed to the hydraulic frame of the Marshall Stability Testing Equipment as in Fig. 2(b). To allow the relative horizontal movement of the upper part of the assembly and the hydraulic actuator, a steel ball plate was placed on top of the upper base plate. The actuator of the Marshall equipment, presses on a steel plate placed on top of the steel ball plate. The steel ball plate was greased before every test so that no friction would develop between the steel balls and the two metal plates. A load sensor (3) measured the maximum load of the actuator as in Fig. 3(b).

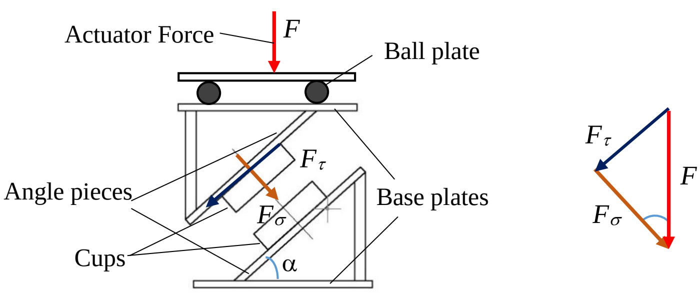
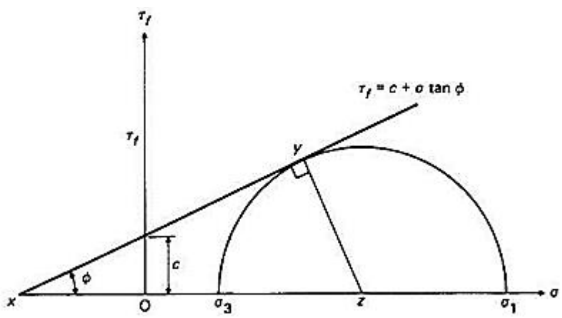
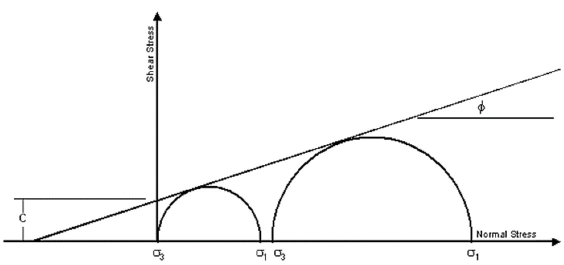


Figure 1. Schematic of device



(a) Mohr's circle and Mohr – Coulomb filure criterion



(b) Mohr – Coulomb criterion drawn based on two tests

Figure 2. The Mohr-Coulomb failure criterion [10]

The longitudinal axis of the specimen are α with the vertical so that the shear stress at the interface and the normal stress has the fatigue values at the same time. That makes the tests become simpler and the results have higher accuracy and reliability. The gap between the two cups must also be consistent with the settlement of specimens. If the gap is too small, under the action of vertical force F two cups will come into direct contact with each other before the normal stress reaches the fatigue. If the gap is large, the test specimens will be deformed before it is destroyed. So in two cases the value tests are not accurate.

- Shear angle (α) is one of the important parameters of the device. Base on the Mohr-Coulomb failure criterion [10], the relationship between normal stress σ and shear stress τ at fatigue is:

$$\tau = c + \sigma \tan \phi \tag{1}$$

where c is the cohesion interception, ϕ is the internal angle of friction of asphalt concrete. The shear strength parameters (c and ϕ) are normally based on triaxial tests carried out at different confinement levels, as shown in Fig. 2.

In addition, from the device model, the shear angle can be calculated as follows:

$$\tan \alpha = \frac{F_\tau}{F_\sigma} = \frac{\tau}{\sigma} \tag{2}$$

where F_τ, F_δ are the shear load and normal load at fatigue.

$$\overrightarrow{F}_\tau + \overrightarrow{F}_\sigma = \overrightarrow{F} \tag{3}$$

on the other hand:

$$\begin{cases} F_\tau = F \sin \alpha, \ kN \\ F_\sigma = F \cos \alpha, \ kN \end{cases} \tag{4}$$

The Eqs. (2), (3) and (4) shows that, if we know the parameter values of standard asphalt concretes (c, ϕ or τ, σ) then not only the α value but also the maximum applying force F can be identified.

In the opposition, if having the values of shear stress and normal stress at the fatigue of asphalt concrete we can determine the friction angle ϕ and the bonding coefficient c.

From the parameter of asphalt concretes in [9], we calculated the values of shear angle are from 28° to 40° depending on the type of asphalt concrete.

- The gap between two cups (k) is also an important parameter. The value of this gap could not smaller than the settlement of specimen under fatigue normal load but also not more than this settlement. The value of k needs to choose the equation:

$$k \geq \varepsilon = \frac{\tau}{E} h \quad \text{or} \quad k = \varepsilon + (1 \div 2 \text{ mm}) \tag{5}$$

where ε is the settlement of the specimen; h is height and E is the modulus of the specimen.

Similarly, the diameter of cups should be chosen larger than the specimen diameter 1 or 2 mm.

- The ball plate was used to change from sliding friction to rolling friction at the contact place between Marshall equipment and upper base place. It also helps to reduce the load action on the upper base plate. In this research, the ball bearings were used in the ball plate. They are calculated to choice following the equation:

$$C_d = QL^{1/m} \leq C \tag{6}$$

where C_d (kN) is the basic dynamic load rating; Q (kN) is the equivalent dynamic bearing load; m is the exponent in the life equation (the load life exponent), for ball bearings: $m = 3$; C (kN) is the load rating of bearing; L is the long life of bearing (revolutions per life).

3. Manufacturing and testing

The asphalt concrete specimens were created following the Marshall method in the Vietnam standards [9] with 100 mm diameter and 60 mm height. With this type of asphalt concrete, the shearing angle $\alpha = 40^\circ$ and using 08 ball bearings 6301-2RSL for the testing device (Fig. 3(a)).

(a) The testing device

(b) Installing the device on the Marshall equipment

1 - Testing device; 2 - Marshall Stability Testing Equipment; 3 - Load sensor

Figure 3. The testing device with $\alpha = 40^\circ$

Test results on specimens were compared to the AST-2 instrument of [9]. It shows that this device operated more stable, value of each test was closer together and smaller than AST-2 test result.

Table 1. Value of fatigue loads of some asphalt concrete specimens, (kN)

Specimen	C9.5		C12.5		C19		P12.5	
α	40°	35°	40°	35°	40°	35°	40°	35°
Test 1	27.107	37.878	31.433	40.479	27.403	31.424	33.814	64.289
Test 2	21.380	33.547	31.074	38.821	29.363	33.558	39.644	55.561

Table 1 presents the value of fatigue loads of two devices with $\alpha = 35^\circ$ and 40°. It means these values will be smaller and more reasonable if the correct cutting angle is selected. Where C9.5, C12.5, C19 are the hot mix asphalt concrete specimens using bitum with maximum size of particles 9.5, 12.5 and 19 respectively. And P12.5 is the hot mix asphalt concrete specimen using polyme with maximum dimension of stones 12.5.

4. Conclusions

Based on the modified AST-2 instrument and the test results on specimens of asphalt concrete reported and analyzed in this paper, we may conclude that:

- The Mohr – Coulomb criterion may be used to evaluate the shear angle α of the testing device;

- The shear angle α was calculated from the ratio of normal and shear stress at fatigue of each asphalt pavement type should be given the most reliable results. With the standards of asphalt concrete types, the shear angle (α) equals 28° to 40°

- The gap between two cups (k) and the diameter of cups also make an effect on the accuracy of tests.

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