Construction and Building Materials 153 (2017) 337–345

Contents lists available at ScienceDirect

Construction and Building Materials

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

The evaluation of relative effect of moisture in Hamburg wheel tracking test

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HIGHLIGHTS

- Power law model was used to determine the creep stage in Hamburg wheel tracking (HWT) test.
- Wet HWT can be deployed as a substitute to the dry HWT test in the creep stage.
- Bitumen Bond Strength (BBS) test can also verify the moisture sensitivity occurred in the dry and wet HWT.

ARTICLE INFO

Article history:
Received 23 April 2017
Received in revised form 12 July 2017
Accepted 14 July 2017

Keywords:
Hamburg wheel tracking (HWT) test
Dry HWT
Wet HWT
Rutting
Moisture damage
Bitumen bonding strength test

ABSTRACT

Hamburg wheel tracking (HWT) is prominently used for rutting resistance test. The HWT is a versatile device to determine moisture susceptibility and permanent deformation, which has been widely used in many states and agencies in the United States. However, the standard of the test for the HWT device conducted in water is not related to a primary result of rutting, which is due to repeated traffic loading cycle especially in the dry condition. In this study, the HWT test in different conditions (i.e. dry and wet) was conducted to compare the behavior of hot mix asphalt (HMA) during testing. The objective is to determine the comparison between the dry and wet condition testing in HWT test, and to evaluate relative effect of moisture conditioning in wet HWT on the creep stage. Fitting curve using Francken model was applied to determine the tertiary point of HWT curve. Power law model was used to determine the effect of the moisture conditioning in wet HWT on the creep stage. The moisture damage in the wet HWT test was also verified by the Bitumen Bond Strength (BBS) test. The results indicated that the wet HWT currently specified in the AASHTO 324 can be deployed as a substitute to the dry HWT test in the creep stage (before the stripping inflection point) since the difference in creep slope estimated for both conditions is within the experimental error. The wet HWT results after the creep slope remain useful for detecting the moisture sensitivity with the confirmation by the measured cohesion/adhesion of asphalt mastics from each mixture. The BBS test can also verify the moisture sensitivity occurred in the dry and wet HWT with the creep slope and tertiary/stripping slope well correlated to mastic cohesion change in BBS test.

1. Introduction

The Hamburg wheel tracking (HWT) test is gaining popularity due to being fast and reliable for testing of hot mix asphalt (HMA) mixes [1,2,3]. Esso, A. G. of Helmut-Wind Inc., Hamburg, Germany, originally manufactured the HWT in the 1970s. The HWT test was intended to measure rutting performance and moisture damage of asphalt mixture. In the early 1990s, the device was initially introduced to the United States by pavement engineers and officials, and a European asphalt study tour [4,5]. Many studies began to emerge the evaluation of HWT test to characterize moisture sensitivity of asphalt mixtures and to predict field performance [2,6,7,8,9]. Some studies found that HWT device was sensitive to aggregate quality, asphalt cement stiffness, short-term aging duration, asphalt source or refining processes, antistripping treatments, and compaction temperatures [7,8,9].

Many studies of HWT test have reported measuring rut depth in the wet condition, which may confound moisture effect in asphalt mixtures with the rutting behavior. This confounding effect is the main challenge in how HWT device can be used to distinguish

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http://dx.doi.org/10.1016/j.conbuildmat.2017.07.133

rut depth at high temperatures without confounding moisture with rutting due to moisture damage. Recently, Chaturabong and Bahia (2016) studied the potential of dry HWT to be the alternative test for measuring rutting resistance without confounding moisture effect [20].

However, the standard of the test for the HWT device conducted in water is not related to a primary result of rutting, which is due to repeated traffic loading cycle especially in the dry condition. Water conditioning may result in stripping of asphalt from aggregates creating a tertiary phase which is distinct from the permanent deformation occurring in dry HWT test. In wet HWT test, specimens are cured in the test temperature water for 30 min to equalize test temperature to specimens as specified in AASHTO 324. During a test running, the volume of specimen changes with increasing in air voids. Whenever HMA air voids exceed about 8 percent by volume, they may become interconnected and allow water to penetrate the HMA quickly and cause moisture damage through pore pressure, thus reducing the durability of pavement. Two main moisture damage mechanisms include the cohesive and adhesive failure in HMA, and may be due to two causes: the diffusion of water into bitumen weakening of the mastic and the migration of water through mastic to the interface of mastic and aggregate.

Williams and Prowell (1999) proposed that HWT test is the most robust equipment among other wheel tracking tests, i.e. Asphalt Pavement Analyzer (APA) and French Rutting Tester (FPRT), to quantify rut depth of HMA [10]. However, moisture in asphalt mixture, in some tests, may confound the result of rutting performance. Therefore, the resolution of the moisture effect problem in HWT device is needed.

2. Material and testing procedure

The goal in designing this experiment was to quantify the correlation of failure stages occurring in the dry and wet HWT specimens; therefore, both conditions of the HWT test were carried out in this study.

Mixes ranging from permanent deformation resistance to permanent deformation susceptibility were selected to allow for evaluation and analysis of the HWT in the dry and wet conditions at a wide range of sensitivities. The use of mixes with a wide range of behaviors provides a valid means of comparison by ensuring that the results of the test would not be confounded with the variability inherent in the test method. The mix selection process was produced based on the Wisconsin Department of Transportation (WisDOT) mix design specification for medium and heavy traffic from aggregate sources that have a variety of angularities resisting and susceptible to permanent deformation. To identify the mix design susceptible to moisture and permanent deformation, the results of this analysis provided four mix designs with different aggregate gradations and aggregate sources. The experimental matrix is provided in Table 1.

The experimental plan involves two types of binders and mixtures procured from the company in Wisconsin (Mathy Construction), including S-28 and V-28, where S and V represent the binder used for the standard and very heavy traffic, respectively. The mixture types included MT and HT, which represent the gradation design used for medium and high traffic. To verify the properties of the supplied binder, the binder properties measured in this study included complex modulus (G^*), phase angle (δ), and $G^*/\text{Sin}(\delta)$. All binder properties were measured using the dynamic shear rheometer (DSR). Temperature testing and binder properties are provided in Table 2.

The performance grade (PG) at a high temperature for these two binders can be evaluated based on the PG standard. The PG for these two binders are 58 °C and 64 °C for S-28 and V-28, respectively. The multiple stress creep recovery (MSCR) analysis as specified in AASHTO TP-70, and MP-19 was carried out to quantify the

Table 1
Summary of factors to determine the correlation between the dry and wet condition testing in HWT test.

Factors	Level	Description
Methods	2	Dry HWT, Wet HWT
Aggregate types	2	Cisler (Granite), Waukesha (Limestone)
Binder types	2	S-28, V-28
Mixture types	2	MT and HT

non-recoverable creep compliance (J_{nr}) and the recovery of each binder, both original and rolling thin film oven (RTFO) binders. Because the temperature to conduct the HWT testing was 50 °C, 50 °C was used in the MSCR testing. The summary results of each binder are presented in Table 3.

Non-recoverable creep compliance (Jnr) at 3.2 kPa and the percentage of recovery at Jnr 3.2 kPa results were reported for both original and RTFO binders. The results show that the Jnr of the V-28 binder is less than that of the S-28 binder. This means that, at the same traffic level, the V-28 binder can be more resistant to creep behavior than the S-28 binder. The percentage of binder recovery also shows that the V-28 binder's capability to recover was greater than that of the S-28. As seen in Tables 3–6, after releasing the constant load, almost fully permanent deformation was observed in the S-28 binder.

The mix designs were evaluated using a different gradation of aggregate and binder replacement. The mix designs used in this study are provided in Table 4.

All mixes presented in Table 4 were designed to compact and test in the HWT test to determine the correlation between the dry and wet HWT indices.

2.1. Hamburg wheel tracking test

The HWT test was used to measure the effects of rutting and moisture damage performance. The HWT test displays sensitivity to the premature failure of the HMA mixtures due to improper binder stiffness, weak aggregate packing, moisture damage, and insufficient adhesion between the aggregate and binder. The HWT uses a steel wheel rather than a rubber wheel, which was utilized in the British device. The procedures for using HWT and preparing specimens are specified in AASHTO T324. Based on the standard, the device is operated by moving a steel wheel with the load of 705 ± 4.5 N (158 ± 1.0 lb) backward and forward across the surface of HMA specimens (cylindrical or slab/cubical) submerged in a constant temperature water bath specified at 50 ± 1 °C. The equipment is capable of testing a pair of specimens simultaneously. The steel wheels have a diameter of 203 mm (8 inches) and a width of 47 mm (1.85 inches) and oscillate at 52 ± 2 passes per minute. The typical setup of the HWT device, specimen preparation, and failure specimens are shown in Fig. 1. The dry HWT conditions for conducting the tests in this study followed the same conditions as specified in AASHTO T324 in wet HWT test.

2.2. Bitumen bond strength test (BBS)

Bitumen Bond Strength test is the test developed from the Pneumatic Adhesive Tensile Testing Instrument (PATTI) test as shown in Fig. 2 to evaluate the bitumen-aggregate bond strength. As shown in Fig. 2, the BBS device is composed of a portable pneumatic adhesion tester, pressure hose, piston, reaction plate and a metal pull-off stub. During the test, a pulling force is applied on the metal pull-off stub specimen. Raquel et al. (2011) found that BBS test is feasible for assessing moisture susceptibility of aggregate and asphalt binder [11]. Bahia and coworkers (2012) developed the test to account for the stiffness of the binder on BBS measurements [17]. The test can be conducted with specimens curing in both the dry and wet conditions. In the study by Raquel et al. (2011), it is shown that the pull-off strength in the wet condition was highly dependent on conditioning time [11]. To confirm that moisture fully infiltrates to between asphalt mastic and aggregate, longer conditioning time of 96 h was used for the wet condition measurement.

After preparing the asphalt mastics, all specimens were setup on substrate as shown in Fig. 2(b). Two set of specimens were cured in the dry condition at room temperature for 24 h and in the wet condition specimens were first left at room temperature for 1 h to allow for the aggregate-bitumen-stub system to reach a stable temperature, then specimens were submerged into a water bath at 40 °C for 96 h. After curing, specimens were taken out of water and maintained at room temperature for 1 h before testing. The parameter for evaluation that needs to be calculated and recorded is pull-off tensile strength (POTS), which is calculated by Eq. (1):

$$POTS = \frac{(BP - A_g) - C}{A_{ps}} \quad (1)$$

where POTS = Pull-off tensile strength (kPa); BP = Burst pressure (kPa); A_g = Contact area of Gasket with reaction plate (mm^2); C = Piston constant (provided by manufacturer); A_{PS} = Area of pull-off stub (mm^2).

2.3. Iso-stiffness temperature test

Before testing bonding strength between asphalt mastic and aggregate, obtaining the same stiffness in asphalt mastic is necessary to avoid the confusion of the pull-off tensile strength in different stiffness. Bahia and co-workers (2012) proposed the method for determining binder stiffness by interpolating among three DSR test temperatures (25, and 30 °C) to calculate the temperature at which the $|G^*|$ is equal to 1 MPa [17]. These temperatures were adjusted to cure the specimen for 5 min to maintain a test temperature before BBS testing. The equipment to control temperature is shown in Fig. 3.