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Sensitivity analysis and validation of the Simple Punching Shear Test (SPST) for screening HMA mixes

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HIGHLIGHTS

- Evaluated the Simple Punching Shear Test (SPST) sensitivity to HMA mix variables.
- Validated SPST against the HWTT at 50 °C and elevated temperatures (60 °C).
- Established good correlation between the SPST shear strength and HWTT rutting.
- Validated the practicality of the SPST for daily routine screening of HMA mixes.
- The initial indication show that SPST can supplement HWTT at higher temperatures.

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ABSTRACT

This study assessed the sensitivity of the Simple Punching Shear Test (SPST) to different hot-mix asphalt (HMA) mix-design variables, as part of the TxDOT efforts to improve the screening of HMA prone to rutting, permanent deformation, and shear failure under heavy traffic loading, high temperature environments, and severe shear stress conditions. The SPST, which is simply a monotonic penetration of a 1.5-inch diameter solid steel block into a typical Hamburg Wheel Track Test (HWTT) HMA specimen, was further compared to Hamburg Wheel Track Test (HWTT) in order to validate its usefulness. Both the SPST and HWTT tests were comparatively conducted at the traditional 50 °C and elevated temperature of 60 °C. Three SPST-HMA parameters namely, shear strength, shear strain, and shear modulus, were identified to validate the SPST and only the shear strength exhibited a good correlation with HWTT rutting. Additionally, both the HWTT and SPST tests showed that the HMA shear strength and shear failure are sensitive to changes in asphalt-binder content/type, mix types, and test temperature. Most of the HWTT rutting tests failed prematurely when the temperature was elevated to 60 °C, whereas for the SPST, only the magnitude of the HMA shear strength reduced. This suggests that the SPST could be a good supplementary test to identify and screen HMA prone to rutting and shear failure, particularly in high-temperature regions under high shear stress conditions. In addition, the findings indicate that balancing and optimizing the HMA design variables with consideration of field temperature conditions is imperative to ensure adequate HMA shear strength and satisfactory rutting performance.

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1. Introduction

Excessive traffic loading and high temperatures are among the major sources of rutting and shear failure in hot-mix asphalt (HMA) pavements. Unfortunately, in the recent years, pavements in several Texas districts have experienced an increased number of truck axle loads and volume due to improved economic activities such as agricultural, oil, gas, and energy industry [1]. In addition, the State of Texas has experienced prolonged periods of higher summer temperatures in decades. In 2016 alone, cities such as Austin, San Antonio, Dallas-Fort-Worth, Galveston, and College Station all posted high recorded temperatures close to or above 110 °F (43 °C). During the same period, most of these cities

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experienced temperatures that lingered above 100 °F (38 °C) for more than 30 days [2]. According to previously recorded data, the 110 °F can quickly warm up the HMA pavement to about 140 °F (60 °C) [3]. The increased traffic and temperatures in Texas have detrimentally exacerbated the pavement rutting, permanent deformation, and shear failure of surface HMA mixes even after passing the routine screening and laboratory testing using the traditional Hamburg Wheel Tracking Test (HWTT) at 50 °C. For example, recent studies showed excessive rutting of relatively new sections on US 96 (Beaumont District) and US 79 (Bryan District) where rut depths of above 1 in. were recorded for HMA mixes that had passed the routine HWTT test in the laboratory with rutting less than 0.5 in. [3–5].

Elsewhere, studies have documented that HMA punching tests (Uniaxial penetration, Double punch tests etc.) demonstrated a good correlation with HMA rutting parameters especially at high temperatures [6,7]. Similarly, in this paper, in an effort to improve the HMA shear laboratory screening tests and mitigate high temperature rutting and shear failure in surface HMA, particularly under high shear stress conditions, the Simple Punching Shear Test (SPST) protocol (documented elsewhere) was established to supplement the traditional HMA rutting tests procedure (i.e. HWTT) [3]. Accordingly, this paper documents and presents the laboratory work executed (including preliminary findings) towards implementing the SPST alongside the HWTT for screening HMA mixes susceptible to rutting, permanent deformation, and shear failure. The specific objectives include performing the SPST and the traditional HWTT on HMA at both the standard (50 °C) and elevated test temperatures (i.e., 60 °C) to:

a) Evaluate the SPST sensitivity to HMA mix-design variables such as the asphalt-binder type/grade, and asphalt-binder content.
b) Correlate and validate the proposed SPST procedure against the traditional Hamburg rutting test (HWTT) procedure when running at both the standard (50 °C) and elevated test temperatures (i.e., 60 °C).
c) Establish a reliable statistical correlation between the HMA shear/rutting parameters obtained from the two test methods so that the tests can be used alternately or in lieu of one another.
d) Comparatively, evaluate the practicality and cost-effectiveness of the SPST for daily routine use as a laboratory-screening test for surface HMA mixes to be placed in high-temperature regions subjected to high traffic loading and high shear stress conditions.

In the subsequent sections of the paper, the laboratory design plan and experimental matrix are discussed; followed by a description of the laboratory test methods, namely the SPST and HWTT. The laboratory test results are then comparatively presented, analyzed, and synthesized to assess the SPST sensitivity to HMA mix-design variables in correlation with the HWTT. The paper, then, concludes with a summary of key findings and recommendations.

2. Experimental design plan

Table 1 shows a list of the mix types and other HMA mix variables such as asphalt-binder grade (stiffness) and asphalt-binder content that were evaluated. In total, the experimental matrix comprised of over 20 HMA mix-design variables incorporating fine-graded (CAM and Type F), dense-graded (Type C and Type D), coarse-graded (Type B), and porous friction course (PFC) mixes. As evident in Table 1, the HMA comprised of both laboratory-prepared mixes from raw materials (asphalt-binder and aggregates) and plant-mix materials sampled from various highways (Hwy) and APT sites in the field during construction. The detailed typical constituents of the mix types as used in Texas can be found elsewhere [8].

As illustrated in Fig. 1, the experiments used typical cylindrical Hamburg-sized HMA samples, 6-inch in diameter by 2.5-inch thick, molded using the Superpave gyratory compactor (SGC) to 7 ± 1% air voids, i.e., 93 ± 1% density (except for PFC mixes where 20 ± 2% air void was targeted), for both the SPST and HWTT tests [9,10]. Two and three replicate samples for HWTT and SPST tests respectively, per test temperature per HMA mix-design variable were molded/fabricated from both lab-prepared and plant-mix (field) materials for SPST-HWTT parallel testing.

Prior to molding/compaction (after mixing), each HMA mix had to undergo a short-term oven aging at different temperatures depending on the asphalt-binder grade (stiffness). Table 2 shows a summary of the mixing, short-term oven-aging, and molding/compaction temperatures used in this study. Note that while the lab-prepared mixes were subjected to about 4 h of oven-aging before molding/compaction, the plant-mixes from the field (Hwy and APT) required only about 2 h (≤15,000 g in weight) prior to molding/compaction. The plant mixes had already been subjected to some level of aging during plant production and transportation to the sites and thus subjected to shorter oven aging period [10–14].

SPST and HWTT are destructive tests – therefore, each test temperature condition requires a new HMA specimen. So, to complete testing for all the HMA mix-design variables listed in Table 1, a total of 270 HMA specimens, with a total weight of about 1,500 lbs. (675,000 g) were molded/fabricated and tested [10]. Both tests used more than one replicate as follows (consequent variability will be discussed in subsequent sections):

- SPST testing at 50 and 60 °C = three HMA Hamburg-sized sample replicates at each test temperature per mix type per HMA mix-design variable.
- HWTT testing at 50 and 60 °C = one pair of two HMA Hamburg-sized samples at each test temperature per mix type per HMA mix-design variable.

2.1. The Simple Punching Shear Test (SPST)

The SPST experiments were performed using a UTM machine at 50 and 60 °C with three HMA sample replicates at each test temperature per mix type per HMA mix-design variable. The adapted preliminary SPST testing protocol is credited to Walubita et al. (2014) and is reported elsewhere (3). Among others, Walubita et al. also reported the immense work to establish the testing parameters such as lateral confinement pressure and punching cylinder diameter, etc. In this study, each HMA specimen was confined, using a metal collar strap bolted at 20 psi lateral pressure (using Torque Wrench) as shown in step 4 of Fig. 2. Details of the typical SPST testing procedure are illustrated in Fig. 2.

A displacement-controlled load through a punching metal block with a diameter of 1.5 in. at a monotonic rate of 0.5 in/min was then applied to the HMA specimen after the desired test temperatures had been achieved in accordance with the SPST protocol [3]. Note that the test temperature was observed through a thermocouple wire inserted into the center core of a dummy sample placed in the same chamber along with the tested sample. On average, SPST loading/testing to failure took less than 20 min with the real-time load-displacement data being recorded and displayed on the computer as exemplified in step 6 of Fig. 2.