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Mechanisms of asphalt mixture rutting in the dry Hamburg Wheel Tracking test and the potential to be alternative test in measuring rutting resistance

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HIGHLIGHTS

- The dry Hamburg Wheel Tracking (HWT) test is proposed in measuring the rutting resistance of asphalt mixtures.
- The dry HWT test can simulate rutting mechanisms including densification and shear failure analyzed by image processing analysis system 2 (IPAS^2).
- The dry HWT test shows a strong correlation of creep slope and cumulative strain with equivalent cycles observed for FN test.

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ABSTRACT

Rutting is one of the most important failures occurring in hot mix asphalt (HMA) especially in the summer season and slow moving traffic areas. Rutting is a pavement surface failure compromising the safety and ride comfort of traveling and thus needs to be accurately evaluated in a laboratory. Although the flow number (FN) test is commonly used for evaluating the rutting resistance of HMA in a laboratory, there are some shortcomings in using FN test such as the costly and complicated equipment. Another potential test that is likely to be more advantageous than the FN test for evaluating the rutting resistance is the Hamburg Wheel Tracking (HWT) test, however, it is typically conducted in wet condition, and inadequate results in dry condition have been reported. The objective in this study is to optimize the HWT test subject to dry condition to be one potential method in measuring rutting resistance in a laboratory. Two rutting mechanisms (densification and shear failure) of HMA samples conducted in the HWT device were determined by Image Processing and Analysis version 2 (IPAS^2). Results indicate that HMA samples under the dry HWT test can exhibit both rutting mechanisms in which typically occur in the field. Also, the dry HWT test shows a very good R^2 for a relation of creep slope with the confined and unconfined FN test. As a result, the dry HWT can be an effective tool of quantifying rutting potential with better simulating to field behavior, lower cost of equipment, and less complicated geometry that can also accommodate field cores.

1. Introduction

Rutting, often referred to as permanent deformation, is the surface depression in the wheel path. Ruts primarily occur in hot areas. They can often be found in slow moving traffic areas, especially intersections or the lanes of a bus stop. However, ruts also can occur in high-speed traffic. Typically, there are two basic types of rutting namely: asphalt mix rutting and subgrade rutting. Mix rutting occurs when the subgrade does not rut yet and surface presents wheel-path depression due to compaction and mix design problems. Subgrade rutting happens due to deformation of the subgrade from loading. In this case, the surface settles into subgrade ruts causing wheel-path depression.

The two primary mechanisms of rutting have been identified as shear failure (lateral movement) and densification (volume reduction). Shear failure (lateral movement) of the HMA courses occurs in the top 100 mm of the pavement surface [1]; however, if the material is unsatisfactory, shear failure can occur deeper. Permanent Deformation in pavement is usually created gradually with increasing numbers of load applications. Typically, it appears as longitudinal depressions in the wheel paths and sometimes occurs in conjunction with upheavals on the sides. It is caused by a

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combination of densification (decrease in volume and, hence, increase in density) and shear deformation and can occur in any one or more of the HMA layers as well as in the unbound materials underneath the HMA. Eisenmann and Hilmer [2,11] also found that rutting was mainly caused by deformation flow rather than volume change. As a result, significant challenges have been realized in developing a cost-effective laboratory test that can accurately simulate how rutting occurs in the field. This problem raises both policy issues within the agency and economic issues within the industry. Two tests that are widely used in the United States to determine the rutting in a laboratory are flow number (FN) Test and Hamburg Wheel Tracking (HWT) Test.

Currently, HWT test is one prominent method in a laboratory to test rutting in asphalt mixture as it can represent the cyclic loading using actual wheel loads and it is less expensive than flow number Test device. However, the HWT standard test is conducted in a wet environment, and there is no sufficient research for dry HWT use for permanent deformation measurements without confounding the effect of moisture damage. In addition, the use of flow number requires defining a confining pressure of the sample, which can vary depending on the thickness of layer and type of pavement structure. The use of confined flow number can also make the test even more costly and complicated. Therefore, to optimize the HWT test by conducting it in dry as a rational test in a laboratory to be alternative test in measuring rutting resistance is the objective of this study.

2. Materials and testing procedure

2.1. Material

The experimental design was classified into two phases to determine the aggregate structure during densification and shear failure in rutting mechanisms of dry HWT and to correlate the values of failure strain between confined/unconfined FN and HWT tests. Two mix designs that are prevalently used in the US road were selected including E-3 and E-10. E-3 represents the mixture for low traffic volume of 3 million ESAL, while E-10 is the mixture for 10 million ESAL. These mix designs received from Mathy Construction Company, Wisconsin were evaluated with different aggregate gradations and asphalt contents.

In the first phase, HWT samples were prepared with targeted air voids of 7% ± 0.5. The samples height and cutting process complied with the AASHTO T324 [8]. Table 1 shows the factors that were conducted in the first phase.

All samples were carried out in Dry HWT test until the specific cycles of each zone. Each zone was determined from the rut plots of failure samples. Then, each sample which was run to the specific cycle was cut into 6 pieces as shown in Fig. 1 to be analyzed aggregate structure by Image Processing and Analysis System (IPAS) [3].

In the second phase of this study, two methods of testing including Dry HWT Test and Confined FN were used to determine HMA permanent deformation performance. Two aggregate types namely Cisler-Granite and Waukesha-Limestone were used for the mix designs.

Table 1
Summary of factors to determine aggregate packing of HWT Samples.

Factors	Level	Description
Mixture	2	Loose Mixes from Wisconsin (E-3, E-10)
Point of Cycles to analysis	5	Original Mixture, Primary Zone, Secondary Zone, Onset Tertiary Zone, and Failure Mixture
Replicates	2	

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 inherent variability to the test method. The mix selection process was produced based on the 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 mix designs with the different aggregate gradations and aggregate sources. All samples targeted air void at 7% ± 0.5. The sample procedure to make dry HWT and confined FN samples was specified in AASHTO T324 [8] and AASHTO TP79 [9]. The factors and level for carrying out in this phase are shown in Table 2.

2.2. Hamburg Wheel Tracking test

The Hamburg Wheel Tracking Test (Fig. 2) is used to measure the effects of rutting and moisture damage performances. The HWT test displays sensitivity to premature failure of hot mix asphalt mixtures due to improper binder stiffness, weak aggregate packing, moisture damage, insufficient adhesion between aggregate and binder. As HWT is a simulative loaded wheel tester, the Hamburg test showed consistently better creep results as the ESAL level of the mix increased and as the high temperature PG grade of the binder increased for a given base asphalt [4]. The HWT uses a steel wheel rather than rubber wheel which was utilized in British device. The procedures of using HWT and preparing sample are specified in AASHTO T324 [8]. Based on the standard, the device is operated by moving a steel wheel backward and forward across the surface of HMA samples (cylindrical or slab/cubical) submerged in a water bath with the constant temperature of 50 ± 1 °C specified in AASHTO T324 [8]. The equipment is capable of testing a pair of samples simultaneously. The steel wheels have a diameter of 203 mm (8 in.), a width of 47 mm (1.85 in.) and oscillate at 52 ± 2 passes per minute. Each steel wheel weighs 158 lbs. with average contact stress of 105 psi. The rut depth data was recorded by the Linear Variable Differential Transformer (LVDT) at the side of the wheel. The deflection of the LVDTs collected begins at 0 mm. While the wheel runs over the sample, the LVDT records the rut depth at each cycle with the maximum of 11 points along the test sample at the accuracy of 0.01 mm.

The conditions for conducting the tests in this study followed the same conditions as specified in AASHTO T324 [8] in wet HWT test as follows:

- Temperature: 50 °C ± 1 °C with the chamber controlling the temperature
- Speed of the wheel test: 52 ± 2 passes/minute

An initial study for comparing wet with dry HWT clearly showed that for almost all mixtures included in this study, operating the HWT in the wet condition resulted in different results than that in dry condition due to the moisture damage in a wet environment. As shown in Fig. 2(b), wet condition results in much faster creep accumulation and, in many cases, stripping point. Therefore the testing in this study was done in the dry condition.

2.3. Confined flow number test

Confined flow number test is conducted in an Asphalt Mixture Performance Tester (AMPT) as shown in Fig. 3. The confined flow number procedure has not been standardized. However, many researchers use confined flow number test for determining the permanent deformation of the asphalt mixture. It is believed that confining pressure is needed to differentiate the difference in rutting resistance for various mixture types as it can eliminate the prema-