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Evaluation of rutting and friction resistance of hot mix asphalt concrete using an innovative vertically loaded wheel tester

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HIGHLIGHTS

- Developing a novel vertically loaded wheel tester to evaluate both rutting potential and friction resistance of HMA.
- Assessing the rutting and friction resistance of four types of two-layer HMA specimens with different mixture combinations.
- Validating the developed test method with Pavement ME simulations.

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ABSTRACT

HMA's rutting characteristics and friction properties play vital roles in defining pavement structural functions and driving safety. This paper developed a novel vertically loaded wheel tester which can uniquely evaluate the rutting potential and friction resistance of eight multi-layer specimens with one experimental set-up. In this study, the rutting and friction resistance with loading cycles for four types of two-layer structures with different mixture combinations were experimentally determined. According to the results, the structures made with the AC-20 mixture as the bottom layer had significantly lower rutting depths; this infers the bottom layer properties have a more pronounced impact on the rutting resistance of the two-layer structure. For the friction resistance, the property of the top layer is more relevant the structure's friction resistance, so use of the SMA-13 mixture in the top layer is favorable. The developed test method was validated with the simulation results using the Pavement ME.

1. Introduction

Asphalt pavement rutting is the accumulation of permanent deformation in all or a portion of the layers in a pavement that causes a distorted pavement surface [1]. It is one of the three major flexible pavement distresses and has a significant impact on pavement service life. Many tools/methods have been developed to characterize rutting characteristics of asphalt concrete pavement; these tools/methods include asphalt mixture performance tester, loaded wheel tester (LWT), and large-scale accelerated pavement tests. The loaded wheel tester is widely considered as a simple and effective tool to assess the rutting potential of hot mix asphalt (HMA) in the lab. A LWT runs simulative test by rolling a small loaded wheel device on an asphalt concrete specimen with a specified size. The LWTs predominantly used in asphalt industry are French LWT, Hamburg Wheel Tracking Device (HWTD), and Asphalt Pavement Analyzer (APA). The French LWT has been used in France for over 30 years for evaluating HMA rutting potential [2], and some U.S agencies such as Colorado Department of Transportation and FHWA's Turner Fairbank Highway Research Center also adopted this device. The HWTD was developed and has been heavily used in Germany to assess rutting and stripping characteristics of HMA. The APA, initially called as the Georgia LWT, was developed by Georgia DOT and Georgia institute of Technology. It is considered the most used laboratory wheel tracking device in the U.S.

Unlike the rutting characteristics which is primarily considered as pavement structural properties, the friction resistance plays a vital role in pavement driving safety. According to Hall, Smith, Titus-Glover, Wambold, Yager and Rado [3], there might exist a linear relationship between pavement slipperiness and amount of traffic accidents. When the friction resistance of pavement surfaces

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drops to a certain value, the chance of traffic accident increases dramatically [4]. There are several existing devices for measuring pavement surface friction, and such devices are summarized in Kogbara, Masad, Kassem, Scarpas and Anupam [5]. Since different friction measuring devices give different values for the same pavement surface, an international friction index has been developed to harmonize the different values reported from different testing devices.

The rutting and friction properties of HMA depend on multiple factors. Numerous amount of researches have been published to investigate the rutting potential of HMA [6–12]. In terms of the mix design, the rutting resistance of HMA is primarily controlled by aggregate properties, binder properties, and air void contents. According to Button, Perdomo and Lytton [13], a combined use of large top-sized crushed aggregate and manufacture particles could reduce the rutting potential of HMA significantly. Several studies indicate that HMA with a larger nominal maximum aggregate size usually has a better rutting resistance [14–16]. For the asphalt binder properties, a binder which is stiffer and more elastic at high temperature is preferable; the $G^*/\sin\delta$ has already been adopted as a controlling parameter for HMA rutting in the Superpave design specification. According to Scherocman [17], the higher the air void, the lower the rutting potential of a mixture. However, the air void content should not exceed 8 percent; when asphalt mixture has lower than 3 percent air void content, the rutting susceptibility is usually much higher. Besides, use of advanced design procedure (such as Superpave Mix Design) can yield high quality HMA mixtures. A properly designed HMA can transmit loads through an interlocked aggregate frame. With less shear on the asphalt, the rutting of the mixture can be minimized [13]. The friction resistance of HMA primarily relies on aggregate properties and aggregate graduation. It has been reported that aggregate with hard, strongly bonded, interlocking mineral crystals embedded in a soft matrix usually has the best friction properties [5]. The shape, texture, and angularity of aggregate (especially coarse aggregate) are of great importance in defining micro and macro texture of mixture, which ultimately determines the pavement surface friction. On the other hand, aggregate with a good polish resistance and soundness is a key to production of a HMA which can maintain a good friction for a long time. Besides the aggregate properties, aggregate gradation is another important factor but its impact on friction might be smaller than that of aggregate properties. It has been confirmed by many investigations that OGFC and SMA mixtures have a much better friction performance than the conventional dense HMA mixture [18–21]. Other than the aggregate properties and gradation, the use of higher asphalt content can also improve HMA friction to some extent [5].

2. Research significance

While the French LWT, HWTD, and APA have been widely adopted in the lab to evaluate HMA's potential for rutting, all of them suffer from some limitations. One common limitation of these LWTs is that they all track a loaded wheel back and forth over the specimen. In the field, however, the traffic load applied in the pavement is one-directional. The deviation in mimicking the actual field load might cause a different rutting mechanism in the lab: One-directional loading induces a consistent shearing plane in the asphalt specimen, leading to plastic flow for rutting, while the two-directional loading induces two alternating and different shearing planes when the back and forth of the wheel load is applied in the conventional wheel tests, which differs from the real traffic loading in the field. This limitation is likely to be one of the reasons for the poor correlations between the rutting depth measured in the lab and that from the field in some previous studies [2]. Besides, to the best of authors' knowledge, there is no existing device which can measure the HMA rutting and friction resistance from a single experimental set-up. In fact, the existing friction resistance measuring devices do not have a loaded wheel, so they cannot evaluate the change in friction resistance as a function of loading cycles directly.

This study developed an innovative vertically loaded wheel tester (VLWT) which can uniquely measure the rutting potential and friction resistance of multi-layer specimens from a single experimental set-up. The developed device only applies the shear loading one-directionally on the specimen's surface, so it is able to better mimic the field traffic loading condition. In this study, the rutting and friction resistance with loading cycles for four two-layer structures with different mixture combinations were experimentally determined. A simulation study to assess the rutting of the tested structures was carried out using the Pavement ME software. The findings from the Pavement ME simulation matched well with those from the experiments, which validated the new VLWT test method developed in this study.

3. Design of vertically loaded wheel testing system

3.1. Vertically loaded wheel tester

A VLWT for evaluating paving material's rutting and friction properties has been developed in this study. Fig. 1 shows a design drawing of the VLWT. A photo of the machine is presented in Fig. 2. The device uses a 39.2-kW motor, which drives the loading wheel running at a speed up to 30 km/h during the test. A heavy duty tire, produced by Jiaozuo Rubber Product Inc. (Model 4.00-8/3.00D), is used as the loading wheel. The specification of the tire is presented in Table 1.

During the test, the annular track which is covered by eight arc shaped asphalt concrete specimens rotates under the friction force between the specimens and the loading wheel. The loaded wheel ruts and abrades the specimens so that the rutting and friction performance of different materials can be assessed with a well-designed data acquisition system.

3.2. Arc specimen roller compactor

The specific configuration of the VLWT requires to fabricate arc specimens. Since the existing asphalt concrete compactors are not able to make specimens with an arc shape, a novel arc specimen roller compactor (ASRC) was developed in this study. The design drawing of the compactor is shown in Fig. 3. The specification of the compactor is presented in Table 2. A photo of the ASRC is shown in Fig. 4.

3.3. Rutting and friction measuring devices

The rutting measurement is made using a specially designed displacement measuring device (DMC). In the DMC, two pulleys are mounted on the top and bottom surfaces of the annular track. Two springs (one on each side of the annular track) are used to ensure full contacts between the pulleys and specimen surfaces. The positions of the pulleys are also adjusted so that the line connecting their centers passes through the center point of the annular track. The rutting depths of the specimens are then precisely recorded by the linear variable differential transformers (LVDT) on each side of the annular track.

A free body diagram of the interaction between the tire and pavement is shown in Fig. 5. During the test, the motor applies a moment M to the loading wheel. The friction between the loading wheel and the specimen drives the track to rotate at a constant