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Effect of three-dimensional macrotexture characteristics on dynamic frictional coefficient of asphalt pavement surface

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HIGHLIGHTS

- Rebuild the 3D pavement surface images using data collected by laser scanner.
- Describe characteristics of road macro-texture in detail using eight 3D parameters.
- Increasing sharp-angular aggregates exposed in surface can improve skid resistance.

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ABSTRACT

The surface macrotexture of asphalt mixture significantly influences the skid resistance of pavement. In this study, a handy laser scanner was employed to collect (3D) macrotexture data of asphalt pavement surface, and the dynamic friction coefficient of pavement surface was measured by a dynamic friction tester. In order to qualitatively analyze the influence of macrotexture on the skid resistance, the 3D images of macrotexture were re-constructed based on the measured data, eight different parameters were used to describe the 3D characteristics of macrotexture images. Furthermore, the influence of these parameters on dynamic friction coefficient was analyzed by statistic methods. The results show that the relationship between mean profile depth and friction coefficient at different test speed is not close as expected. The peak density and the arithmetic mean peak curvature of 3D macrotexture images have significant positive influence on the dynamic friction coefficient. However, the effect of these two factors on the friction coefficient depends on the test speed. The study recommends improving the skid resistance of asphalt pavement by increasing the number of aggregates exposed in pavement surface and using sharp-angular aggregate.

1. Introduction

Asphalt pavement surface should provide sufficient skid resistance for vehicle tires based on the requirement of traffic safety [1]. The skid resistance of pavement surface is primarily dominated by the surface textures of asphalt mixture [2]. Pavement surface texture is defined as the deviations of the amplitude from a true planar surface. According to the wavelength values of surface textures, the textures are classified into four types: microtexture, macrotexture, megatexture and unevenness [3]. Existing studies [4–6] revealed that macrotexture and microtexture have great influence on skid resistance while megatexture and unevenness are only related to noise, rolling resistance and vibration in the tire wall. The microtexture is described as the fine-scale texture on the coarse aggregates surface, in which the wavelengths are less than or equal to 0.5 mm [3]. It is frequently a function of aggregate particle mineralogy and petrology. The microtexture is of fundamental importance to skid resistance in dry and low-speed condition [2,6]. The macrotexture is defined as the amplitude of deviations with wavelengths from 0.5 mm to 50 mm [3], which is a function of aggregate particle sizes, shapes and spacing between aggregates. It impacts the pavement friction in wet and high-speed condition [2,6].

As a result of the shortage of high-quality rock, there are always no sufficient aggregates with expected microtexture. Moreover, the surface microtexture of asphalt pavement is more difficult to be measured on site than the macrotexture [7]. By contrast, the macrotexture is easily modified by gradation design and can be

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collected rapidly by laser-based, stereo photogrammetry technique etc [1]. Therefore, the skid resistance of asphalt pavement can be improved by macrotexture design. The related macrotexture standard has been developed to evaluate the skid resistance of asphalt pavement in many countries. The widely-used parameters of assessing macrotexture are Mean Texture Depth (MTD) [8] and Mean Profile Depth (MPD) [9]. MTD is usually measured by sand patch method and MPD is always detected by laser texture scanner. Although the conception of these two parameters is clear and reasonable, it is difficult for them to describe the enough details of macrotexture characteristic. Some studies [10,11] had verified that the relationship between these two parameters and skid resistance is not as closed as expected. In order to further understand the impact mechanism of macrotexture on pavement skid resistance, several other attempts should be focused on studying characteristics of macrotexture.

The development of three-dimensional (3D) image collection technology provides a possibility for the research of 3D textures in the road surface. João L. Vilaça et al. [12] developed a scanning prototype machine named Texscan to acquire the 3D data of road surface. They calculated the estimated texture depth (ETD) by surface irregularities to characterize the macrotexture. This parameter was recommended to replace the widely-used MPD. However, the ETD also described limited information of macrotexture as MPD does. Hence, it's necessary to develop more reasonable parameters to describe the detail information of macrotexture. Zhang Xiaoning et al. [13] reconstructed the 3D images of pavement surface using 3D dense point to qualitatively analyze the variation of macrotexture under kneading. Then, the fractal dimension, skewness, steepness and number of peaks in two dimensions were calculated to describe the 3D images. They concluded that these parameters influenced the friction coefficient measured by portable pendulum tester. Nevertheless, these 2D parameters cannot provide the enough characteristic of 3D macrotexture images and lack of representativeness. Amin EI Gendy et al. [14] obtained 3D data of pavement surface by photometric stereo technology. He proposed power spectrum energy (PSE) to measure the macrotexture. The results indicated that PSE had a good correlation with MPD and root-mean-square (RMS). However, the research from Mona Mahboob Kanafi [15] indicated that there was not a close correlation between RMS and skid resistance. Therefore, MPD, RMS, and PSE cannot well represent the characteristics of macrotexture. Based on fractal and multifractal characteristics of asphalt pavement macrotexture, Miao Yinghao [16] calculated three indicators including fractal dimension, the difference between the endpoints of multifractal spectrum in horizontal and vertical directions. He found that these three parameters have greater relevance with dynamic friction coefficient than MPD. However, the relationship between them is still not as close as expected.

In the above-mentioned studies, researchers obtained 3D data of road surface and studied the influence of some macrotexture parameters on skid resistance. However, theses parameters just describe limited aspects of macrotexture characterization. Therefore, the relationship between 3D macrotexture parameters and skid resistance should be further studied. This paper utilized a 3D scanner to acquire the dense point of asphalt pavement surface. The 3D image of macrotexture was reconstructed. Then, the skid resistance of asphalt pavement was evaluated by a dynamic friction tester. The effect of characteristic parameters of 3D macrotexture image on the friction coefficient was investigated by statistic analysis. The work in this paper is expected to provide a better understanding of the influence mechanism of asphalt pavement macrotexture on its skid resistance and also to guide the macrotexture design.

2. Experimental program

2.1. Test positions

The macrotexture is affected by aggregate particle size, shape and spacing between aggregate. Test specimens prepared in the laboratory might not reflect the real abrasion and wear of vehicle tires. In this study, eighteen test positions in different asphalt pavement surface were selected randomly. These pavements had undergone a large number of repeated abrasions. Fig. 1 shows photographs of test positions. It is obvious that the aggregate particle size of test positions vary from about 1.18 mm to 16 mm. The spacing between aggregates also varies from small to large. The types of test positions covered the common types and macrotexture range of dense asphalt mixture in wearing course.

2.2. Skid resistance test

A dynamic friction tester (DFTester) showed in Fig. 2 was used to measure the skid resistance of selected positions. In DFTester, three spring-loaded rubber sliders are mounted on the lower surface of a disk that rotates with its plane parallel to the test surface. Dynamic friction coefficient (μ value) can be calculated according to the torque generated by the friction of rubber sliders and pavement. Although the rubber slider of DFT is different from the pneumatic tire and the direction of motion is distinguish from vehicle's, the commonly-used field test vehicle (locked-wheel test vehicle) is high cost and rare in China. Additionally, the index measured by DFT have a high correlation with what measure by locked-wheel test vehicle [17]. Therefore, the DFT was selected to measure skid resistance performance of pavement surface. Of course, use of test vehicle will improve the practical usefulness of test result.

In the standard test procedures, water should be sprayed on the test surface by a special water system. The required thickness of water film is about 1 mm. The specific test procedures are discussed in ASTM E2157-09 [9]. The microtexture of road surface has little influence on skid resistance performance in wet condition. Therefore, the measured μ value can be considered as the function of macrotexture. In this study, the friction coefficient was extracted at different test speed. During the process, the surface temperature of all test positions is at 20 °C. In the same test condition, the greater μ value means higher skid resistance.

2.3. Macrotexture image and parameters

2.3.1. Image reconstruction

A 3D scanner (HandySCAN 300 produced by CREAFORM Inc, Canada) was employed to collect the 3D information of pavement surfaces. During the measurement, the laser emitter produces a beam of energy that comes from the instrument at an angle. After hitting test positions' surface, the laser beam undergoes a reflection and the receiving sensor recorded the position of the laser spot. According to simple trigonometric, the incoming angle can be calculated. Based on the geometrical relationship between components, the coordinates of the 3D data of surface point cloud can be determined. The device provides resolutions as clear as 0.100 mm, and precision as high as 0.040 mm.

As shown in Fig. 3, the original surface texture of asphalt pavement is composed of microtexture and macrotexture, in order to obtain the macrotexture data, a Gaussian filter with wavelength 0.5 mm was used to taking out the microtexture from the original surface texture. Before filtering, the transverse and longitudinal slope should be removed.

The 3D macrotexture images were reconstructed using MATLAB software. Fig. 4presents the reconstructed 3D macrotexture