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Research on skid resistance of asphalt pavement based on three-dimensional laser-scanning technology and pressure-sensitive film

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HIGHLIGHTS

- Make a manipulator loaded with a highly accurate laser device.
- This study comes up with a method that removes the wrong laser data.
- Select the aggregates with the best anti-skid performance by 3D technology.
- Evaluate the anti-skid performance of asphalt pavements by pressure-sensitive film.

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ABSTRACT

This article introduces a 3D dense point scanning technology and a new standard for evaluating the anti-skid performance of asphalt pavements. This study examines the reasons that lead to errors in the laser device measuring process and provides suggestions for improvement, such as adopting a median filter to process the data. In this study, four types of aggregates (A, B, C and D) under different states of grinding and abrasion have been measured, and their parameters, such as the fractal dimension and peak angle, have been calculated to evaluate the anti-skid performance. This study further measures the surface after different grinding times and calculates parameters such as fractal dimension and average depth. A 3D image is obtained. Pressure-sensitive films are then adopted to measure the pressure distribution on the track board surface under loading on the pavements at different slopes. The results show that asphalt gradation and aggregate characteristics can significantly impact the anti-skid performance of the asphalt pavements; grinding and kneading will lower the indices, including the fractal dimension, average depth, number of peaks and friction coefficient of both the aggregate and track board; asphalt pavements of aggregate A and a design gradation of GAC are adopted.

1. Introduction

Asphalt pavements provide good driving conditions for all types of vehicles, even though safety problems still exist across the world. An increasing number of traffic accidents result from poor anti-skid performance of asphalt pavements. Related studies have proved that parameters such as the size, shape and surface texture of aggregates of asphalt pavements are important for skidding resistance [1–4]. A number of accidents can be related to the skid resistance coefficients [5]. There are three scales of texture on the road surface: the mega-texture, the macro-texture and the micro-texture. Traditional ways to measure texture are direct-contact measurements and non-contact measurements, the former mainly adopting a needle-like contour-graph with parameters of height, wavelength and shape of the bulge; the latter uses a digital image method to obtain a comprehensive distribution of texture from 2D or 3D images of the target to quantitatively describe the superficial characteristics based on the fractal dimension or wavelet theory. The image analysis has been widely used in numerous studies on aggregate size and shape. J.R.J. Lee describes a system for acquisition and analysis of 3D data from the surfaces of coarse aggregate particles [5–8].

Fractal analysis is a simple and powerful tool for quantifying the roughness and irregularities of fractured surfaces [9–12]. The concept of fractal geometry has been successfully used in material science to discover the relationship between the fracture surfaces

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and fracture toughness [9] and to estimate the theoretical strength of materials based on crack tip geometry and generated fracture.

Savas Erdem and Marva Angela Blankson characterize the fracture surface roughness of concrete by means of 3D laser profilometery. They have found higher interfacial zone porosity results in higher fractal dimension and roughness; the fracture energy and toughness correlates very well with the roughness numbers of the surface. In other words, concrete with a porous interfacial zone has a greater propensity to limit the critical fracture length, and thus, more energy is consumed in the coalescence of the cracks, resulting in a fracture surface with a high degree of roughness and fractal dimension. They also indicated that as the aggregate changes from smooth and rounded to more angular shapes, there is a corresponding increase in roughness of the fracture surfaces.

The friction coefficient of aggregates and asphalt pavements also has some correlation with the fractal dimension. Researchers often using a Skid Resistance Tester and a British Pendulum Tester to evaluate the skid-resistance of aggregates and asphalt pavement [13–15]. Meanwhile, contact pressure and its distribution between pavements and the Cab tire also exert influence on the anti-skid performance.

2. Objective and scope of this study

The multi-scale structure of asphalt pavements and aggregates can significantly influence the anti-skid performance. Hence, the objectives and the scope of this study are as follows:

1. Make a manipulator loaded with a highly accurate laser device. Facilitate a repeated rectangular-shaped movement by the manipulator led by a servomotor. This process is controlled by a touch-screen and PLC programme. Collect the 3D elevation data on the basis of the previously described method.
2. Because the laser measuring will be influenced by the colour and crystal particles of the target surface, this study comes up with method that removes the noise in the laser data and adopts a median filter to smoothly process the data points.
3. Choose four types of aggregates of different lithology and measure their surface. Select the aggregates with the best anti-skid performance by considering the aggregate parameters, including peak characteristics (amounts and angle), fractal dimension, skewness, steepness and grinding value.
4. Choose two typical aggregates and two types of gradation, and prepare a moulding track board test-piece. Continue grinding it for 2, 4 and 6 h. Collect the parameters of the track board, including fractal dimension, average depth, texture depth (sand patch method), laser data 3D image, friction coefficient and pressure distribution (film method). Furthermore, quantitatively analyse the influence of aggregate and gradation on the anti-skid performance of the asphalt pavements. Finally, provide instructions for designing an anti-skid asphalt pavement.

3. Materials

See Tables 1–3.

4. Laboratory tests

4.1. 3D Laser scanner

The following paragraphs describe how the 3D laser scanner is manufactured.

1. This study adopts the LTC-050-20SA laser ranging sensor produced by an American company. Its linear midpoint is 15 mm, range of measurement is ±10 mm, resolution ratio is ±2.5 μm and the spot size is 30 μm. The computational formula is

$$PS = \frac{\text{count} - (2^{16}/2)}{2^{16}/2} \times 2 \times sf \times 10^{-dp}$$

   where PS = elevation, count = count value returned by the laser device, sf = amplification coefficient and dp = laser device point location parameter. Before the experiment, examine the laser signal and lateral displacement of the measuring system with a standard block and gauge to ensure that accurate and stable data can be measured.
2. Make a manipulator for the X axis, Y axis and Z axis. Ensure that it is has a high stiffness and precise movement. Attach the laser device on the removable iron slider of the Z axis (vertically); attach one 24 V brushless DC-servomotor on one side of the X and Y axis, respectively; attach one 24 V DC step motor on the other side of Z axis; design a one touch screen control system constituted by a touch screen, a PLC control system, a power switch, a servo controller, manual buttons, wires and a crate. The touch screen interface is equipped with a start menu, reset, scram, X-axis speed, Y-axis speed, X-axis journey, Y-axis journey, Z-axis rising, Z-axis descending and inching interface. Design a PLC control system. Connect a 24 V brushless DC-servomotor with a power supply, and then connect a 24 V DC step motor with a motor power supply; connect the laser device with its power supply; attached the laser device on the slider of the Z-axis. This is shown in Fig. 1.
3. System start-up: switch on the computer, laser device data-collecting software, power supply switch and touch screen. Finally, determine the reference datum.
4. Read and store the data. Turn on the touch screen and adjust the laser device height on the Z-axis until the green light of the laser device is on. Set a movement velocity for the x-axis, y-axis and distance as well as times of circulation. Set a proper interval between each data collection. Switch on the touch screen interface and laser device data collecting system at the same time. Rotate the Z-axis along a particular route. When the successive lasers reach the target surface, sensing elements can receive diffuse reflection lasers and acquire elevation data. In the end, click the data storage button to save the data as .TXT files.

The selected laser device is based on a point launch. The laser device will follow the rectangular movement of the Z-axis repeatedly. In this way, the 3D surface of the target can be restored. MATLAB software is used to obtain the 3D elevation data of the target surface.

4.2. Kneading machine

To simulate how traffic loads can affect the anti-skid performance of asphalt pavements, an international standard rut-meter has been improved by adding one independent motor. This independent motor can drive and force the test-piece to move laterally and repeatedly, which leaves the original motor continuing to pull the wheels vertically and repeatedly. In this way the whole track board will experience grinding to the largest extent. Additionally, the test should be performed with both dry and humid conditions. The temperature for the test is between 20 °C and 70 °C. Movement for the test-piece laterally is 10 cm/min; wheel walks 42 ± 1 times per minute. The grinding wheel weighs 42–100 kg (adjustable). Size of test-piece is 30 cm × 30 cm × 5 cm–30 cm × 30 cm × 10 cm. It is shown in Fig. 3.