MACRO-TEXTURE AND ACOUSTIC PERFORMANCE CHARACTERIZATION OF CONCRETE PAVEMENTS WITH VARIOUS TYPES OF SURFACE TEXTURES

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ABSTRACT

With the ever-increasing cost and ever-decreasing resource of petroleum, concrete pavements are becoming a more competitive paving alternative compared to asphalt pavements and have gained increasing interest of highway agencies. Different surface texturing methods may lead to different surface characteristics of the concrete pavements, such as skid resistance, drainage and road-tire noise. The main objective of this study is to assess the surface characteristics of concrete pavements with four common types of surface textures, namely wire brushing, exposed aggregate, transverse tining, and artificial turf dragging. To achieve this objective, full-scale concrete panels (3.65mx4mx0.25m), with the four different textures were first constructed following the standard construction procedure adopted in Hong Kong. 250mm-diameter cores were then extracted from the hardened concrete panels for various surface characteristic tests, including macro-texture profile tests and mirco-texture profile tests with associated road-tyre noise prediction. To assess the durability of the surface characteristics of each type of surface texture, each of the aforementioned tests was repeated six times after the test samples were subjected to 0, 16, 33, 100, 200, and 300mins of real tire polishing applied by the advanced Aachen Polishing Machine (APM). The test results indicated that among the four types of surface textures evaluated in this study, exposed aggregate provides the best overall performance in terms of macro-texture depth and tyre-road noise, while the performances of the others are relatively similar. Recommendations on further improving the surface characteristics of each type of surface texture were also provided.

Keywords: Concrete Pavement, Surface Texture, Macro-Texture, Tyre-Road Noise.

INTRODUCTION

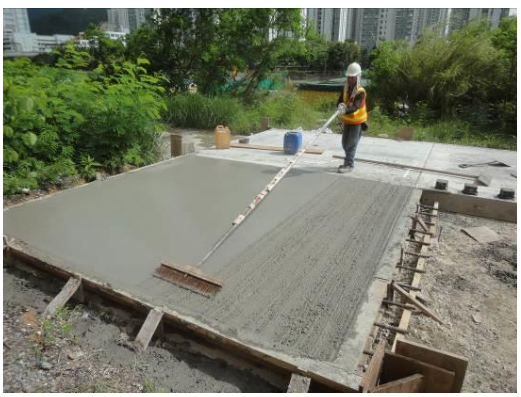
In many countries around the world, asphalt pavement has been used as the major type of pavement, because of its various advantages, such as comfortable driving, relatively low noise, and quick traffic opening after construction. However, in recent years, with the ever-growing price of crude oil and the increasing concern of diminishing petroleum resource, Portland Cement Concrete (PCC) pavement is becoming a more competitive pavement alternative.

For PCC pavements, macro-texture and traffic noise are two important surface characteristics that affect the driving safety and comfortability, respectively. To optimize these two characteristics, various surface texturing methods have been developed and applied to PCC pavements, such as wire brushing, tining, artificial turf-dragging and exposing aggregate for plastic concrete, and diamond grinding and grooving for hardened concrete (Hoerner et al. 2003; Cackler et al.). These surface texturing methods have received varying popularities in different countries, depending on the local experience, and resource availability (Hall et al. 2009; Nelson 2011; Hall et al. 2007). In Hong Kong, steel wire brushing has been conventionally implemented as the sole surface texturing method. To further improve the concrete carriageway paving technology, especially the surface texturing technology, in Hong Kong, this study characterized the macro-texture and acoustic performance of four types of surface texturing methods, including transverse tining, exposed aggregate, artificial turf dragging, and steel wire brushing conventionally applied in Hong Kong. Based on the surface characteristic measurement, an optimum surface texturing method using local construction technologies and materials was identified and further improvement measures were recommended.

EXPERIMENTAL PROGRAM

Testing Sample Preparation

To assess the macro-texture and acoustic performance of various types of surface textures, full-scale concrete panels were first constructed following the standard construction procedure adopted in Hong Kong. Four types of surface textures were then created on these panels, including steel wire brushing (V1), artificial turf dragging (V2), exposed aggregate (V3), and transverse tining (V4), as shown in Figure 1.



(a) Steel Wire Brushing (V1)

(b) Artificial Turf Dragging (V2)

(c) Exposed Aggregate (V3)

(d) Transverse Tining (V4)

Figure 1: Surface Texturing of PCC Panels

The PCC used to build panels V1, V2, and V4, had a grade of C40/20, which is conventionally used in PCC pavements in Hong Kong, while the PCC used in panel V3, had a grade of C40/10, because the European experience has shown that PCC with smaller aggregate size produces better skid and acoustic performance when the exposing aggregate texturing method is used. Table 1 shows the batching proportions for C40/20 and C40/10 used in this study. The design slump values for both PCC mixtures were 80.

Table 1: Batch Proportions of PCC (kg/m^3)

Mix	C40/20	C40/10
Cement	345	330
Pulverized Fuel Ash	115	110
20mm	-	725
10mm	1060	345
Fines	585	620
Water	195	185
Aggregate Cement Ratio	3.57	3.84
Water Cement Ratio	0.42	0.42

After the concrete panels were hardened, four pairs of 240mm-dimater cores were extracted from the panels with different surface textures for the following surface characteristics testing.

Surface Characteristics Tests

The surface characteristics of the field cores assessed in the laboratory testing include both macro-texture and acoustic performance. To assess the durability of each type of surface texture, these two tests were conducted after the core samples were subjected to various cycles of polishing loading from the Aachen Polishing Machine (APM)

<u>Macro-Texture</u>

The macro-texture of each type of surface texture was characterized based on the results of Mean Profile Depth (MPD) test. The MPD test was conducted using a device named ELAtextur®, which measures pavement macro-texture with a rotating laser sensor. In general, a higher macro-texture corresponds to better skid resistance, especially at high speed (60km and above), as well as better drainage.

<u>Acoustic Performance</u>

The acoustic performance of each type of surface texture was predicted from the high-resolution surface profile measurement using professional software. A profilometer from Fries Research & Technology GmbH in Germany was used to produce the three-dimensional surface texture of each sample. Based on the texture data, the acoustic properties of the study variants were predicted using the simulation software SPERoN from Müller BBM, which allows for predictions of noise levels induced by individual excitation mechanisms and the overall noise level of different surfaces with vehicles at different rolling speeds (Skarabis and Stöckert 2015).

<u>Polishing Test Using Aachen Polishing Machine (APM)</u>

The polishing resistance is critically important for pavement surface texture, because it directly affects the texture's durability. In this study, the polishing effect of tires was simulated by the advanced Aachen Polishing Machine (APM) as shown in Figure 2 , which is equipped with real vehicle tires (Type: Vanco 8, 165/75 R 14 C 8PR 97/95 R TL from Continental).

Figure 2: Aachen Polishing Machine

The APM applies shear stresses to the test plates by providing a superimposed translational and rotational motion. The translational motion is achieved by a horizontally movable sled onto which the test plates are fixed, while the rotational motion is realized by rotating two polishing wheels around the vertical axis. The polishing tires have an inner pressure of 0.2 MPa and an imposed load of 200 kg. The sled moves horizontally 9 times back and forth per minute, while the tires spin 41 rotations per minute. The horizontal distance between the centers of the two tires is 55 cm. Thus, the velocity of the circular motion is about 1.2 m/s. Such configuration was designed to make the entire test plate subjected to equal polishing effect. Since dust on the road consists of about 60 to 80% SiO_2 by weight, quartz powder were selected as polishing agents. During a typical polishing test, polishing agent and water are spread evenly over the surface at a rate of 27±7 g/min. Based on the findings of the previous studies, after 300 min of polishing, the test samples will reach equilibrium, and little or no changes will be caused by further polishing action.

TESTING RESULTS AND ANALYSIS

Macro-Texture Measurement

错误!未找到引用源。Figure 3 illustrates the development of the measured macro-texture profiles of the test specimens during the polishing process. It can be seen that the MPD values of all specimens decreased at decreasing rates with polishing, and the major decrease occurred within the first 30mins. Among various types of surface textures, V3 (exposed aggregate) exhibited the best results with the least decrease in MPD as well as the highest final value after 300 min polishing, while the other three textures showed similar final values. This indicates that exposed aggregate is expected to provide best high-speed skid resistance and drainage during the service life of a concrete pavement.

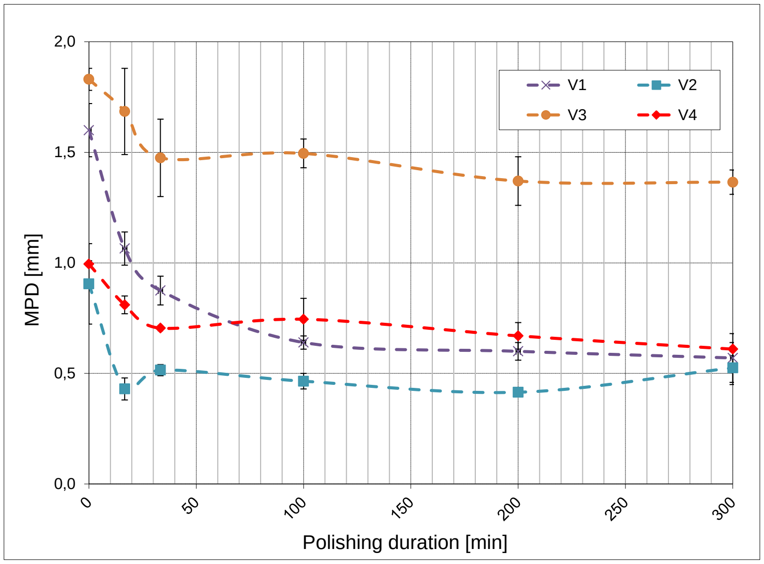


Figure 3: MPD of Specimens at Various Polishing Stages

Acoustic Performance Measurement

The determined texture data of each specimen before and after polishing were used as input data to estimate the acoustic performance using the simulation tool SPERoN. This was done for passenger vehicles at a speed of 50 km/h to simulate the situation of urban roads, where road-tyre noise is a major concern. The obtained noise levels can be used to determine which type of surface texture is the most favourable with regard to noise emissions.

As the results in Figure 4 show, there is no general trend between noise level and polishing duration. This is probably due to the complex sources for tyre-road noise, such as tyre vibration, air pumping, tyre-pavement slippage, and tyre-pavement adhesion. During the polishing process, each of the noise sources might be affected in a different way. Some might be affected positively, while others negatively, resulting in no obvious trend. The simulation shows that the road-tyre noise of V4 (transverse tining) decreased with the polishing, while V1 and V2 did not exhibit substantial changes in the course of polishing. The final ranking of the predicted tyre-road noise from high to low is V2, V4, V1 and V3. However, exposed aggregate surface texture did not show clear advantage in comparison to the other types of textures, because during certain polishing period, the predicted noise of V3 is actually larger than those of the others. However, it is worth noting that, the tyre-road noise of exposed aggregate surface texture is significantly affected by the gradation of the PCC. In this study, a typical PCC mix available in Hong Kong was used for the exposed aggregate surface texture without any special mix design besides a smaller maximum aggregate size. However, according to the European experience, the PCC mixtures for exposed aggregate surface texture usually adopt relatively uniformly-graded aggregate with major of the aggregate within a small aggregate size range from 8 to 11mm. Thus, it is expected that the tyre-road noise of exposed aggregate surface texture can be further reduced by optimizing the mix design of PCC.

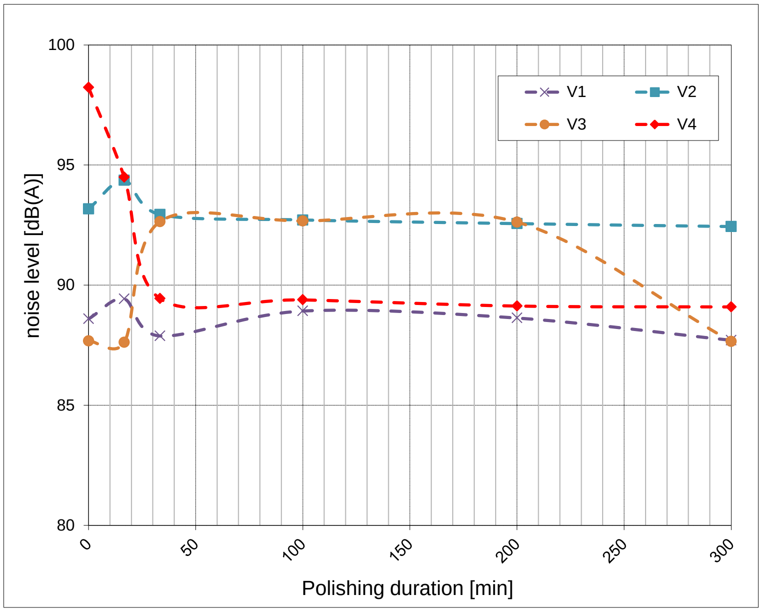


Figure 4 Predicted Noise Levels at Various Polishing Stages for Passenger Car at 50 km/h

FINDINGS AND RECOMMENDATIONS

In this study, the long term macro-texture and acoustic performance of four types of PCC pavement surface textures were characterized through laboratory testing on field extracted cores. The following summarizes the major findings of this study:

1. The macro-textures of all the four PCC surface textures evaluated in this study decreased over the polishing duration and converged toward their final MPD value.
2. Among various surface textures, exposed aggregate has shown the highest and most durable macro-texture depth and is thus the most suitable texture with regard to high-speed skid resistance and drainage.
3. Although exposed aggregate showed lowest long-term tyre-road noise for the passenger cars on urban roads, the acoustic simulation did not show clear evidence that the exposed aggregate surface is quieter than the other types of surface texture. However, it is worth noting that a common type of PCC was used for the exposed aggregate surface texture in this study, while available studies have shown that a relatively uniformly graded PCC with smaller aggregate size should be used for the purpose of best acoustic performance.

In considering of the above findings, it is concluded that exposed aggregate surface texture has very high potential to provide improved surface characteristics in terms of macro-texture and tyre-road noise in comparison to the current steel wire brushing surface texture adopted in Hong Kong. However, further study is recommended to optimize the mix design of the PCC used for the exposed aggregate surface texture to further reduce its tyre-road noise while keeping its good macro-texture.

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