Achieving a Lower Frictional Noise and Satisfactory Skid Resistance by Designing Surface Texture of SMA Asphalt Mixture

Gongyun Liao¹, Bo Jiang², Peixiang Sun³, Huaqing Chen⁴

¹Associate professor, School of Transportation, Southeast University, 210096 Nanjing, Jiangsu, China; lg@seu.edu.cn
²Orbit, Hefei Municipal Design Institute CO., LTD, 230000 Hefei, Anhui, China; 649944353@qq.com
³Graduate student, School of Transportation, Southeast University, 210096 Nanjing, Jiangsu, China; sunpx@seu.edu.cn
⁴Graduate student, School of Transportation, Southeast University, 210096 Nanjing, Jiangsu, China; chenhq@seu.edu.cn

ABSTRACT: Rougher surface texture on stone mastic asphalt (SMA) provides higher skid resistance, but mostly produces louder frictional noise. The objective of this paper was to design the surface texture which contributed to a lower noise and satisfactory skid resistance. Lab-mixed slabs with four aggregate gradations were compacted and cut into small test blocks, which were polished to obtain different texture levels. Frictional noise level (FNL) and British pendulum number (BPN) on unpolished slabs and polished blocks were simultaneously measured, and 3D surface textures were scanned. The relationships between surface texture and noise levels/skid resistance were analyzed. An optimal surface texture was established. The results showed that, a lower FNL and satisfactory BPN were achieved by designing surface texture, which was captured by the proposed cumulative curve of texture depth and were characterized by its parameter CR₂ (cumulative ratio at 2mm of texture depth). BPNs decreased linearly with the increasing of CR₂ and a minimal FNL was observed when CR₂ value was between 73 and 77. These helped to build a quiet and safe SMA pavement.

INTRODUCTION

A safe, quiet and durable highway (SQDH) is one of the dreams civil engineers all over the world persistently pursued. Until now, this goal has not been achieved yet (Bernhard, 2005; Praticò & Anfosso-Lédée, 2012; Rymer, Donavan, & Kohler, 2010).

A safe highway usually requires a rough surface texture which typically produces loud frictional noise. Also, too rough surface texture causes terrible discomfort and increases considerable fuel consumption (Wayson, 1998). Both skid resistance and noise level strongly depends on the characteristics of surface texture. Therefore, the design of surface texture is essential to balance them. But the method about designing aggregate gradation to obtain the desired surface texture is not clear (Kowalski, 2007).

A smooth surface usually contributes to a lower noise. Increased macrotexture with wavelengths of 2mm to 10mm decreases noise level caused by tire/pavement interaction (Sandberg & Ejsmont, 2002), but it is not the case for the other texture wavelength. For instance, noise level at 500Hz increases as the increasing of mean texture depth (MTD) of surface texture (Liao et al., 2014). All these researches provide the possibility that a lower noise level can be achieved with a specific surface texture.

Current methods separately measure skid resistance and noise level on
different surfaces other than on the exactly same surface textures (Staiano, 2015). Skid resistance is usually measured by the BPT on a small test area of a sample/pavement while near-field noise is collected by two sound probes along a wheel path of pavement (AASHTO, 2012; ASTM, 2013). This makes obstacles to reveal the correlation of skid resistance and noise level, and to establish a specific surface texture to balance them.

Surface texture is usually characterized by mean texture depth (MTD) or mean profile depth (MPD). The relationships between MTD or MPD and noise level/skid resistance have been established (Ostadi & Howard, 2015; Serigos, Smit, & Prozzi, 2014). But MTD and MPD cannot fully capture the surface texture since they are only one-dimension measures of surface textures.

In this research, lab-mixed slabs and test blocks were prepared. Simultaneous measurement method of BPN and FNL and cumulative curve of texture depth were proposed. The relationships between surface texture and BPN/FNL were analyzed. An optimal surface texture which led to a lower noise and satisfactory skid resistance was established.

METHODOLOGY
Preparation of Slabs
Four 12.5-mm SMA-type gradations, which differed in their percent passing of fine aggregates (<4.75mm), were design to achieve distinct surface textures. For each gradation, percent passing of fine aggregates linearly related to sieve orders, as shown in Fig.1.

Figure 1. Four SMA-type gradations.

Unmodified asphalt was used for all mixtures and optimum asphalt contents for SMA-1, SMA-2, SMA-3 and SMA-4 mixtures were 5.85%, 5.78%, 5.73% and 5.70%. Four slabs with the dimension of 300*300*50mm for each gradation were compacted to about 4% air void.

Measurements of BPN and FNL simultaneously on the slabs
Currently skid resistance and noise level were separately measured, they were simultaneously collected on the same surface in this research. The general measurement procedure was: (a) Select a closed and quiet room. (b) Place the slab on room floor and level its surface. Select two test areas (each 126mm by 76mm) on each slab surface. (c) Set up British pendulum tester (BPT) and
adjust its location and height. Fix a sound level meter (SLM) which locates 50cm higher than and 50cm away from the test area, as shown in Fig.2 (a). (d) Wet one test area and the rubber slider. Release the pendulum and immediately record the noise with the SLM. Conduct another two consecutive measurements on the same test area. (e) Record skid resistance in terms of BPN and report the maximum frictional noise in decibels (dBA) and also in the spectral contents in one-third octave bands.

**Scan and characterization of surface textures of the slab**
A 3D texture scanner illustrated in Fig.2 (b) was employed to capture 3D textures of the slab. (a) Level the slab surface and paint a white contrast intensifying agent on the two test areas. (b) Set up the 3D scanner on the tripod and face two cameras to the two test areas. (c) Connect the computer with the scanner. (d) Take the first scanning of textures. Turn clockwise the slab 45° and take the second scanning. Then, turn the slab another six times and finish the entire scanning. (e) Analyze the scanning data and report surface texture in terms of mean texture depth of scan (MTDS) and also in the cumulative ratio (CR) of texture depth.

![Figure 2. BPN and FNL Measurements and Texture Scanning. (a) BPN and FNL measurement; (b) Texture scanning with a 3D scanner.](image)

Cumulative curve of texture depth and cumulative ratio (CR) at the specific texture depth were proposed. Cumulative ratio at i mm (CR_i) was defined by:

\[
CR_i = \frac{A(Z \leq Z_0 - i)}{A(Z_0)} \times 100
\]

Where CR_i denotes cumulative ratio at i mm, %; i presents the specified texture depth, mm; Z_0 denotes z coordinate of a point on the calculation plane of the 3D texture model, mm; Z presents z coordinate of a desired point; A(Z \leq Z_0 - i) denotes enclosed area of all points whose texture depths were smaller than i mm; A(Z_0) presents the total area of the 3D texture model.

**Cutting of the slab and polishing of the block**
The Wessex aggregate abrasion machine was employed to polish the texture to obtain different texture levels. The slabs were cut into two small blocks (91.5mm by 56.5mm by 50mm) and they were polished for 500 cycles.

**Measurements of BPN and FNL simultaneously on the blocks**
Measurements of BPN and FNL on the blocks were similar to those on slabs.
The area of 60mm by 56.5mm was selected for measuring of BPN and FNL. The measured skid resistance, \( BPN_{bl} \), and frictional noise, \( FNL_{bl} \), on the block were determined by equation 2 and 3, respectively:

\[
BPN_{bl} = \frac{BPN_{bp}}{BPN_{bu}} \times BPN_{sl} \quad (2)
\]

\[
FNL_{bl} = \frac{FNL_{bp}}{FNL_{bu}} \times FNL_{sl} \quad (3)
\]

Where \( BPN_{bl} \) and \( FNL_{bl} \) present the corrected BPN and FNL on the polished block, respectively; \( BPN_{bp} \), \( BPN_{bu} \), and \( BPN_{sl} \) denote the BPNs on the polished block, unpolished block and unpolished slab, respectively; \( FNL_{bp} \), \( FNL_{bu} \), and \( FNL_{sl} \) present the FNLs on the polished block, unpolished block and unpolished slab, respectively.

**Scan and characterization of textures on the polished block**

Except for the smaller test area, the procedures for scanning and characterizing of textures on polished blocks were the same as those on unpolished slabs.

**RESULT AND DISCUSSION**

**3D textures of the unpolished slabs and polished blocks**

Fig.3 plotted the photographs (with the white contrast intensifying agent painted) and the 3D textures of the test areas on unpolished slabs with four gradations. As expected, unpolished slabs with “SMA-1” gradation exhibited smoother texture and the one with “SMA-4” gradation rougher texture. Fig.4 illustrated the photographs of the smaller test blocks before and after the polishing test. Obviously some exposed aggregates and asphalt mortar were worn out after 500 cycles of polishing.

**BPNs and FNLs measured on the samples**

The average BPNs, FNLs and corresponding MTDS of unpolished slabs and polished blocks with four gradations were presented in Table 1. MTDS of unpolished slabs or polished blocks increased as the increasing of relative coarse aggregate content (namely from SMA-1 to SMA-4 gradation). Also, MTDS of each gradation reduced about 4% after 500 cycles of polishing. Either the \( BPN_{sl} \) of unpolished slabs or the \( BPN_{bl} \) of polished blocks increased as the increasing of the MTDS.

![Figure 3. Photographs and 3D textures of the test areas on unpolished slabs. (a) SMA-1; (b) SMA-2; (c) SMA-3; (d) SMA-4 slab. Each chart was 70mm by 45mm.](image)

\( \text{Figure 3. Photographs and 3D textures of the test areas on unpolished slabs. (a) SMA-1; (b) SMA-2; (c) SMA-3; (d) SMA-4 slab. Each chart was 70mm by 45mm.} \)
Table 1. BPNs, FNLs and Corresponding MTDS of the samples.

<table>
<thead>
<tr>
<th>Sample and gradation</th>
<th>Unpolished slabs</th>
<th>Polished blocks (after 500 cycles of polishing)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MTDS (mm)</td>
<td>BPN(_d)</td>
</tr>
<tr>
<td>SMA-1</td>
<td>1.54</td>
<td>70.3</td>
</tr>
<tr>
<td>SMA-2</td>
<td>1.80</td>
<td>71.3</td>
</tr>
<tr>
<td>SMA-3</td>
<td>1.97</td>
<td>71.5</td>
</tr>
<tr>
<td>SMA-4</td>
<td>2.50</td>
<td>72.3</td>
</tr>
</tbody>
</table>

Fig.5 illustrated 1/3-octave band FNLs on unpolished slabs and polished blocks. FNLs of polished blocks were 6 dBA lower than those of unpolished slabs partially due to the loss of asphalt film covering the aggregates. Also, the FNLs below 3150Hz of polished blocks decreased with the increasing of fine aggregate content while FNLs above 4000Hz increased as fine aggregate content increased. Furthermore, minimal noise levels were found on the samples with SMA-2 gradation. It provided the possibility that a lower noise level and satisfactory skid resistance could be achieved by designing surface texture.

Cumulative curve of texture depth and its characteristic parameters

Fig.6 illustrated the cumulative curve of texture depth of all samples (with the average values of four duplicates). As expected, samples with SMA-1 gradation had higher CR values at each texture depth since they imposed of large amount of fine aggregates. Specially, CRs at 2mm of texture depths (CR\(_2\)) increased progressively. This indicated that exposed coarse aggregates were partially worn out and the polishing process created much smoother surface texture.
Figure 6. Cumulative Curves of Texture Depth.

Characteristic parameter CR$_2$ versus BPN and FNL

Fig. 7 (a) plotted the relationship between BPN and CR$_2$. BPNs on both unpolished slabs and polished blocks decreased linearly with the increasing of CR$_2$. This confirmed that BPN was mainly controlled by the microtexture. Moreover, BPNs on polished blocks decreased more significantly than those on unpolished slabs. This indicated that asphalt film covering the aggregates enhanced anti-skid performance.

Fig. 7 (b) showed a steady decline followed by a progressively increase in FNLs as the increase of CR$_2$. Minimal FNLs were found on both unpolished slabs and polished blocks with SMA-2 gradation. This confirmed that the lowest noise can be achieved with a proper texture. When CR$_2$ on unpolished slab reached 73.4, this led to the lowest FNL of 74.1 dBA. Similarly, the lowest FNL of 73.9 dBA on polished block was reached when CR$_2$ was 77.2.

Figure 7. Relationship between CR$_2$ and (a) BPN and (b) FNL.
Establishing of the optimal surface texture

CR$_2$ depended on the aggregate gradation. Fig.10 illustrated the correlation of CR$_2$ of unpolished slab with gradation parameter $k$, which was defined by equation 5. This correlation helped to achieve the specific CR$_2$ value through the parameter $k$. For example, parameter $k$ would be 3.3 if CR$_2$ was expected to be 75.

$$k = (P_{4.75}-P_{0.075})/(N_{4.75}-N_{0.075})$$

Where $P_{4.75}$ and $P_{0.075}$ denote percent passing of 4.75mm and 0.075mm sieve, respectively; $N_{4.75}$ and $N_{0.075}$ present the sieve order numbers of 4.75mm and 0.075mm sieve, respectively.

CONCLUSIONS

(1) A lower frictional noise level and satisfactory skid resistance could be achieved by designing surface texture of SMA mixture.

(2) Surface texture was captured by the proposed cumulative curve of texture depth and was characterized by its parameter CR$_2$ (cumulative ratio at 2mm of texture depth).

(3) BPNs on all samples decreased linearly with the increasing of CR$_2$ and a minimal FNL was observed when CR$_2$ value fell into the range between 73 and 77.

(4) For SMA mixture, CR$_2$ increased positively and linearly with the increasing of gradation parameter $k$.

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REFERENCES


Kowalski, K. J. (2007). Influence of Mixture Composition on the Noise and Frictional Characteristics of Flexible Pavements. (Diss.) Purdue University, W. Lafayette, IN.


