The effect of grinding and grooving on the noise generation of Portland Cement Concrete pavement

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In this investigation, studies were done to understand the effects of various grinding and grooving parameters to investigate their effect on noise generation at the tire-pavement interface. Grinding uses diamond-infused blades that are closely-spaced such that the fins between the blade tracks break off exposing an entirely new surface. For grooving, the blades are more widely spaced such that the fins do not break off and the surface texture remains largely unchanged except for grooves that are used for water drainage control. Both procedures, used independently or in combination, have an effect on the noise produced by the tire-pavement interaction. Variation of grinding parameters was shown to have as much as a 3 dB effect on noise generation. Variation in grooving parameters has a secondary effect, which allows grooves to be added to texture without overall effect on overall noise. In this paper the effects on noise of the different parameters, such as grinding depth, blade width, and blade spacing, for grinding and grooving will be illustrated.

1 Introduction

Grinding and grooving of Portland cement concrete (PCC) surfaces with diamond-infused steel cutting blades are both effective methods of rehabilitating roadway surfaces. Grinding is the process of cutting away the megatexture and unevenness of a surface [1]. The blades are spaced closely such that the fins of pavement remaining break off, leaving only a rough microtexture remaining as the pavement surface. This is an entirely new surface with a very rough contact patch as fin breakage is non-uniform.

For grooving, the blades are spaced farther apart, allowing for more pavement to remain between the channels created by the blades. The surface of the pavement is largely unchanged except for the grooves. The contact patch is very similar to that of the original road surface. Grooving is often used to control water drainage and increase wet friction.

Using On-Board Sound Intensity (OBSI) procedures to test the newly created pavements, it has been determined that ground and grooved surfaces can have significantly different noise characteristics than the original pavement [2]. In this study, the relationship between the noise characteristics and the physical properties of the texture is examined. Both the grinding and grooving processes and OBSI testing were conducted using Purdue University's Tire-Pavement Test Apparatus (TPTA), which allows for accurate control of speed and normal load and allows researchers to make highly controlled measurements in a short period of time. Comparisons were made between different blade configurations and different combinations of surfaces and tires using A-weighted, narrow-band, one-third octave-band, and overall intensity measurements.

2 Test Method

OBSI measurements were conducted using Purdue University's Tire Pavement Test Apparatus (TPTA). The TPTA is a 3.7 m diameter drum containing a motor, gear box, and pulley that drive a steel plate above the drum. The TPTA is shown in Figure 1. Attached to the plate are two arms, with a tire/wheel assembly attached to each. Six curved, concrete samples are mounted around the drum. As the steel plate rotates, the two testing tires roll along the outside of the samples. Normal loads up to 7 040 N (1 600 lbf) can be applied to each tire, simulating a 1 800 kg vehicle. Speed can be controlled from 0–48 kph (0–30 mph). Both the tires and the samples can be exchanged to study other tire-pavement combinations. All tire-pavement combinations were tested at 48 kph (30 mph).

Figure 1: Tire-Pavement Test Apparatus

Intensity probes were mounted near one of the test tires on the TPTA according to the draft AASHTO standard for On-Board Sound Intensity (OBSI) [3]. Phase-matched microphone pairs were mounted near both the leading and trailing edges of the contact patch, with the center of the probes 70 mm from the pavement and 100 mm above the edge of the tire as shown in Figure 2. The microphones were Brüel & Kjær Type 4197 Sound Intensity Microphone Pairs and the separation between the two microphones for each probe was 17 mm. The probes were connected to a Brüel & Kjær Type 7533 LAN Interface Module. Data were transferred to a laptop computer using a wireless router. Magnetic triggers were used to ensure the same section of pavement was measured with each pass of the tire.

Figure 2: On-board Sound Intensity Probes

For each measurement, A-weighted, narrow-band intensity spectra were collected and averaged over 100 passes of the test tire over the pavement sample with a sampling rate of 12 800 Hz. The narrow-band intensity data resolution was 12.5 Hz over the frequency range from 12.5 to 5 000 Hz. The intensities from the leading and trailing probes were averaged at each frequency. One-third octave band intensity spectra from 630 to 4 000 Hz were calculated by summing the narrow-band intensity in each one-third octave band. Overall intensity levels were calculated by adding all of the narrow-band intensities from 500 to 5 000 Hz. Both one-third octave band and overall intensity data were averaged over at least two different tires to average the tire effect.

The tires used were a Uniroyal Tiger Paw (P205/70R15 95S M+S) and a Goodyear Aquatred (P205/70R15 95T M+S). They were each inflated to a pressure of 230 kPa (33 psi) and were loaded to 2.7 kN (600 lb).

3 Test Samples

A significant number of concrete segments have been constructed for the purpose of the grinding and grooving study. The concrete for each sample was specified as “27.6 MPa (4 000 psi) non-air gravel PCC with an average slump of 150 mm (6 in.)”. Concrete was poured into steel forms and allowed to set for one week. The samples were then removed from the forms and wrapped in burlap and plastic sheeting to preserve moisture. The samples were allowed to cure for one month, during which time they were uncovered and moistened with a hose every three to four days. After the samples had cured, they were loaded onto the TPTA one at a time to be ground. All samples initially had a smooth surface, as shown in Figure 3.

Figure 3: Original, smooth (blank) surface of all PCC samples

To achieve the desired textures on the samples, a grinding system was mounted on the TPTA in place of one of the tires. The grinding apparatus, as shown in Figure 4, consists of a 15 kW (20 hp) motor attached via a belt to a shaft holding a stack of diamond-infused cutting blades. These blades are shown in Figure 5. A full stack of blades is 200–230 mm (8–9 in.) high so that the tire contact patch fits in the ground track. Blades with diameter 368 mm (14.5 in.) were available in 2.29, 2.79, 3.18, and 4.19 mm (0.090, 0.110, 0.125, and 0.165 in.) thicknesses. In addition, blades with diameter 364 mm (14.34 in.) and thickness 3.18 mm (0.125 in.) were available. These smaller “chopper blades” were used in conjunction with the regular blades to create different textures on the samples. Spacers, which do not have cutting tips, were available in 0.76, 2.29, 2.79, and 3.81 mm (0.030, 0.090, 0.110, and 0.150 in.) thicknesses to separate the cutting blades.

Figure 4: Grinding apparatus with stack of diamond cutting blades

Figure 5: Diamond-infused cutting blade and non-cutting spacer

Initially, five samples were ground then tested for noise characteristics. These samples are designated by blade and spacer width (e.g., B125S130 was ground with a stack of 0.3175 mm (0.0125 in.) blades separated by 3.302 mm (0.130 in.) spacers). Based on the results from the first set of textures, another set of six samples were ground. However, as shown in Figure 6, there was no significant change in the second phase compared to the first phase. Phase 1 and phase 2 samples were ground using a single pass process. The grinding apparatus was set to grind the desired amount (usually 3.18 mm) below the average pavement height. During the grinding process, water was sprayed on the sample to minimize the amount of dust created and to lubricate and cool the blades.

Seven samples were ground in the third phase. The grinding sequences for each sample in this most recent phase are shown in Table 1. For the two “full grind” samples, the grinding head was shifted downward by 2.29 mm for a second pass, so that the texture left behind by the first pass would be ground away, leaving a flat surface. For the full grind with grooves sample, a third pass was used to create grooves in the ground track.

<table>
<tr><th>Sample</th><th>First Pass</th><th>Second Pass</th><th>Third Pass</th></tr>
<tr><td rowspan="2">Conventional diamond grind</td><td>4.19 mm blade
3.81 mm spacer</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>3.18 mm deep</td></tr>
<tr><td>Double</td><td>4.19 mm</td><td></td><td></td></tr>
</table>

chopper	blade 0.76 mm spacer chopper blade 0.76 mm spacer chopper blade 0.76 mm spacer 3.18 mm deep		
Triple chopper	4.19 mm blade 0.76 mm spacer chopper blade 0.76 mm spacer chopper blade 0.76 mm spacer chopper blade 0.76 mm spacer 3.18 mm deep		
Blank	None		
Blank with grooves	2.29 mm blades 12.7 mm on center 3.18 mm deep		
Full grind	2.29 mm blade 2.29 mm spacer 6.35 mm deep	2.29 mm blade 2.29 mm spacer 6.35 mm deep *Grinding head shifted by 2.29 mm	
Full grind with grooves	2.29 mm blade 2.29 mm spacer 3.18 mm deep	2.29 mm blade 2.29 mm spacer 3.18 mm deep *Grinding head shifted by 2.29 mm	2.29 mm blades 12.7 mm on center 3.18 mm deep from full grind level

Table 1: Repeated blade configurations for most-recent phase of diamond-grinding

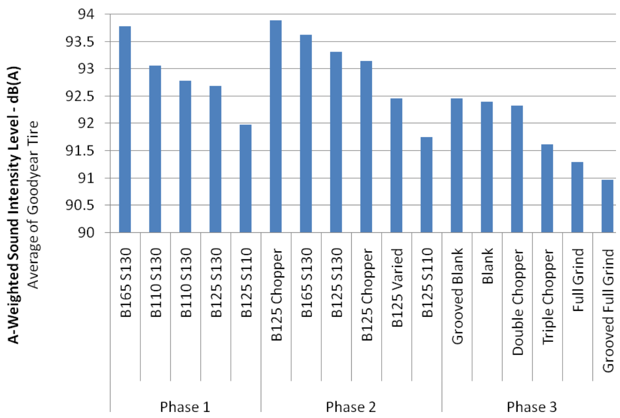

Figure 6: Overall A-weighted sound intensity levels for all surfaces created in all phases

4 Results

The surface texture of the quietest samples is different than the texture for the conventional ground surfaces. The conventional diamond grind configuration leaves fins between the grooves. As in the field, the fins break off in an irregular pattern, leaving a rough contact patch, as shown in Figure 7. The double and triple chopper blade configurations yield smoother contact patches with much less fin breakage. Both the blank with grooves and the full grind with grooves have little breakage. The full grind and the full grind with grooves has microtexture (less than 0.5 mm texture wavelength) that is much smaller than the fins left over by the conventional grind.

Figure 7: Example ground surface; conventional grind texture

The difference in overall A-weighted sound intensity levels for all of the pavements compared to the conventional grind are shown in Figure 8. The repeatability of the measurements is approximately 0.2 dB. The quietest pavements are the full grind with grooves and the full grind. The blank with grooves and the un-grooved blank are both approximately 1 dB louder than the full grind sections. Even though the triple chopper texture appears to be physically identical to the full grind with grooves, it is approximately 0.8 dB louder. The double chopper configuration is about 1.2 dB louder than the quietest pavement. All surfaces are quieter than the conventional grinding pattern, which is 2.5 dB louder than the quietest sample. The blank is as quiet as the blank with grooves. The intensity levels of the two blank samples and the double and triple chopper samples are very similar. All four of these samples are significantly quieter than the conventional grinding pattern. For all samples except the full grind, the Uniroyal tire is quieter than the Goodyear tire.

In general, spectra from tests with the Uniroyal tire shown in Figure 9 have the highest sound levels around 1 000 Hz, while the spectra from tests with the Goodyear tire shown in Figure 10 have flat, wider peaks from 700–1 500 Hz. The average spectra have a combination of these two properties. Above 1 500 Hz, all spectra have decreasing intensity levels with increasing frequencies. Figure 11 shows the average of both tires.

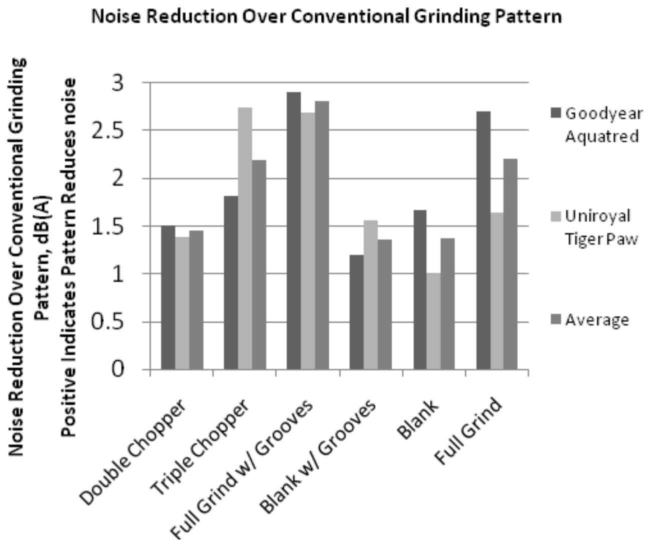

Figure 8: Difference in overall A-weighted sound intensity levels

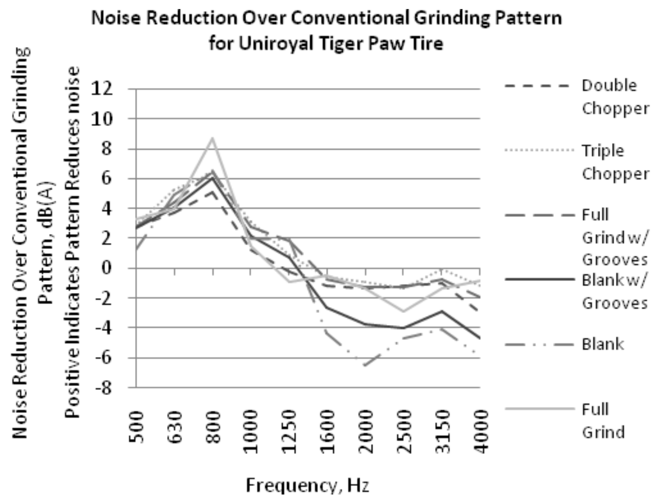

Figure 9: Difference in A-weighted one-third octave band spectra for Uniroyal Tiger Paw tire

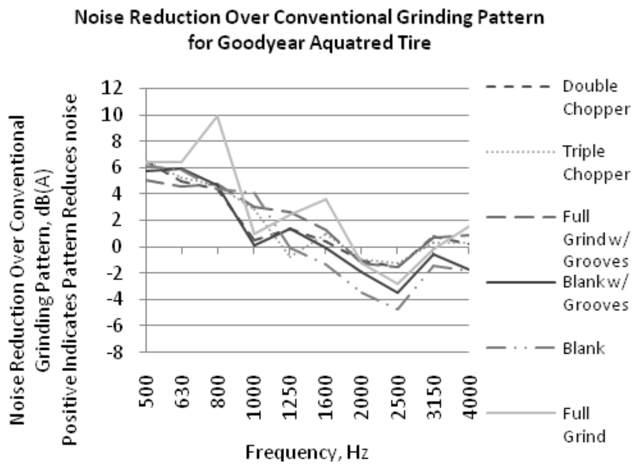

Figure 10: Difference in A-weighted one-third octave band spectra for Goodyear Aquatred tire

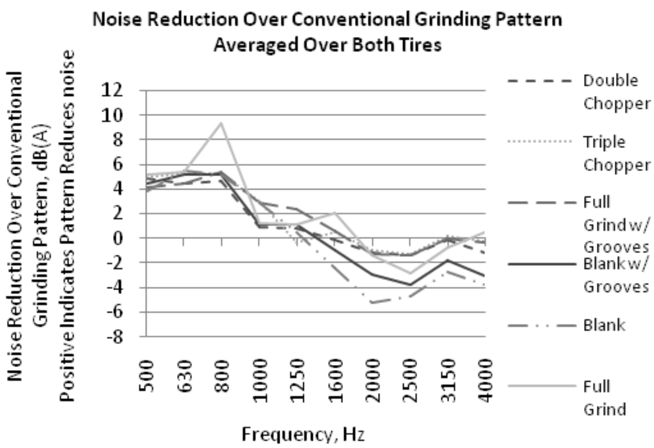

Figure 11: Difference in A-weighted one-third octave band spectra averaged over both tires

5 Conclusions

Diamond grinding can be successfully used to rehabilitate PCC pavements and improve many surface characteristics, such as smoothness and friction. In addition, conventional diamond grinding has been found to successfully reduce tire-pavement noise from PCC pavement. However, it would appear that further improvements in the noise performance of the diamond ground pavements are possible. Parameter studies of the effect of depth, width, and spacing of grooves is ongoing in hopes of creating quieter roadway surfaces.

The overriding property in determining noise characteristics is macrotexture (0.5–50 mm texture wavelength) in the contact patch left after the grinding process. With conventional grinding blade configurations, the fins between the grooves break off, resulting inmacrotexture in the 5-50 mm range. With two or three chopper blades, the fin breakage is significantly smoother and the noise level is reduced.

By comparing the full grind with the blank samples, it was shown that a small amount of microtexture creates a surface that is quieter than a blank surface. The full grind sample was about 1.2 dB quieter than the blank sample.

In general, grooving has only a small effect on noise generation and can be used to improve wet friction by allowing control of water without either adverse or positive effect on the noise characteristics of a pavement.

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References

[1] Ulf Sandberg and Jerzy A. Ejsmont, “Design guidelines for noise reduction related to road surfaces,” *Tyre/Road Noise Reference Book,* INFORMEX, Kisa, Sweden, Chapter 21, pp. 446-447, 2002.

[2] Mark B. Snyder, *Pavement Surface Characteristics – A Synthesis and Guide,* American Concrete Pavement Association, Skokie, Illinois, 2006.

[3] AASHTO Draft: “Standard Practice for Measurement of On-Board Tire-Pavement Noise”, personal communication, FHWA Expert Task Group, 2007.