Evaluation of the Effectiveness of Different Mix Types to Reduce Noise Level at the Tire/Pavement Interface

Joseph Ponniah
Pavements and Foundations Section, Ministry of Transportation Ontario

Seyed Tabib
Bituminous Section, Ministry of Transportation Ontario

Becca Lane
Pavements and Foundations Section, Ministry of Transportation Ontario

Chris Raymond
Bituminous Section, Ministry of Transportation Ontario

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ABSTRACT

Quiet pavement is designed specifically to reduce highway noise. Many factors play a role in the generation of sound due to tire-pavement interaction. These include: 1) tire size, design, condition (new versus worn) and loading; 2) vehicle type, size, condition (new versus old) and speed; 3) traffic volumes; 4) pavement porosity; and 5) pavement surface texture. Assuming all other factors are constant, the traffic noise levels will vary with variation in pavement surface characteristics such as porosity or texture. Therefore, to minimize tire-pavement noise, the type of pavement surface and/or the associated texturization are of paramount importance.

Tire-pavement noise has become an increasingly important consideration for highway agencies as the public consistently demands that highway traffic noise be mitigated. Although sound walls provide a means for addressing highway noise, improved pavement structures and surfaces may provide a competitive alternative for noise mitigation.

While the approaches may differ slightly from agency to agency, the general practices observed include using both quieter pavements and noise barriers, as well as implementing policies that set noise level thresholds and seek noise reductions from both vehicles and tires. Overall, the European approach was found to be more comprehensive than U.S. practices, addressing nearly every aspect of noise reduction.

As part of the effort in evaluating different methods for reducing noise level on freeways, MTO initiated a project by building five trial sections to examine the effect of various asphalt mixes in reducing the tire-pavement noise level. These include two types of open friction course, stone mastic asphalt, open graded rubberized asphalt concrete, and a control section. Immediately after construction, pavement noise measurements were performed using the ON-Board Sound Intensity (OBSI) method for measuring the noise level at the tire/pavement interface using a sound intensity probe. All five test sections were measured simultaneously, by driving the vehicle across the test area. Three different speeds, 60 km/h, 80 km/h, and 100 km/h were used. Multiple passes were undertaken to obtain at least 2 valid measurements per test section. This paper will present results of the investigation analyzing the effects of different mix types in reducing the noise level generated as a result of interaction between tire and pavement surface.

INTRODUCTION

In an era of dramatically increasing traffic volumes, heavier trucks, and more intense urban development, the problem of traffic noise has grown to the extent of creating an environmental pollution that warrants mitigation. The highway/transportation agencies and municipalities are under increased pressure to reduce the noise pollution associated with roadway traffic because of its detrimental effect on public health and environment. The most significant impact of noise is the annoyance and the associated effects on quality of life [1, 2]. As a result, traffic noise has become an increasingly important consideration for highway agencies. In Canada, guidelines for noise mitigation have been developed by the Ministry of Environment (MOE) to keep the traffic noise level below some acceptable limits [3]. The common practice for noise reduction is to obstruct sound propagation from the roadway to the neighbouring community by building sound barrier walls, particularly in urban areas. Such noise mitigation measures are generally very costly and in some cases they are not feasible or an ideal solution for minimizing noise pollution [4].

In view of the above, highway agencies have explored alternative solutions to noise barriers to mitigate noise not only for adjacent residences but also for drivers and even for citizens farther from the highway. Engineers in the European Union and elsewhere have developed alternative pavement types and surfaces that reduce noise generated at the tire-pavement interface. It was found that the noise generated at the tire-pavement interface is the major source of contributor to traffic noise for vehicles traveling at a speed of ≥35 km/h [5]. Figure 1 illustrates the significant contribution of noise generated at the tire-pavement surface to the overall noise interaction [2, 6]. Thus, the best practice to provide a cost-effective option for noise abatement would be to take steps to mitigate noise at the source where it is generated. This can be achieved only by improving pavement structures and surface textures to absorb noise generated at the tire-pavement interface. While not a universal remedy, certain pavement type and texture options have led to improvements in noise levels; in some cases, improving the quality of life while reducing the need for or height of noise walls. It was reported by the European Union that in France, porous surfaces have been successfully used to reduce noise at the tire-pavement interface [7]. Results there have shown that noise generated at the tire- non-porous pavement interface can be reduced by between 3 to 5 decibels on average by the use of alternative porous pavement surfaces.

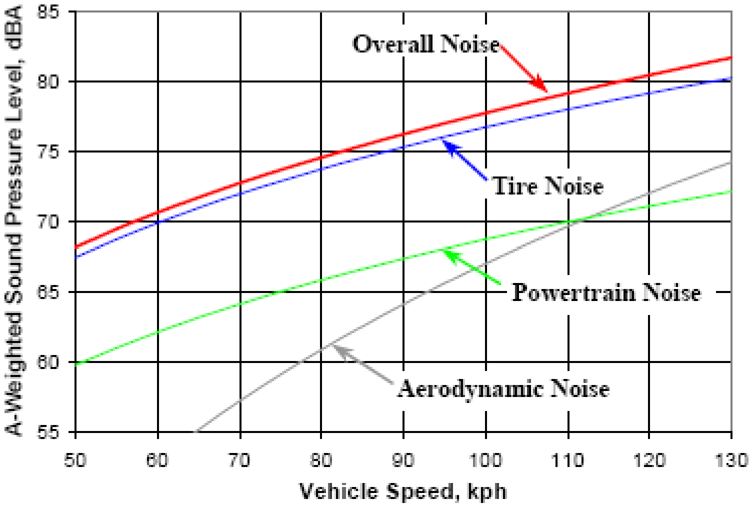


Figure 1 - Contribution of Traffic Noise Sources [Bernhard 2005b, Donavan-IP]

As part of the effort in evaluating the feasibility of implementing the innovative alternative solutions to noise barriers for reducing noise level from freeways, MTO initiated a project by building five trial sections to examine the effect of various asphalt mixes in reducing the tire-pavement noise level. These include two types of open friction course (single and double layers), stone mastic asphalt, open graded rubberized asphalt concrete, and a control section. Immediately after construction, pavement noise testing was performed for measuring the noise level at the tire/pavement interface using an On-Board Sound Intensity (OBSI) method as described later.

SCOPE AND OBJECTIVE

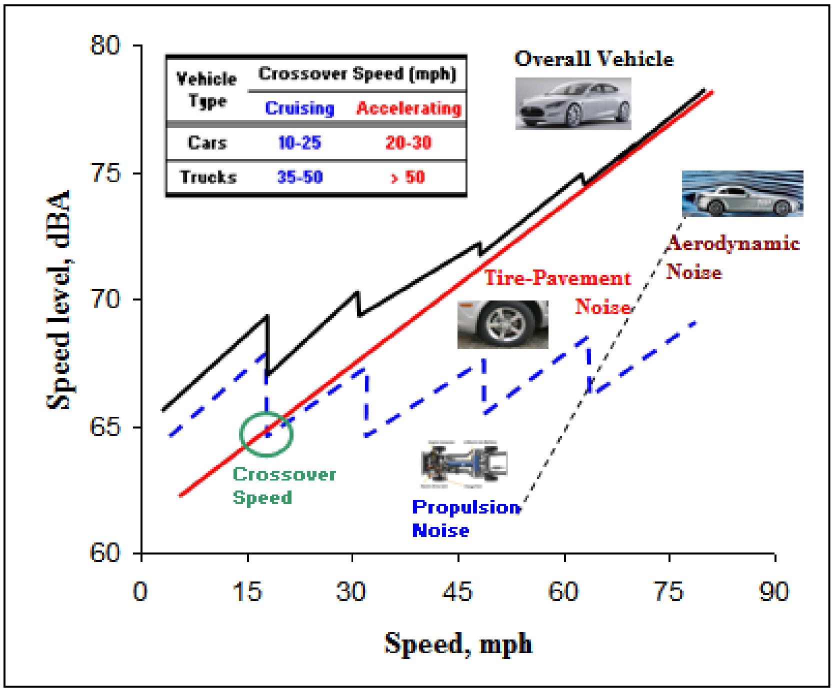
The objective of this research project is to develop and execute a comprehensive, long-term study to determine if a particular pavement surface type and/or texture can be successfully used in Ontario to meet the MOE noise mitigation requirements. The study is needed to accomplish the following:

1. Determine the noise generation/reduction characteristics of pavements as functions of pavement type, pavement texture, age, time, and traffic loading, under a regular routine and winter maintenance program.
2. Determine a correlation between source measurements using on-board sound intensity (OBSI), and statistical passby (SPB) and/ or time-averaged wayside measurements; and
3. Accumulate information that can be used for validation and verification of the accuracy of the available Traffic Noise models

The scope of the work included construction and monitoring of trial sections as described subsequently.

RATIONAL FOR QUIETER PAVEMENTS

Vehicles travelling down the road can generate noise in various ways from three different sources: propulsion, the tire/pavement interaction, and aerodynamics as illustrated in Figure 2 [8]. It appears that at very low speeds, propulsion noise will dominate the total noise. Propulsion noise is independent of speed and includes sounds generated by the engine, exhaust, intake, and other power-train components. The tire-pavement noise is generated as the tire rolls along the pavement surface and is speed dependent. As speed increases, the tire-pavement noise increases and surpasses the propulsion noise level when it reaches a certain speed limit which is called a crossover speed. Beyond this speed, tire/pavement interaction becomes the dominant source of noise. Aerodynamic noise refers to the noise caused by turbulence around a vehicle as it passes through the air. This will begin to dominate only at very high speeds, usually higher than the typical speed limit of 100 kph on freeways. Thus, the crossover speed concept has identified a practical threshold speed, above which quieter pavements will be most helpful. This provided the rationale for focusing our attention on reducing the noise generated at the tire-pavement interface on secondary highways and freeways where the operating speeds exceed the crossover threshold speed as the primary target studies.



Vehicle Type	Crossover Speed (mph)	
	Cruising	Accelerating
Cars	10-25	20-30
Trucks	35-50	> 50

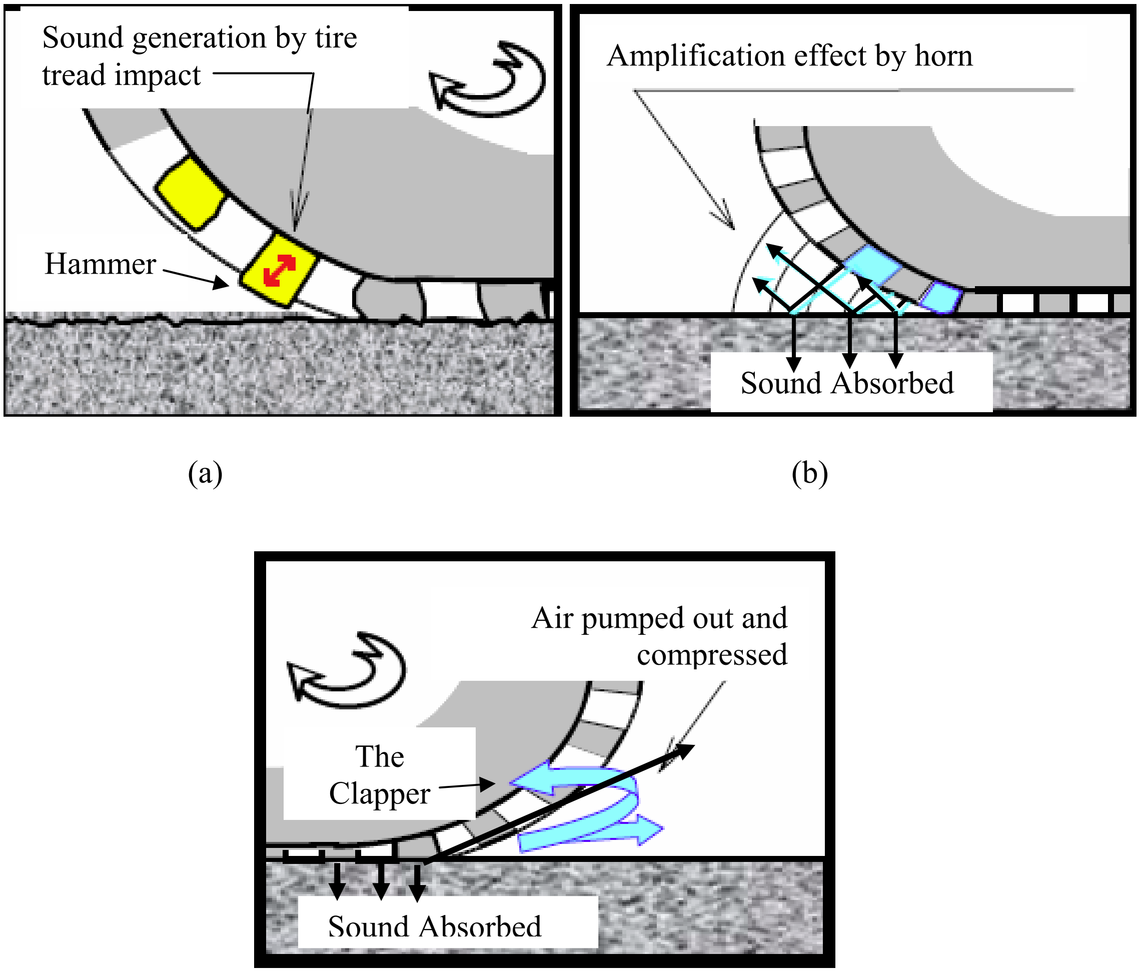
Figure 2 - Speed Effects on Vehicle Noise Sources and Crossover Speed [Rasmussen 2007-8]

MECHANISM OF NOISE GENERATED BY TIRE-PAVEMENT INTERACTION

When tires and pavement come into contact at highway speeds, noise is generated due to complex interactions between the tire tread block and pavement surface with numerous types of mechanisms occurring simultaneously. In addition, there are a number of amplification mechanisms which also contribute towards increasing the sound level. Various types of mechanisms that generate and amplify sound are described in ref [8]. This paper will focus on relevant mechanisms which are directly influenced by the pavement texture.

Figure 3 illustrates the most predominant mechanisms by which the sound is generated and amplified. The first mechanism, known as ‘The Hammer’ (Figure 3-a), occurs as the tire rolls along the pavement. In this case, the sound at the tire-pavement interface is produced initially by the impact between the tread on the tire and the texture on the pavement which is subsequently amplified by the ‘acoustical horn’ created by the wedge-shaped segment formed between the tire geometry and the pavement surface (Figure 3-b). In addition, the air trapped in the gaps between the tread on a tire and the texture on a pavement would be squeezed out in the direction of the moving vehicle resulting in multiple reflections of sound generated near the throat of the ‘acoustical horn’, similar to the sound that reflected within a musical horn or megaphone. Some of the air trapped is compressed and forced out in the opposite direction of the moving vehicle as the tire loses contact with the pavement moments later.

If the pavement is built with dense graded mix, the volume of air squeezed out in front and the back of the tire would likely be the same and so would be the intensity of the amplified sound produced. However, if the pavement is an open graded mix, the compressed air would likely escape through the porous surface of the pavement, resulting in a relatively lower volume of air leaving at the trailing edge of the tire (Figure 3b and 3c).



(a)

(b)

(c)

Figure 3 - Noise generation mechanism [8].

This phenomenon is often linked to the sound absorption property of the pavement which is related to pavement porosity. In this case, it is expected that traffic noise generated for the dense graded mix would be higher than the noise observed for porous asphalt pavement. In addition it is expected that noise recorded at the trailing edge of the tire would be less than that observed in the leading edge for porous pavements.

EXPERIMENTAL DESIGN

The experimental design involved construction of five 500 m length test sections, A, B, C, D and E on Hamilton bound lanes of Highway 405 in Ontario as shown in Figure 4.

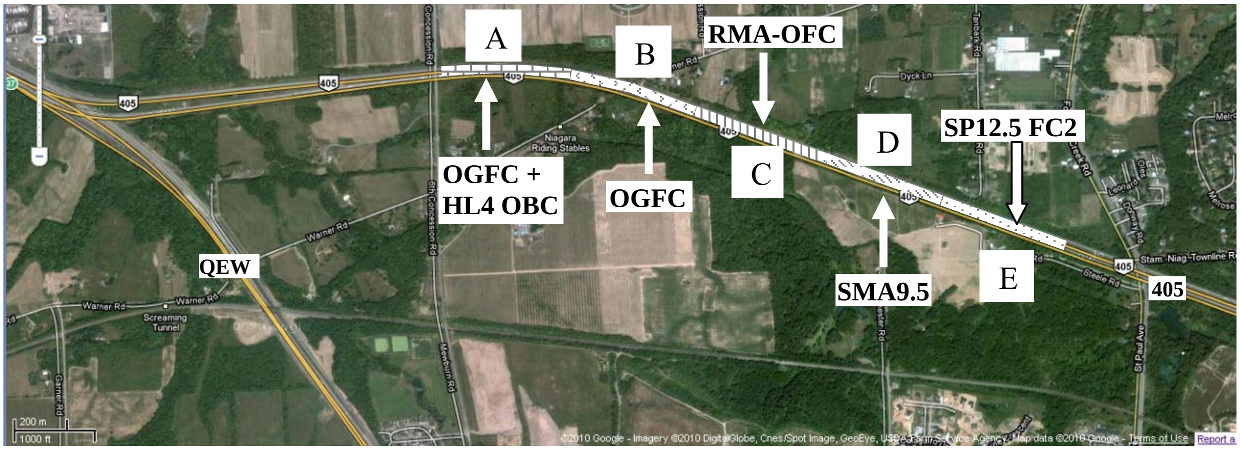


Figure 4 - Site map of the test sections

Each test section consisted of two sampling areas as well as one monitoring portion as shown in Figure 5 below:

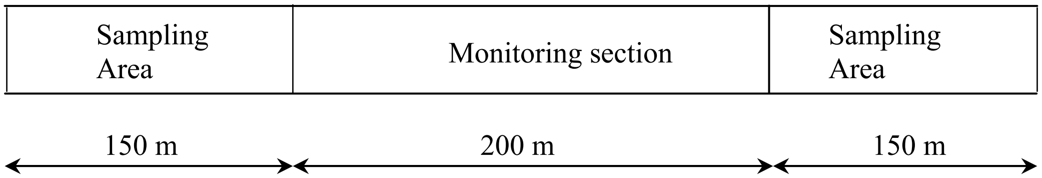


Figure 5 - Layout of each test section for monitoring and sampling

The different types of asphalt concrete mix layers used in each section are described as follows:

- Section A consists of three layers including a double open graded mix layer placed over MTO designated Superpave 19.0 binder course mix. The double open graded mix layer is made of a single lift of Open Friction Course (OFC) mix surface layer containing polymer/fibre modified Performance Grade Asphalt Cement (PGAC) combined with another lift of an intermediate MTO designated HL4 Open Binder Course (OBC) mix layer.

- Section B includes an open friction course (OFC) mix containing polymer/fibre modified PGAC placed over Superpave 19.0 binder course mix.
- Section C consists of a Rubber-modified Open Friction Course (ROFC) mix containing 1% crumb rubber obtained through the semi-wet process, placed over Superpave 19.0 binder course mix.
- Section D was built with Stone Mastic Asphalt containing 9.5 mm nominal maximum size aggregate (SMA 9.5) placed over Superpave 19.0 binder course mix.
- Section E (Control) was comprised of MTO designated Superpave 12.5 FC2 surface course mix placed over Superpave 19.0 binder course mix.

The thickness and types of layers used in each is summarized in Table 1.

Table 1 - Length and thickness of test sections

Test Section	Length (m)	Mix Thickness and Type
A	500	30 mm OFC over 50 mm HL4 OBC over 50 mm Superpave 19.0
B	500	30 mm OFC over 50 mm Superpave 19.0
C	500	30 mm ROFC over 50 mm Superpave 19.0
D	500	30 mm SMA 9.5 over 50 mm Superpave 19.0
E	500	40 mm SP 12.5 FC2 over 50 mm Superpave 19.0

Mix Design

The following standards were followed to achieve the mix design requirements:

- Superpave mixes: LS-309, Practice for Superpave Mix Design.
- SMA 9.5: LS-311, Practice for SMA Mix Design.
- OFC, HL4 OBC, ROFC: ASTM D7064-04, Practice for Open-Graded Friction Course Mix Design.

Tables 2 and 3 show the gradations and the volumetric properties of each mix based on the mix design. The tolerance for acceptance of each mix was based on the criteria given in Table 4.

CONSTRUCTION OF TEST SECTIONS

The test sections were constructed in October 2009. The Superpave 19.0 binder course had been placed in 2008. Field compaction of the open graded mixes (i.e., HL4 OBC, OFC, and ROFC) was achieved using a steel roller only. The mix was compacted not to meet some specified density, but rather, to seat the aggregates. Vibratory rollers tend to fracture aggregates during compaction and pneumatic tire rollers tend to pick up the mix [9].

Table 2 - Aggregate gradation of different mixes placed on the test sections

Sieve Size (mm)	OFC	HL4 OBC	ROFC	Crumb Rubber	SMA 9.5	SP 12.5FC2
16.0	100	100	100	100	100	100
13.2	100	79.6	100	100	100	95.5
9.5	94.9	49.8	94.9	100	78.6	80.2
4.75	23.1	13.1	23.5	100	33.4	51.1
2.36	6.4	6.2	7.3	100	20.1	42.3
1.18	4.0	4.8	5.0	99.6	14.4	28.1
0.600	3.3	4.3	4.3	99.6	12.2	18.5
0.300	2.8	4.1	3.2	47.7	10.2	11.9
0.150	2.3	4.1	2.4	13.1	8.6	7.2
0.075	2.0	4.0	2.0	2.1	8.1	4.5

Table 3 - Volumetric properties and asphalt content of the different mixes

Hot Mix Properties	OFC	HL4 OBC	ROFC	Crumb Rubber	SMA 9.5	SP 12.5FC2
AC %	5.5	6.0	5.3		6.3	4.9
% Voids	19.1	18.8	18.1		4.0	4.0
Crumb rubber	n/a	n/a	1%		n/a	n/a
Cellulose Fibre	0.3%	0.3%	0.3%		0.5%	n/a
BRD	2.148	2.043	2.147	1.14	2.321	2.582
MRD	2.655	2.516	2.620		2.419	2.689
Aggregate type	Meta Gabbro	Meta Gabbro	Meta Gabbro		Dolomitic Sandstone	Diabase
AC Type	PG 70-28	PG 70-28	PG 70-28		PG 70-28	70-28

Table 4 - Specification Limits from Job Mix Formula (JMF)

Test	Lower Limit (%)	Upper Limit (%)
Asphalt Cement Content	JMF - 0.5	JMF + 0.50
4.75 mm Sieve	JMF - 5.0	JMF + 5.0
75 µm Sieve	JMF - 1.0	JMF + 1.0

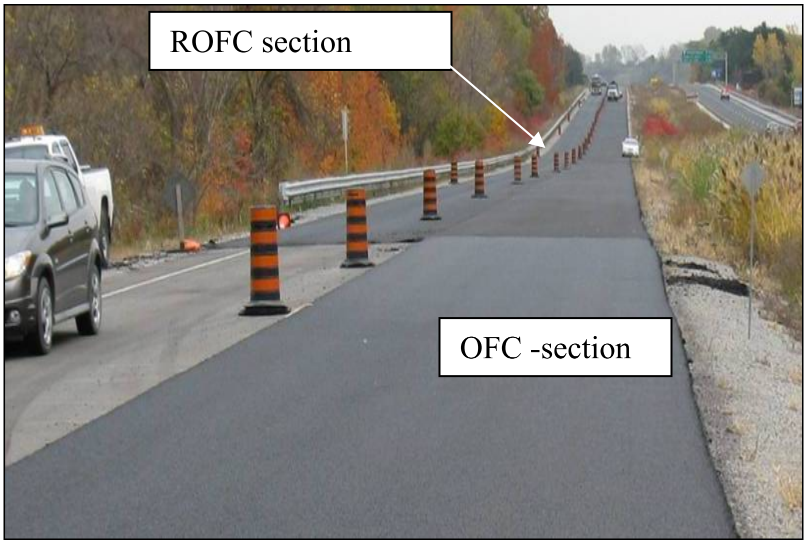


Figure 5 - ROFC/OFC test sections; ROFC appears darker due to rubber content

Inclusion of rubber in the ROFC gave it a darker appearance that made it clearly distinguishable from the adjacent sections (Figure 5).). Crumb rubber was supplied in 23 kg bags. The contractor utilized man power in the asphalt plant to manually feed the rubber into the pug mill.

Figure 6 - Pick up of OFC asphalt mix during compaction

Fibre was also fed manually. An elevated mix temperature was noted occasionally due to erroneous infrared thermometer readings at the asphalt plant. This resulted in excessive smoke and odour, especially during paving of ROFC, that warranted the crew members to wear masks. Ambient temperature varied from 10 to 16 degrees Celsius. Hauling trucks were covered with tarpaulins to avoid rapid cooling of the mix. Minor asphalt pickup occurred during compaction, mainly due to the use of fibre (Figure 6).

Rubber Modification Process

A semi-wet process was used to incorporate crumb rubber into the hot mix asphalt. This process involves an ultrafine rubber powder (passing 600 μm sieve) added to the heated aggregate before addition of the asphalt cement. The mixing time is slightly longer than the normal hot mix production and the rubber application rate is one percent by mass of the mix. Semi-wet process will generate some reaction between the crumb rubber and the asphalt cement which results in partially modified asphalt cement. In other words, in the semi-wet process, some of the rubber will modify the asphalt cement while some will remain unchanged in the asphalt.

Crumb Rubber Type

A cryogenic ground crumb rubber was used in this project. Cryogenic grinding is a process that uses liquid nitrogen to freeze the scrap tire rubber until it becomes brittle and then uses a hammer mill to shatter the frozen rubber into smooth particles with relatively less surface area. Figure 7 shows a microscopic view of the rubber particles used in this study. Particles range in size from 0.10 mm to 1.0 mm. Conchoidal to plumose fracture patterns present on many surfaces. Clear flexible synthetic fibres (1-3 mm long) and glassy to yellow glassy silicate particles are also present.

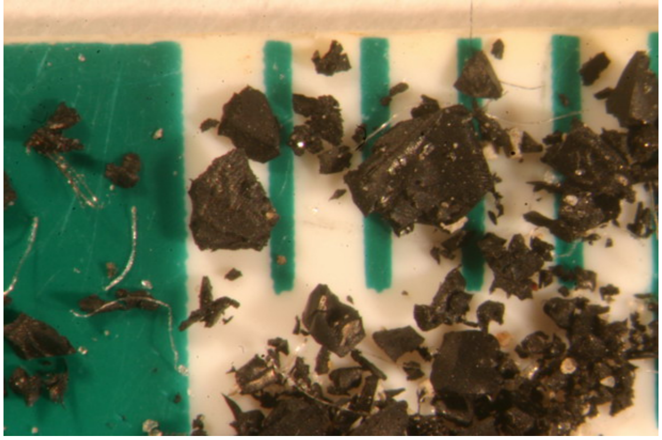


Figure 7 - Cryogenically ground crumb rubber particles

Quality Control (QC)/Quality Assurance (QA) Results

In general, QC/QA results were in agreement with the JMF. Some variations from the JMF were observed in the QA samples but they were not found to be significant enough to necessitate remedial action.

Thermal Imaging

An infrared thermography camera was used to obtain thermal images from the surface of the pavement and to detect thermal segregations. In this study, thermally-segregated mix was defined as an area of the hot mix surface that had a temperature that was different than the surrounding areas by at least 10 ^{o}C. Review of thermal images indicated slight thermal segregation in some areas mostly in a form of longitudinal (streak) of thermal segregation. Using the thermal camera, cooling rate of OGFC was reviewed at one location. It was observed that the mat temperature dropped from 110 to 95 ^{o}C in 5 minutes (i.e., 3 ^{o}C per minute). Figure 8 depicts thermal images taken during construction of OFC and ROFC.

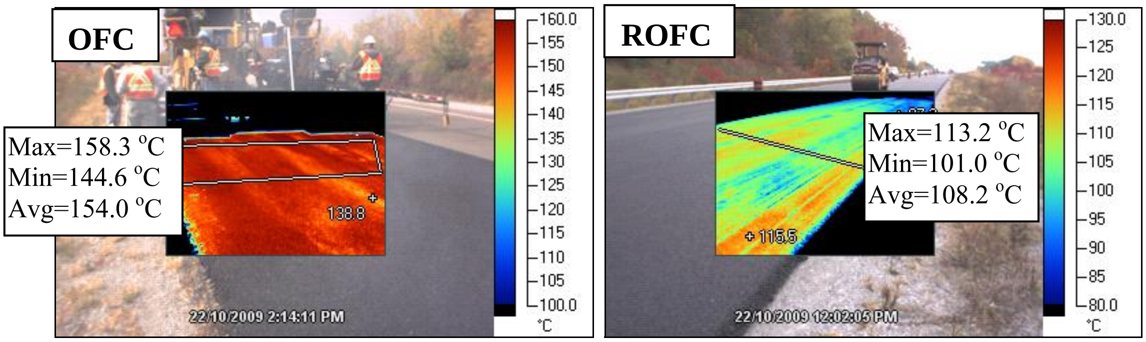


Figure 8 - Thermal images of surface course mixes

NOISE MEASUREMENTS

Acoustical testing of the test sections built on Hwy 405 was carried out on December 2009 by the consultant, Howe Gastmeier Chapnik (HGC) Engineering Ltd, using the proposed On-Board Sound Intensity (OSBI) method of test described in the National Cooperative Highway Research Program (NCHRP) Report 630 [10]. This method includes some modifications to AASHTO Designation Standard TP076-08, Provisional Standard Test Method for the Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method. This test method provides procedures to measure tire pavement noise very near the source in isolation from other vehicle noises. The specified standard test tire was used in the experiment to compare noise measurements taken across different pavement types. The test vehicle consisted of a front wheel drive 2004 Chevrolet Venture van mounted with Uniroyal TigerPaw tire at the rear axle. This tire was as close as could be found locally to the standard Reference Test Tire (SRTT). The tests were conducted at the recommended cold tire pressure of 30 psi.

The sound measurements were taken using a Hewlett Packard model 3569A Real Time Frequency Analyzer, connected to a sound intensity probe consisting of two 12. 5 mm (½”) phased matched condenser microphones installed on two 12.5 mm (1⁄2″) microphone preamplifiers, set apart by 16 mm by a fixture mounted to the vehicle as shown in Figure 9. The probe was positioned at the trailing edge or leading edge of the tire contact patch as required by the standard and covered with a spherical foam to protect from air flow during testing. Calibration of the system was performed before and after testing.

The tests were first carried out with the probe positioned at the leading edge and the data was taken first every ½ a second during testing for each 500 m section at three different speeds, 60kph, 80kph, and 100 kph and the sound intensity levels were measured in 1/3 octave bands. All five test sections were tested simultaneously, by driving the vehicle across the test area. Multiple passes were undertaken for each speed to obtain at least 2 valid measurements per test section. This procedure was repeated with the probe located at the trailing edge of the tire contact patch.

Figure 9 - Sound intensity probe mounted on test vehicle at leading edge of tire contact patch

Data Quality

Experience shows that data are usually contaminated with flow noise, such as ambient environmental noise and wind noise, when OBSI measurements are made in flow. The Pressure-Intensity Index (P-I) is used to assess the quality of the data. P-I is defined as the linear average of the sound pressure level minus the sound intensity (SI) level to provide an index of the accuracy of a sound intensity measurement. In other words, the measured sound intensity levels using the sound intensity probe were compared with the levels derived from sound-pressure measurements from a single standard microphone for all 1/3 octave bands from 400 to 4,000 Hz. The lower the P-I the better the quality. Generally, if the P-I index is above 5 dB, the measurement is considered contaminated by flow noise [10]. The result showed that PI was less than 5 dB for 92% and 93 % of the time for the leading edge and the trailing edge respectively, implying the quality of the data collected was good.

ANALYSIS OF NOISE DATA

The A-weighted frequency spectrum of the sound intensity (SI) measured for each pavement type at different speeds is shown in Table 5. An interesting observation is that the average difference in noise level between the leading edge and the trailing edge as seen in Column 6 of Table 5 was between 2-3 dBA, particularly when the speed was less than 80 kph, for all pavement types except for the control section, where the difference was less than 1 dBA. This observation is quite consistent with the expected outcome based on the sound absorption theory discussed before. The theory postulated that the noise recorded at the trailing edge of the tire would be less than the one recorded at the leading edge for porous asphalt pavements as a result of sound dissipation through the existing pores in the pavement layer when the air was compressed at the tire contact area ahead of the trailing edge. This difference in the noise level decreases with speed probably due to the decrease in volume of air or sound dissipation associated with the decrease in the tire-pavement contact duration when the speed increases.

Table 5 - Average measured sound intensity level

Pavement Type (1)	Sound Intensity Level, dBA					
	Speed, kph (2)	**Leading Edge** (3)	**Trailing Edge** (4)	**Average** (5)	**Difference** (6) =(3-4)	**Average Difference** (7)
Pavement A	60	90.2	86.8	88.9	3.4	2.53
	80	93.6	91	92.5	2.6	
	100	96.1	94.5	95.4	1.6	
Pavement B	60	94.3	91.6	93	2.7	2.50
	80	96.9	94.1	95.8	2.8	
	100	98.9	96.9	98	2	
Pavement C	60	92.1	89.6	91	2.5	2.37
	80	94.5	91.9	93.4	2.6	
	100	97	95	96.1	2	
Pavement D	60	92.4	90.1	91.4	2.3	2.33
	80	95.5	93	94.5	2.5	
	100	98	95.8	97.1	2.2	
Pavement E	60	93.3	92.6	93	0.7	0.37
	80	97.3	96.8	97.1	0.5	
	100	99.8	99.9	99.9	-0.1	

Note: Column 6 gives the SI difference between the leading edge and trailing edge for each speed and column 7 gives the average SI difference.

Variation of Sound Intensity with Speed and Pavement Types

The results shown in Column 5 of Table 1 indicate that the SI level increases with speed as expected regardless of the pavement type. More specifically, SI generated at the tire-pavement interface on pavement Section A containing double open-graded layers was consistently the lowest at all speeds followed by single rubberized open graded mix (Pavements C), SMA (Pavement D), single open grade mix (Pavement B) and the control section E respectively. In general, these results were anticipated with the exception of Pavement B which was expected to be quieter than Pavement E. For example, at 60 kph, the average SI level of 93 dBA corresponding to single open graded mix (Section B) is almost identical to the average SI level of 93.1 dBA observed for the control Section E. More tests will carried out to validate this observation.

Table 6 - Noise reduction of different pavement types in comparison to Pavement E

Pavement Type	A			B			C			D		
Speed, kph	60	80	100	60	80	100	60	80	100	60	80	100
Average Noise Reduction, dBA	4.1	4.6	4.5	0	1.3	1.6	2	3.7	3.8	1.6	2.6	2.8

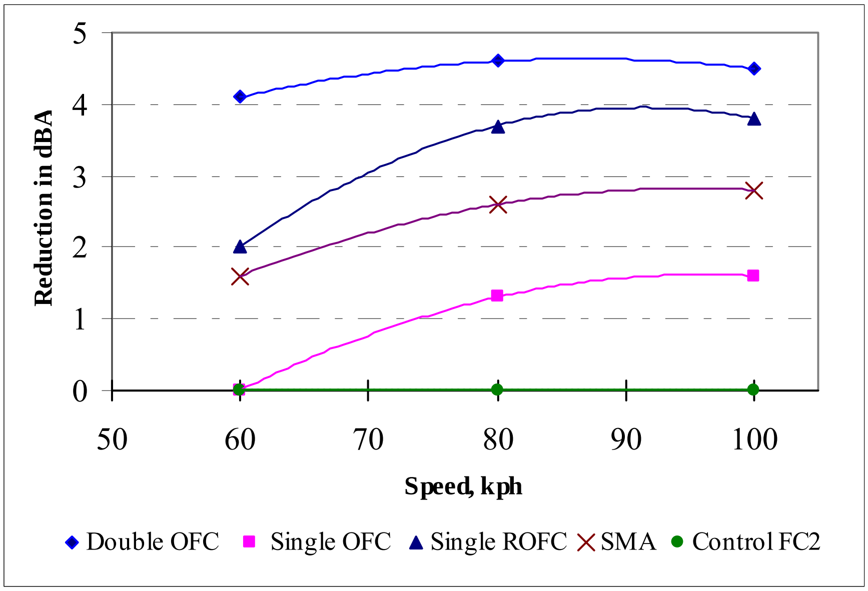


Figure 10 – Noise reduction for each pavement test section

Comparison of Noise Reduction

Using the noise test results shown in Table 5, the noise reduction, which is the difference in noise level between the control Section E and the relevant quiet pavement section, was calculated as shown in Table 6. The results show that the maximum noise reduction of 4.6 dBA was observed at 80 kph for the double open graded mix (Section A). The noise reduction at 100 kph is 4.5 dBA, which is slightly less than the reduction observed at 80 kph. In general, the reduction in noise levels at 80 kph and 100 kph are almost the same. This observation is further illustrated in Figure 10. The highest level of reduction is seen in the double layer OFC pavement Section A in comparison to the control section at all speeds.

PAVEMENT TEXTURE/POROSITY MEASUREMENTS

In order to assess the influence of pavement porosity on noise reduction, an in-situ test using an outflow meter was conducted in accordance with ASTM E2380-05 procedure.

Figure 11 Outflow Meter (ASTM E2380)

The outflow meter is a transparent vertical cylinder fitted with a valve at the bottom that rests on a rubber annulus placed on the pavement surface at the desired location as shown in Figure 11. Prior to testing, the valve was closed and the cylinder was filled with water. The test was initiated by opening the valve to allow the water flow through the pavement voids under gravity. The cylinder is equipped with an electronic timer which measures the time in seconds for the water level to fall from an upper electrode to a lower electrode when the valve is opened. The outflow time provides a measure of permeability which is a surrogate for porosity. It is expected that the time taken for the water to flow will be relatively short for open-graded mix in comparison to dense-graded mix. In other words, the shorter the outflow time, the higher the permeability or porosity. The test was performed in two ways: non-standard sealed test and the standard unsealed test. When the non-standard test method was used, the rubber ring's perimeter was sealed using plumber's putty to provide a water tight contact between the pavement surface and the bottom surface of the outflow meter.

Table 7 – Results of Pavement Texture Measurements using Outflow Meter

Test Section	Average Outflow Time (sec)	
	Unsealed	Sealed
A	1.8	7.5
B	2.0	10.5
C	2.5	12.5
D	3.0	22.5
E	11.5	Impermeable (Assigned 100)

In this case, the test result is expected to provide a measure of the pavement permeability associated largely with voids within the asphalt layer.

When testing was carried out without sealing the rubber annulus as per the standard ASTM procedure, the water flowed freely through both the pavement voids in the subsurface as well as the voids between the rubber annulus and the pavement surface. The tests were repeated four times for every test section and the average test results are shown in Table 7. As expected, the results indicate that the higher the permeability (smaller the outflow time), the lower the noise generation at the pavement-tire interface except for pavement Section B. The shortest outflow time corresponds to the double layered OFC mix and longest time corresponds to the dense-graded SP12.5FC2 mix.

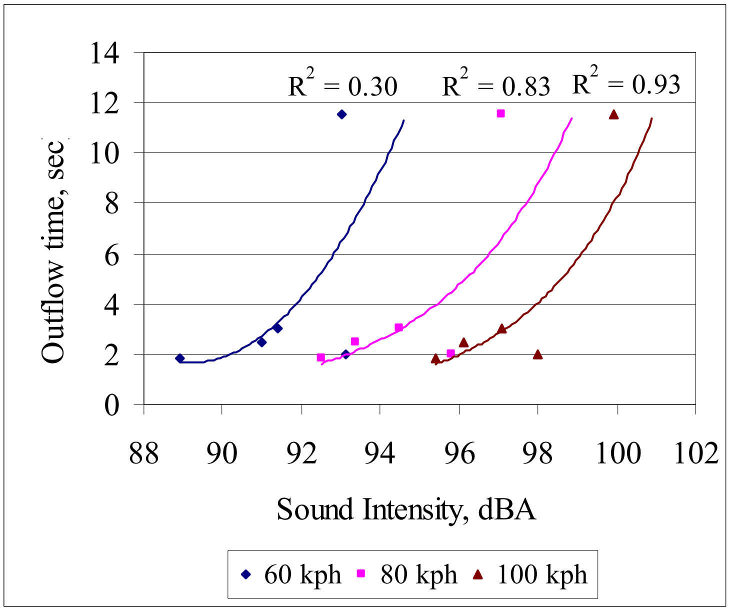


Figure 12 – Unsealed outflow time vs. Sound intensity

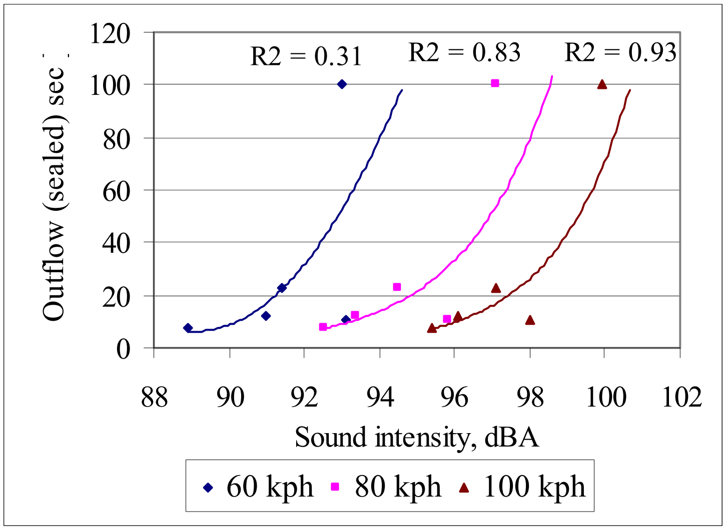


Figure 13 – Sealed outflow time vs. Sound intensity

Further, the correlation between the outflow time based on the standard test and the sound intensity measurements at different speeds was examined using a regression analysis as shown in Figure 12. As can be seen, the strength of correlation is weak at 60 kph and improves steadily as speed increases as indicated by the coefficient of correlation (R^2 = 0.3 to 0.93). Similar observation was found with non standard test results as well (Figure 13). It appears that the variation associated with the noise measurement observed for pavement Section B at 60 kph has contributed to the weak correlation at 60 kph. As such, the noise observation for pavement Section B is identified as an outlier in this case. Subsequently, additional regression analysis was carried out without the outlier as shown in Figures 14 &15.

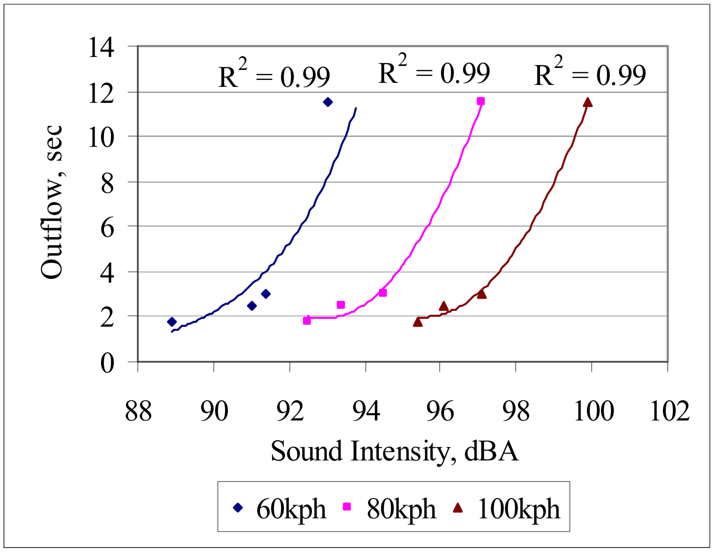


Figure 14 – Unsealed outflow time vs. Sound intensity without the outlier

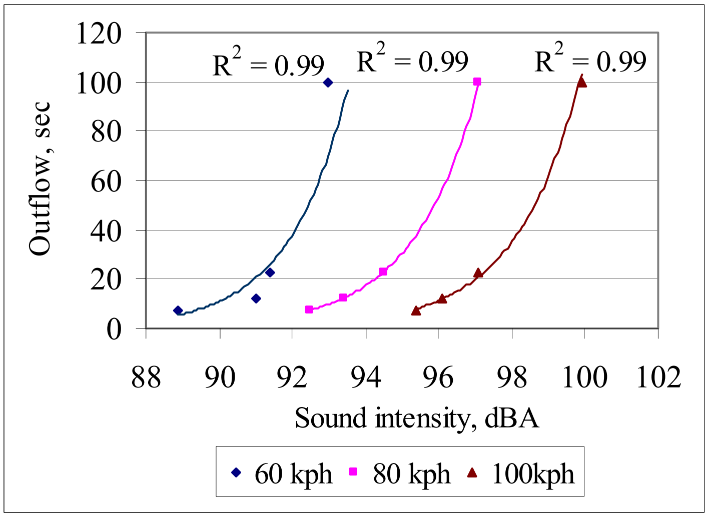


Figure 15 – Sealed outflow time vs. Sound intensity without the outlier

The results of both the standard and non standard outflow meter tests show that R^2 values improved significantly for all speeds in the absence of outlier. The noise tests will be repeated this summer to verify the findings of the results of this analysis.

SUMMARY AND CONCLUSIONS

This paper summarizes the results of the tire-pavement noise measurements taken using the OBSI method soon after the construction of five trial sections with five different mix types. All the test sections were measured simultaneously by driving the vehicle across the test area at three different speeds, 60 km/h, 80 km/h, and 100 km/h. The results show that a double layer open graded mix was consistently the quietest at all speeds followed by a single layer rubberized open-graded mix, SMA, single layer open-graded mix and the control section, respectively. As well, the results also indicate that the rubberized asphalt layer contributes to a reduction of at least 2 dBA as compared to the conventional single open-graded mix supporting the claim that crumb rubber has the potential to absorb the noise.

A surrogate in-situ pavement porosity was measured using an outflow meter. In general, the measured outflow time showed a good correlation with the noise data except for Section B where the noise reduction observed at 60 kph was not compatible with the outflow time. These test sections will be monitored annually to investigate the observed abnormally of the noise measurements on pavement Section B and the potential clogging of the voids in time and its effect on pavement noise level.

In summary, based on the initial test results of noise and flow meter measurements, the following conclusions are drawn:

- A double layer open-graded mix has the noise reduction potential for use as one of the alternatives to noise barriers for reducing noise level from freeways.
- The noise reduction potential of open-graded mix could be further enhanced by the use of rubberized asphalt binder.
- The use of SMA 9.5 mix has an advantage of reducing the noise level in addition to other benefits such as long-term performance in comparison to the dense-graded mix.
- The permeability measurement using the outflow meter based on ASTM E2380 test procedure provided a good indicator of the porosity of the pavement test sections.
- Good correlation exists between the pavement permeability determined by outflow meter and the noise level measured using the OBSI method.

NEXT STEPS

These test sections will be monitored annually to determine the long-term performance of quiet pavements in terms of noise reduction as well as serviceability. Future activities will include: tire/pavement noise measurement, assessment of permeability using outflow meter, porosity tests using cored samples from the field, roughness and friction measurements, and manual pavement condition survey.

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