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Long term acoustic performance of different asphalt configurations

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ABSTRACT
VicRoads (now Victoria's Department of Transport) and Vipac Engineers & Scientists have been conducting a long-term asphalt noise trial since early 2013. Noise levels for five different asphalt configurations have been measured using the Close Proximity Method and On-Board Sound Intensity Method. One of the trial sections is an Open Graded Asphalt (OGA) initially treated by horizontal grinding of the top 1 to 2 mm of the surface, resulting in a smooth, negative texture. Early tests have shown that the overall noise levels for this section were consistently lower than those for the standard OGA by up to 3 dB. The acoustic performance of the pavements over a period of nearly six years is presented.

1 INTRODUCTION
It is well established that traffic noise is largely produced by the interaction of vehicle tyres with road surfaces when passenger cars are travelling over about 30 km/h or when trucks are travelling over about 80 km/h (Beckenbauer 2013). This leads to the conclusion that there is potential to reduce traffic noise by changes to tyre or road surface properties, of which the latter falls within the sphere of control of road management authorities. It is also well established that porous road surfaces such as open graded asphalt (OGA) can result in lower noise levels than dense surfaces, but that they lose this advantage over a period of years due to loss of porosity (Sandberg and Ejsmont 2002). The challenge for road managers is to reduce noise over the longer term.

In 2013, VicRoads, the government authority responsible for managing the road network in the Australian State of Victoria commenced a long-term trial of potential low noise asphalts. This paper presents the results of eight tranches of noise measurements of the trial pavements from November 2013 to January 2019.

2 TRIAL PAVEMENTS
A total of seven asphalts were tested on a section of the Mornington Peninsula Freeway in McCrae, Victoria. The results of only five of the test pavements are reported here as the remaining two pavements were of confidential proprietary mixes. The trial pavements are listed in Table 1. Further detail on the specification of the asphalts can be found in (Simpson, et al. 2014).

Table 1: Test asphalts

Section	Type of asphalt	Length
1	Size 10mm OGA 30mm thick	200m
2	Size 10mm OGA 30mm thick with top 1mm ground off	100m
3	Size 10mm OGA 30mm thick over 14mm OGA 40mm thick	150m
4	Size 10mm OGA 35mm thick over 10mm OGA 30mm thick	150m
5	10mm Stone Mastic Asphalt (SMA)	150m

Section 2 was originally laid as part of Section 1. Its top one millimetre (approximately) was subsequently ground off using a horizontal plane rotary diamond grinding machine with rotor diameter of approximately 50cm. The machine was mounted on the front of a truck which would drive slowly along the road as the grinding machine operated. The machine sprayed water onto the surface as it was grinding, to prevent excessive heat build-up, and a vacuum system collected the contaminated waste water from the grinding process. This grinding process is different from the diamond grinding process commonly used for Portland cement roads that use blades rotating in a vertical plane to create grooves in the road surface.

The grinding machine is shown in Figure 1 and detail of the rotor and a cutting element are shown in Figure 2.

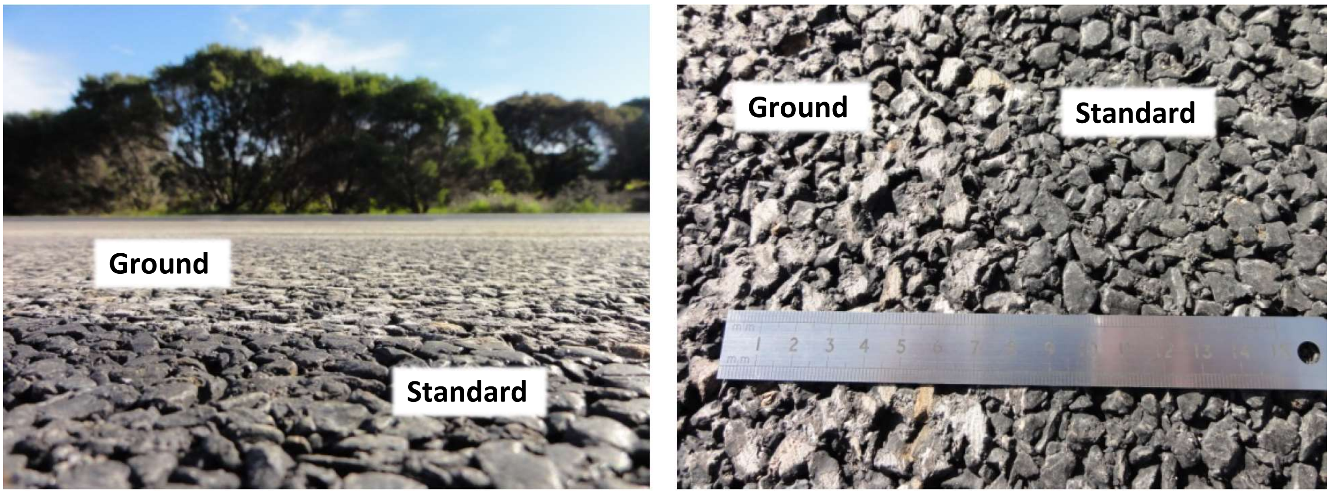
(Source: J McIntosh 2013)

Figure 1: Grinding machine

(Source: J McIntosh, 2013)

Figure 2: Detail of grinding rotor

Figure 3 shows detail of the standard and ground OGAs immediately after the grinding was completed.



(Source: S. Samuels, 2013)

Figure 3: Detail of standard and ground OGA

Texture depths of the pavements were recorded at three stages during the trial using a Multi-Laser Profilometer. Texture depths in the left wheel track of the left lane are shown in Table 2. Texture depths in excess of 1.5 mm are considered to be high (VicRoads 2013). More detail on the tested pavements can be found in (Simpson, et al. 2014).

Table 2: Texture depth (mm)

Section	Jun 2014	Jun 2016	March 2019
1	2.4	1.7	1.5
2	2.3	1.8	1.4
3	2.5	1.8	1.4
4	2.5	1.8	1.5
5	2.1	1.3	1.4

3 MEASUREMENT METHODS

Early in the trial, noise measurements were made using the following methods:

- Statistical Pass-by Method (SPB) in accordance to ISO 11819-1 (ISO 1997)
- Close Proximity Method (CPX) in accordance to ISO/DIS 11819-2 (ISO 2012)
- On-Board Sound Intensity (OBSI) in accordance to AASHTO TP76-12 (AASHTO 2012)

Both CPX and early OBSI measurements were conducted using an enclosed trailer constructed in accordance to the requirements ISO/DIS 11819-2 (2012) and AASHTO TP 76-12 which were the draft reference standards at the start of the trial. The measurement setup and methodology of the ISO CPX standard remains unchanged in the current version (ISO 2017a).

Early CPX and OBSI measurements were conducted simultaneously and not surprisingly were strongly correlated with a coefficient of determination, $R^2 = 0.818$. CPX measurements show a better correlation with the statistical pass-by levels ($R^2 = 0.655$) than the OBSI measurements ($R^2 = 0.382$) (Buret, McIntosh and Simpson 2016). For this reason, as well as for safety and practicality concerns regarding SPB, recent measurements have been restricted to the CPX method. Consequently, this paper presents only CPX results.

All testing was conducted with both a Michelin/Uniroyal 225/690-R16 Standard Reference Test Tyre (SRTT) and an Avon 195-R14C Supervan AV4 light truck tyre (AV4), subsequently defined in ISO/TS 11819-3 (ISO 2017b). While the SRTT is deemed representative of a typical passenger car tyre, the AV4 has been identified as being acoustically representative of a truck tyre whilst being a convenient size for testing. (Morgan, Sandberg and van Blokland 2009).

(Source: ISO 2017b)

Figure 4: Test tyres: SRTT left, AV4 right

The same two tyres were used for all but the final test and were stored in a refrigerated warehouse between tests. Due to the risk of the tyres deteriorating over time, a new pair of tyres were purchased and used for the most recent test and will be used for any more tests in the near future.

All noise levels reported in this paper are corrected to a temperature of 20°C in accordance to standards ISO 11819-2: 2017 and ISO 13471-1: 2017 (ISO 2017c). Note that results we have previously published in (Simpson, et al. 2014) (Buret, McIntosh and Simpson 2016) (Buret, McIntosh and Simpson 2017) were corrected in accordance to the earlier ISO 11819-2: 2012.

It was noted in (Buret, McIntosh and Simpson 2017) that the ISO standards had at that time recently been finalised with revised corrections for temperature effects and that the data collected up to that time should be re-analysed with the new corrections. This has been done in the current paper.

All tests were conducted with a nominal vehicle speed of 100 km/h. For most tests, ten runs were conducted (only nine runs for the tenth test). For each run, the test vehicle was driven over all test surfaces in a single run with sound pressure level (SPL) and vehicle latitude and longitude recorded simultaneously. The recorded data was post processed to extract CPX levels from each section of test pavement.

All testing reported in this paper was conducted in the left (slow) lane.

4 ESTIMATION OF UNCERTAINTIES

For absolute CPX levels, 95% confidence intervals were determined taking account of Type A and Type B uncertainties as defined in the ISO GUM (JCGM 2008).

Type A uncertainties were estimated from the standard deviations of the ten repeats of each measurement using a t test statistic to determine the confidence intervals.

Type B uncertainties were simply taken from the relevant standards as tabulated below (all with coverage factors of two). These are presented in Table 3. The Total Type B uncertainties were calculated from the square root of the sum of the squares of the component uncertainties. They represent inherent uncertainties related to equipment and the like, as distinct from random variation from measurement to measurement.

Table 3: Type B uncertainties (dB)

Error Source	Expanded Uncertainty SRTT	Expanded Uncertainty AV4	Reference standard
SPL Measurement	1.4	1.4	AS IEC 61672.1: 2019
Speed Variations etc	0.2	0.2	ISO 11819-2: 2017
Environmental conditions	0.3	0.3	ISO 11819-2: 2017
External background noise	0.1	0.1	ISO 11819-2: 2017
Vehicle background noise	0.2	0.2	ISO 11819-2: 2017
Tyre related	0.6	1.0	ISO/TS 11819-3: 2017
Temperature related	0.25	0.3	ISO/TS 13471: 2017
Total Type B	1.6	1.8	

For estimates of differences in CPX levels for different pavements, Type B uncertainties were ignored on the basis that they would apply equally to the two pavements being compared in the same test runs.

For the assessment of differences in CPX levels reported in Section 5.2, 95% confidence intervals were calculated from the recorded standard deviations of the test measurements using the *tsum.test()* method of the R BSDA statistical package (Arnholt n.d.). This method of calculation assumes that the measurements of different pavements are independent and are not paired. This assumption is not valid because each test consisted of several measurement runs with all pavements measured in each run, meaning that for the purpose of comparing two pavements, the measurements are in fact paired (Cumming 2011).

However, we assume that random variation in measurements between pavements are positively correlated within individual runs. That is to say, if on the first run of the day, the measured level on the first pavement is higher than the average of all the day's runs, then the measured level on the second pavement also on the first run of the day is more likely than not higher than the average or all the day's runs. Based on this reasonable assumption, the calculated confidence intervals for the differences between pavements are over-sized and consequently conservative.

5 RESULTS

5.1 Long term trends

Overall A-weighted CPX levels (corrected for temperature as specified in ISO 11819-2: 2017) for each pavement and for each test are shown for the SRTT Tyre in Table 4 and for the AV4 Tyre in Table 5. They are also plotted in Figure 5. One third octave spectra for all tests are presented in Figure 5. Note that the error bars in all graphs represent 95% confidence intervals.

Table 4: Long term performance with SRTT Tyre (Overall A-weighted CPX level, dBA);

95% confidence intervals in brackets

	1-OGA Standard	2-OGA Ground	3-OGA 10 + 14mm	4-OGA 10 + 10mm	5-SMA
Jun-2013	99.9 [98.3, 101.6]	97.4 [95.8, 99.1]	99.0 [97.4, 100.7]	99.6 [98, 101.3]	102.9 [101.3, 104.5]
Nov-2013	100.5 [98.9, 102.2]	97.7 [96.1, 99.3]	98.6 [97, 100.3]	98.8 [97.2, 100.5]	101.4 [99.8, 103.1]
May-2014	101.7 [100.1, 103.3]	99.3 [97.7, 100.9]	99.9 [98.3, 101.5]	99.9 [98.3, 101.5]	103.2 [101.5, 104.8]
Nov-2014	101.2 [99.6, 102.9]	98.2 [96.6, 99.9]	100.0 [98.4, 101.7]	99.3 [97.7, 101]	101.8 [100.1, 103.4]
Mar-2015	102.1 [100.5, 103.7]	99.3 [97.7, 100.9]	100.8 [99.1, 102.4]	100.0 [98.3, 101.6]	102.3 [100.7, 103.9]
Nov-2015	101.7 [100.1, 103.3]	98.6 [97, 100.2]	100.7 [99.1, 102.3]	99.9 [98.3, 101.5]	102.2 [100.6, 103.8]
Nov-2016	102.1 [100.5, 103.7]	98.8 [97.2, 100.4]	101.2 [99.6, 102.8]	100.9 [99.2, 102.5]	101.9 [100.3, 103.5]
Mar-2017	101.7 [100.1, 103.3]	98.3 [96.6, 99.9]	100.8 [99.1, 102.4]	100.6 [99, 102.2]	101.5 [99.9, 103.1]
Jan-2019	102.0 [100.4, 103.7]	99.2 [97.5, 100.8]	101.3 [99.7, 102.9]	101.5 [99.8, 103.1]	102.2 [100.6, 103.9]

Table 5: Long term performance with AV4 tyre (Overall A-weighted CPX level, dBA);
95% confidence intervals in brackets

Test Dates	1-OGA Standard	2-OGA Ground	3-OGA 10 + 14mm	4-OGA 10 + 10mm	5-SMA
Jun-2013	99.4 [97.5, 101.2]	97.6 [95.7, 99.4]	98.7 [96.8, 100.5]	99.3 [97.4, 101.1]	101.4 [99.5, 103.2]
Nov-2013	98.9 [97, 100.8]	96.9 [95.1, 98.7]	97.4 [95.5, 99.3]	97.7 [95.9, 99.5]	99.7 [97.8, 101.5]
May-2014	100.3 [98.5, 102.1]	98.3 [96.5, 100.1]	98.8 [97, 100.6]	99.2 [97.4, 101]	101.4 [99.6, 103.2]
Mar-2015	100.2 [98.3, 102]	98.1 [96.2, 99.9]	99.3 [97.4, 101.1]	98.9 [97, 100.7]	100.6 [98.8, 102.5]
Nov-2015	100.4 [98.5, 102.2]	97.8 [95.9, 99.6]	99.5 [97.6, 101.3]	99.3 [97.4, 101.1]	100.9 [99, 102.7]
Nov-2016	100.0 [98.2, 101.9]	97.8 [96, 99.7]	99.0 [97.2, 100.9]	99.2 [97.4, 101.1]	100.0 [98.2, 101.8]
Mar-2017	99.5 [97.7, 101.4]	97.3 [95.5, 99.2]	98.6 [96.8, 100.4]	99.0 [97.2, 100.8]	99.6 [97.8, 101.4]
Jan-2019	101.8 [100, 103.6]	100.0 [98.1, 101.8]	101.4 [99.5, 103.2]	101.0 [99.2, 102.8]	102.0 [100.2, 103.8]

Figure 5: Long term performance (Overall A-weighted CPX level, dBA) over five years

The data indicates a 0.7 dB increase in noise from the SMA for the SRTT tyre and a 0.6 dB decrease for the AV4 passenger car tyre of the duration of the trial. These changes are well within the confidence intervals and we consider them insignificant. They confirm the ability of SMA to retain its acoustical performance over an extended time.

The standard open graded asphalt increased steadily in noise level with both tyres, reaching the level of the SMA by the time of the November 2016 test when it was three and a half years old. This is consistent with the conventional wisdom that the acoustical benefit of OGA only lasts a few years.

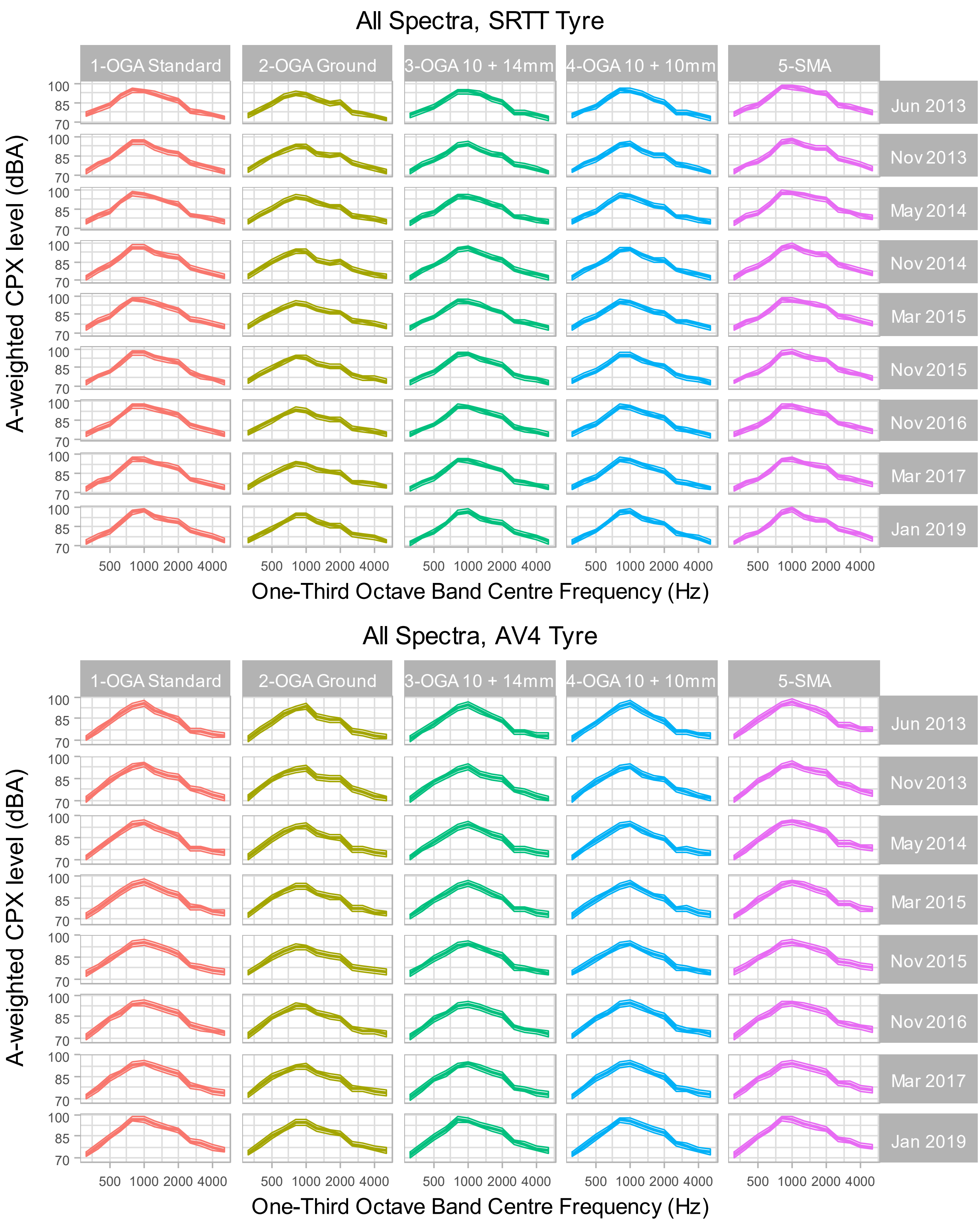


Figure 6: One-third octave spectra (A-weighted CPX level), SRTT and AV4 tyres

Both double layer OGAs showed improved long term performance compared to the standard OGA, and were still about half to one decibel below the level of the SMA in the final test for both tyres. Note that we expect SMA to be about one decibel quiteter than dense graded asphalt which is the nominal standard pavement used in Australian traffic noise modelling (VicRoads 2010).

Of greater interest, the ground OGA performed better than any of the other pavements for the duration of the test program. This is examined in more detail in Section 5.2.

5.2 Performance of ground asphalt

As shown in Figure 5, the ground OGA remained quieter than the other asphalts for the duration of the trial for both tyres. In the most recent test, the ground OGA showed a three-decibel reduction in overall A-weighted CPX level relative to the SMA when tested with the SRTT tyre. The improvement was two decibels when tested with the AV4 tyre. This is a remarkable result.

We compared the one-third octave CPX levels of the standard OGA and the ground OGA for each test as shown in Figure 7. It is apparent that the ground asphalt exhibited substantially lower CPX levels in the 1000 Hz to 1600 Hz bands for both tyres and in the 800 Hz band for the SRTT compared to the standard OGA. However, CPX levels were slightly increased at lower frequencies.

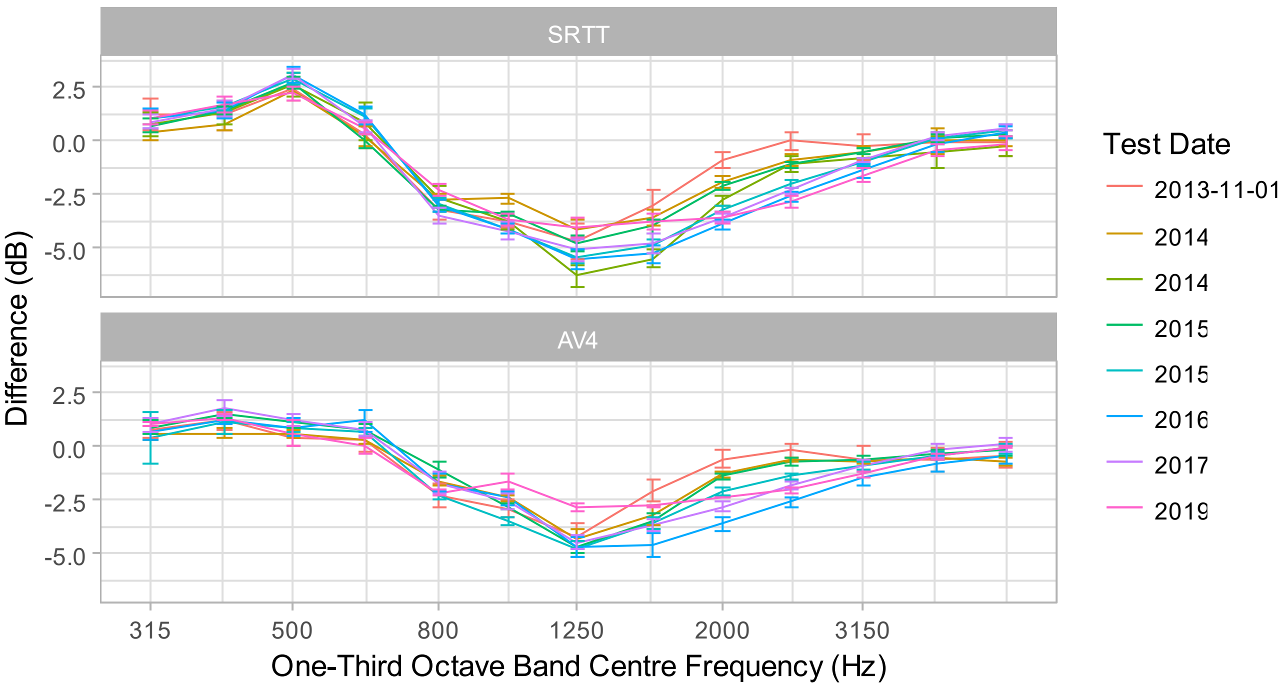
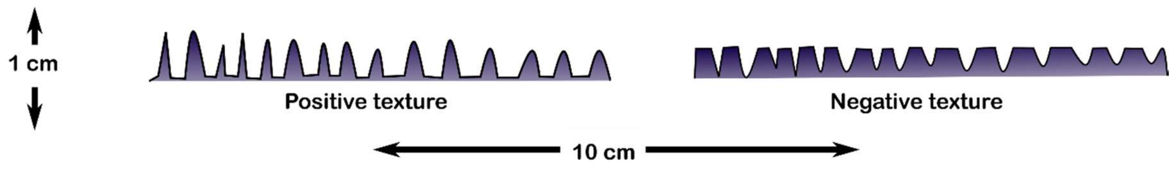


Figure 7: Effect of grinding: CPX levels for the ground OGA subtracted from the standard OGA levels (a negative value represents a reduction in noise levels attributable to the grinding treatment)

For a vehicle travelling at 100 km/h, the 1000 Hz and 1600 Hz frequencies relate to distance travelled of 17 mm and 28 mm per cycle of sound emission. These distances are roughly equal the tread pitches of the test tyres and are similar or slightly greater than the asphalt aggregate size as shown in Figure 3. The differences in the noise levels in these bands may be attributable to a range of mechanisms associated with aggregate and tread size, including tyre impact and air pumping (Sandberg and Ejsmont 2002).

The objective of the grinding process was to provide an improved compromise between the road surface being porous to reduce air pumping effects and increase sound absorption on one hand and to reduce the roughness of the road surface on the other hand. By grinding roughly one millimetre off the top of the aggregate, we aimed to make the texture more negative as shown illustratively in Figure 8. Individual stones should present a more consistent impact with the approaching tyre rather than some being higher than others, reducing the maximum impact forces and consequently reducing tyre vibration.



(Source (PIARC Technical Committee E3 Forthcoming))

Figure 8: Positive and negative texture (schematic)

6 DISCUSSION

There appear to be a number of benefits that may arise from grinding asphalt road surfaces. In addition to acoustic performance, our earlier testing indicated that grinding increases skid resistance which is a safety benefit (Simpson, et al. 2014). We understand that grinding reduces skid by removing the relatively slippery bitumen from the top surface of the aggregate and by cutting a fine micro-texture into the aggregate. This can be seen in Figure 3.

Recent research in Sweden investigated the effect of grinding on stone mastic asphalt (Vieira, Sandberg and Erlingsson 2019). They also identified noise reductions of up to three decibels, but at lower frequencies. They found the greatest noise reduction in the range of 250 to 1250 Hz for the SRTT tyre and 250 to 1000 Hz for the AV4 tyre. In addition, they found that grinding reduces tyre rolling resistance by up to 15%. This important result indicates a possibility of reducing vehicle fuel consumption and greenhouse gas emissions by around one or two percent.

Our trial tested a section of ground asphalt only one hundred metres long. At a speed of 100km, the test tyre would be on the test section for not quite four seconds. Even after ten runs with two tyres, we only have a total of about one minute of measurement time for each test. Although we observed good repeatability, such a short measurement time is not ideal.

7 CONCLUSIONS

Our research has demonstrated that grinding open graded asphalt has the potential to reduce traffic noise significantly, and this benefit lasts at least five years. This is a significant finding and suggests that the grinding process adds three years to the acoustical lifetime of OGA. The additional co-benefits of improved skid resistance and reduced rolling resistance suggest that asphalt grinding warrants further investigation.

The cost of asphalt grinding on a large scale is not known but may be considerable. Certainly, the process used for our trial was time consuming which suggests significant cost. However, we note that grinding with a cutter rotating in a vertical plane is well established for Portland cement concrete roads.

Future research on grinding asphalt should give consideration to:

- validating acoustical performance on a larger sample of road,
- attempting to rejuvenate existing open graded asphalt by grinding,
- acoustical improvements of dense graded asphalts or other types of road pavement,
- measurement of rolling resistance, and
- developing a cost-effective large-scale grinding purpose.

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NOTICE

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their employer organisations or agencies.

REFERENCES

AASHTO. 2012. "TP76-12 Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method." Washington: American Association of State Highway and Transportation Officials.

Arnholt, Alan. n.d. *tsum.test.* Accessed September 2, 2019. https://www.rdocumentation.org/packages/BSDA/versions/1.2.0/topics/tsum.test.

Beckenbauer, Thomas. 2013. "Road Traffic Noise." In *Handbook of Engineering Acoustics*, by Gerhard Muller and Michael Moser, 369-370. Berlin: Springer.

Buret, Marc, James McIntosh, and Cassandra Simpson. 2017. "Comparative acoustic performance in the long term of different asphalt configurations." *InterNoise 2017.* Hong Kong.

Buret, Marc, James McIntosh, and Cassandra Simpson. 2016. "Long-Term Asphalt Trial: Results of Acoustic Tests After Three Years." *Acoustics Australia* 273-281.

Cumming, Geoff. 2011. *Understanding the New Statistics.* Melbourne: Routledge.

IEC. 2004. "AE IEC 61672.1 Electroacoustics - Sound level meters Part 1: Specifications." Standards Australia.

ISO. 2012. "Acoustics – Measurement of the influence of road surfaces on traffic." Geneva: ISO.

—. 2017a. "Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 2: The close-proximity method." ISO.

—. 1997. "ISO 11819-1:1997 Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 1 Statistical Pass-By Method." Geneva: ISO.

—. 2012. "ISO/DIS 11819-2 Acoustics – Measurement of the influence of road surfaces on traffic - Part 2: The close-proximity method." ISO.

—. 2017b. "ISO/TS 11819-3 Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 3: Reference tyres." Geneva.

—. 2017c. "ISO/TS 13471-1 Acoustics -- Temperature influence on tyre/road noise measurement -- Part 1: Correction for temperature when testing with the CPX method." Geneva.

JCGM. 2008. "Evaluation of measurement data — Guide to the expression of uncertainty in measurement." Paris: Joint Committee for Guides in Metrology .

Morgan, Phil, Ulf Sandberg, and Gijsjan van Blokland. 2009. "The selection of new reference test tyres for use with the CPX method, to be specified in ISO/TS 11819-3." *InterNoise 2008.* Ottawa.

PIARC Technical Committee E3. Forthcoming. *PIARC Traffic Noise Best Practice Guide.* Paris: PIARC.

Sandberg, Ulf, and Jerzy Ejsmont. 2002. *Tyre/Road Noise Reference Book.* Kisa, Sweden: Informix.

Simpson, Cassandra, James McIntosh, Marc Buret, and Stephen Samuels. 2014. "Asphalt Trials to Reduce Traffic Noise Levels." *26th ARRB Conference - Research driving efficiency.* Sydney: ARRB Group.

VicRoads. 2013. *Code of Practice RC 500.22, Selection and Design of Pavements and Surfacings.* Kew, Victoria: VicRoads.

VicRoads. 2010. *Interpretation and application of VicRoads Traffic Noise Reduction Policy 2005.* Kew, Victoria: VicRoads.

Vieira, Tiago, Ulf Sandberg, and Sigurdur Erlingsson. 2019. "Negative texture, positive for the environment: effects of horizontal grinding of asphalt pavements." *Road Materials and Pavement Design* (Taylor & Francis). doi:10.1080/14680629.2019.1610476.