Improving surfaces for quieter roads

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ABSTRACT

Waka Kotahi has been investigating how to reduce road-traffic noise for over 30 years. For most of this time the focus has been on reducing noise from the tyre/road interaction, which dominates road-traffic noise emission. 10 years ago, NZ's first close-proximity (CPX) noise measurements unexpectedly revealed very high longitudinal variability in the noise emission of porous asphalts on the highway network (± 4 dB). Subsequent investigation has revealed the cause of that variability and offered numerous additional insights into what makes porous asphalt quieter than other surfaces, and how it can be made even quieter. The influences of surface texture, porosity, and thickness on tyre/road noise level have been quantified. Each variable has a different influence on the resulting frequency characteristics of road-traffic noise from porous asphalt. This improved knowledge has enabled the development of optimised "high-performance low-noise" asphalt surfaces that are reliably 4 dB quieter than standard NZ porous asphalt and 11 dB quieter than chipseal.

INTRODUCTION

The main source of road-traffic noise at highway speeds is the interaction between vehicle tyres and the road surface. The type of road surface has a large effect on the level of road-traffic noise emission. Between the current noisiest and quietest surface types used on NZ highways there is an 11 dB range [1], all other factors held constant. Surface selection is therefore the most powerful tool available for a road-controlling authority (RCA) seeking to reduce road-traffic noise.

Over the last 30 years, Waka Kotahi has investigated how the road surface materials and design contribute to road-traffic noise emission, how to quantify the effect of different road surfaces on noise, and how to optimise surface specifications to reduce noise [2]. Over the last 10 years this investigation has been greatly aided through use of vehicle-based systems for making close-proximity (CPX) measurements of tyre/road noise emission. Unlike traditional roadside techniques, CPX allows 20-metre resolution of the road surface, efficiently collected at 80 km/h.

The first CPX survey of NZ porous asphalt on the highway network unexpectedly revealed very high longitudinal variability of noise emission [3]. Along lane lengths as short as one kilometre, variations in the region of ±4 dB have been observed, and until recently could not be explained. Since those first measurements, surface noise research led by Waka Kotahi has focused on (i) identifying the mechanisms causing the existing variability, and (ii) developing new porous asphalt surfaces that are both quieter and more consistent.

This paper summarises key findings from the research and development work towards new quiet asphalt surfaces over the last 5 years. A companion paper [4] describes the broader work undertaken to implement the new surfaces in practice on the state highway.

ROAD SURFACE INFLUENCE ON NOISE

The acoustic quantity that an RCA seeks to minimise is the noise exposure of those living near the road, typically measured in dB $L_{\mathrm{Aeq(24h)}}$, though special characteristics can also be important. Without control over the vehicles and tyres in the fleet, their influence on that noise exposure is largely through manipulating parameters of road surface construction (such as aggregate size, binder properties, etc) and influencing local propagation of sound using noise barriers.

Optimisation of the surface for noise requires a general understanding of the mechanisms through which each important physical surface property affects tyre/road noise, and which properties are not important. Figure 1 is a simplified representation of how we now understand the dependency of road-traffic noise on surface properties to function in a broad sense. From the wayside noise level, it traces down through the different acoustic mechanisms, to the key surface properties that influence them. The bottom row of the figure identifies just a few of the dozens of construction and material parameters that feed into producing porous asphalts with different physical properties, and hence different tyre/road noise emission. The value of any given construction parameter might influence several different relevant properties of the finished surface (or none of them) but rather than attempt to cover that here, that detail is left to the cited research reports.

The following sections of this paper summarise key findings from research undertaken to quantify the relationships (connections) shown in the figure, which has ultimately enabled new quiet asphalt surfaces to be developed.

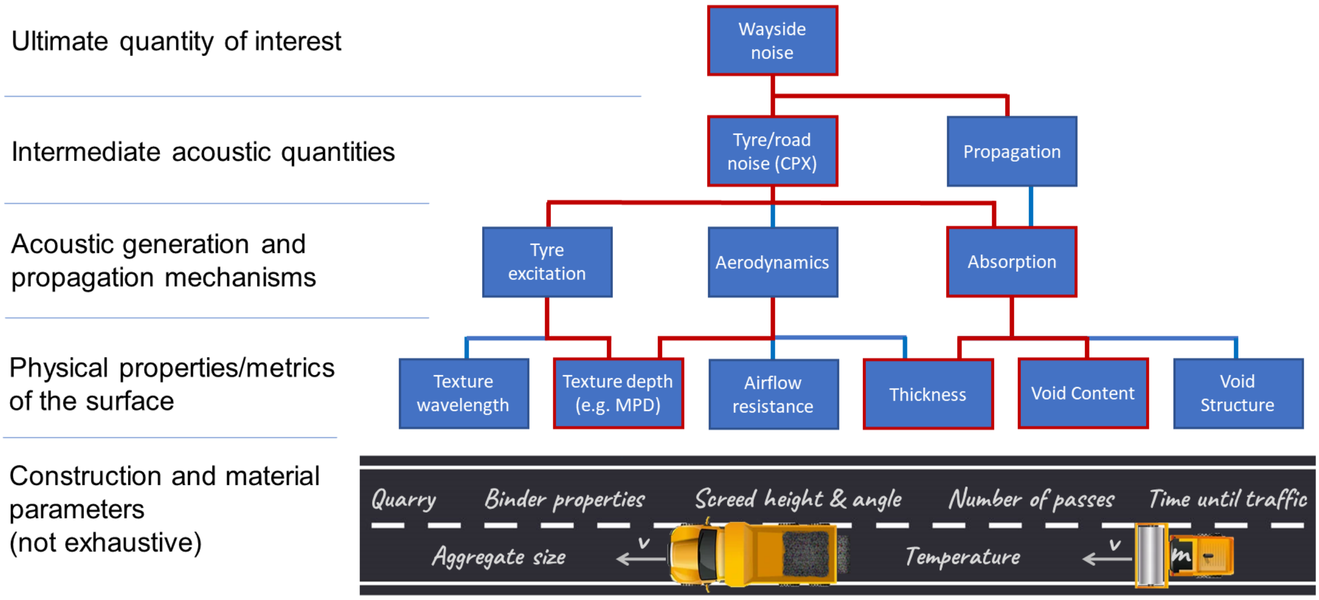

Figure 1: Suggested links from noise level, via acoustic mechanisms, surface properties, to construction and material parameters. Red lines indicate quantified relationships for NZ porous asphalt (omitting the many construction relationships examined).

CPX NOISE MEASUREMENTS

Tyre/road noise measurements, in dB $L_{CPX:P1,80}$, were collected by the Waka Kotahi CPX trailer [5], an ISO 11819-2 compliant measurement system [6]. Several thousand kilometres of state highway were surveyed, with noise data captured at 20-metre resolution. For some specific projects and trial sections, noise and surface parameters (discussed further below) were captured at even higher resolution. The measurements relevant to this paper were mainly made between 2018 and 2024 on Christchurch highway projects WBB, S2G, CNC, CSM2, and on PP2Ō near Wellington.

The relationship between tyre/road (i.e. CPX) and wayside noise levels has been established [7] and is strong but does not fully account for the influence of surface absorption on propagation (Figure 1). Nonetheless it was found that a change in dB $L_{CPX:P1,80}$ due to a different road surface generally results in the same change in dB $L_{Aeq(24h)}$ at the wayside once all factors are considered.

TYRE EXCITATION

The physical excitation of the tyre through its interaction with the road surface is a major source of tyre/road noise across all surface types. The interaction itself and its effect on noise generation via tyre distortion is complex and was not directly studied in our research. Instead the key properties of the surface thought to contribute most to tyre excitation were examined for their influence on $L_{CPX:P1,80}$, the surface macrotexture (texture) depth and wavelength.

Surface texture data were sourced from the annual high-speed data survey of the highway network, and more recently from a laser profilometer fitted to the CPX trailer itself [8] to improve resolution and correlation with the actual path of the CPX tyre.

Texture Depth

Several metrics and envelopment models for quantifying texture depth of porous asphalt were examined. The relatively simple mean profile depth (MPD) was preferred as it showed equivalent performance as a predictor of noise [9] and is already a NZ industry standard metric. A texture depth influence on tyre/road noise level in the region of +0.7 dB $L_{CPX:P1,80}$ per 0.1 millimetre MPD is suggested [8,10], observed across an MPD range from 0.6 mm to 1.5 mm. The effect was not consistent across the spectrum, being driven solely by low frequencies (400 Hz to 1000 Hz).

In terms of construction materials and processes, the strongest influence we identified on surface texture was the aggregate size [8]. Compared to a nominal maximum aggregate size of 10 mm (average MPD=1.17 mm), a 7 mm aggregate (MPD=0.85 mm) was 2 dB quieter, while a 14 mm aggregate (MPD =1.44 mm) was 2 dB noisier.

Currently a 7 mm nominal maximum aggregate size is considered optimal for noise, and is typically also acceptable for road durability and safety requirements.

Texture Wavelength

Initial investigations into surface texture wavelength and noise spectra [8] suggest the presence of a correlation, but with influence that is secondary to that of texture depth.

TYRE/ROAD AERODYNAMICS

The movement of air within the tyre/road interface contributes to significant noise generation through air pumping and resonance mechanisms [11]. Especially when tread blocks are large (e.g. some truck tyres), air flow resistance of the road surface should play an important role in whether air gets temporarily restricted at high pressure or can quietly disperse. Air flow resistance of the road surface has not yet been directly studied by this research programme, beyond incidental observations of high frequency effects while investigating texture [9]. The standard P1 car tyre used for CPX may not be the most appropriate tyre for that task due to tread block size.

ACOUSTIC ABSORPTION

Absorption of sound by the road surface has a strong influence on tyre/road noise in the nearfield, and also on its propagation from the vehicle to the wayside.

Our research suggests the standard CPX microphone positions (45° and 135° incident to the rolling direction of the tyre) adjacent the tyre are only partially sensitive to the nearfield absorption effect [12]. It is hypothesised that porous surfaces are particularly effective at reducing the 'horn-effect' at the front and rear of the tyre, compared to non-porous surfaces, and therefore tyre/road directivity is modified depending on surface acoustic absorption. Combined with additional absorption occurring between the tyre and the wayside, a porous surface may be in the region of 3 dB quieter than a non-porous one at the wayside, for the same value of $L_{CPX:P1,80}$ [7]. Nonetheless the standard $L_{CPX:P1,80}$ parameter retains considerable sensitivity to surface absorption, as will now be discussed.

While our research has included in-situ measurements of acoustic absorption of the road surface [13], it has so far treated this as a discretionary intermediate step between the physical properties of the road surface and tyre/road noise level (see Figure 1).

Surface Thickness

Our research has found that the thickness of the road surface has a strong influence on tyre/road noise, primarily via its influence on acoustic absorption.

Thickness measurement

Direct measurement of the thickness (i.e. depth in millimetres) of finished porous asphalt road surfaces has not been a requirement in NZ. For this research programme, high resolution and accuracy were required, and several measurement methods were considered [14]. Of the trialled methods, LiDAR scans (made before and after the surface is laid) and electro-magnetic induction (metal discs placed at intervals along the road prior to the surface being laid), have provided accurate results [15]. High-resolution thickness data (generally LiDAR) have been measured for three projects, CNC, CSM2, and PP2Ō, and underpin the findings on surface thickness.

Thickness effect on noise

The dataset contained similarly-constructed porous asphalt surfaces with a wide range of wheel-path thicknesses, ranging from 20 mm to 65 mm [9,15]. Across all sites and lanes, a strong negative correlation between surface thickness and tyre/road noise exists. The influence on $L_{CPX:P1,80}$ is in the region of -2 dB per 10 mm of surface thickness [10,15], though the relationship is not completely linear (Figure 2).

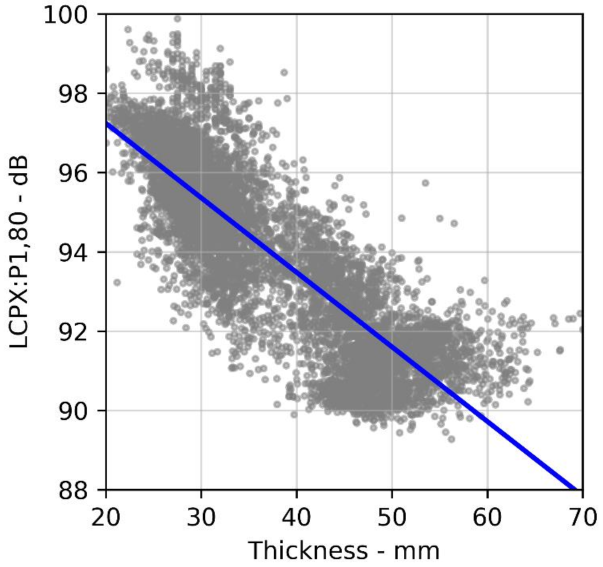

Figure 2: Effect of surface thickness on tyre/road noise ($m=-0.19$, $R^2=0.70$, $n=7122$ across 3 projects)

Spectra for similar porous surfaces of different thickness show an intriguing phenomenon [9,10]. As thickness increases, the centre frequency of a broad 'dip' in the typical tyre/noise emission spectrum decreases. At a surface thickness of approximately 50 mm the dip is coincident with the usual tyre/road emission peak at around 800 Hz to 1000 Hz. The apparent 'frequency-tuning effect' of thickness is broadly consistent with a theoretical model for acoustic absorption of porous asphalt [16]. Initial in-situ measurements of acoustic absorption of a NZ road suggest a similar decrease in frequency of peak absorption with increasing thickness [13].

These results demonstrated that increasing surface thickness from the typical range of 20 – 30 mm to 40 mm or 50 mm provides a substantial reduction in tyre/road noise of about 2 dB and 4 dB respectively. The reduction at the wayside may be greater still, due to the unaccounted-for influence on far-field propagation, but this is yet to be confirmed. The observed frequency-tuning effect suggests a limit to the acoustic benefit of additional thickness, applying beyond about 60 mm.

Implementation of a consistently thicker surface requires more material and additional quality controls [4]. We have observed that the surface thickness is sometimes varied during construction to provide a smooth running surface for traffic, and this can have a knock-on effect on tyre/road noise [9].

Surface Void Fraction

The void fraction, or porosity, of a porous surface has conventionally been considered a critical determinant of its acoustic performance. However, our research suggests that, beyond needing to achieve and maintain some minimum threshold void fraction to function as a porous surface, it is not a strong predictor of the tyre/road noise level of a surface.

The relative void fraction of porous asphalt was measured using a nuclear densometer at 12 independent sites whose average measured void fraction ranged from 10% to 20% (totalling 576 void fraction measurements) [17]. A clear pattern of void fraction influence on tyre/road noise level did not emerge, beyond the suggestion of a local minimum at around 15% voids. Controlling for other variables, the effect on $L_{CPX:P1,80}$ was weaker than ±0.1 dB per percent void fraction, and non-linear over the expected range of void fraction [10].

There was a correlation between void fraction and surface texture, with higher void fraction tending to have higher MPD and consequently more low-frequency noise [17]. Conversely, higher void fraction tended to reduce high-frequency noise, probably due to aerodynamic mechanisms.

While there is logically some minimum porosity that must be maintained by a surface to achieve acoustic absorption, over the typical range tested (10-25% voids) it was not a fruitful avenue for surface optimisation.

Surface Void Structure

The length and shape of the interconnected voids in porous surfaces is suggested by theory to influence absorption in a similar way to surface thickness [16]. However, detailed study of these surface parameters is very difficult in practice and has not yet been attempted in NZ with respect to noise.

OPTIMISING FOR A QUIET SURFACE

Of the studied road surface properties, surface thickness and texture depth have a dominant influence on tyre/road noise of porous asphalt, with other properties having at most a secondary role. The most reliable and effective means of reducing texture depth is to select a relatively fine aggregate for the asphalt mix, thus a nominal maximum aggregate size of 7 mm is preferred (the smallest permissible size). Surface thickness can be controlled at the time of construction, provided the bituminous mix has the appropriate properties, acknowledging there is some tension between acoustic and ride quality demands. A consistent thickness of 50 mm appears close to optimal for porous asphalt that is based on a 7 mm aggregate, while a 40 mm thickness provides a reduced, but still good performance, and uses slightly less material.

It follows that two new high-performance low-noise surfaces have been developed, with thickness and mix designations[1],

- **50 mm EPA7**, with typical noise reduction 4 dB better than standard porous asphalt [1]
- **40 mm EPA7 / PA7**, with typical noise reduction 2 dB better than standard porous asphalt [1]

[1] The initial value is the thickness in mm, in this case the E reflects an epoxy-modified binder, the PA stands for porous asphalt, and the final 7 represents the 7 mm nominal maximum aggregate size.

VARIATION IN TYRE/ROAD NOISE

Multiple non-linear regression of surface thickness, texture depth (via MPD), and void fraction on $L_{CPX:P1,80}$, where all four metrics were available, produced a relationship that accounted for 89% of the variation in the sample (n=334) [10]. Previous sections described approximate tyre/road noise sensitivities for thickness (-2 dB / 10 mm), texture depth (+0.7 dB / 0.1 mm MPD), and void fraction (< ±0.1 dB / % voids). Across the eight to twelve projects/sites for which data was available and a single surface specification was used, typical variations in those quantities were 4.64 mm thickness, 0.064 mm MPD, and 1.63% voids, given here as standard deviations. Figure 3 therefore provides the anticipated relative influence of each surface parameter on tyre/road noise variation within a single porous asphalt mix designation on a 'typical' project.

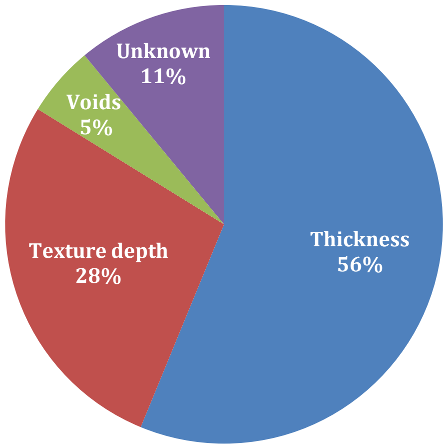

Figure 3: Relative influence of road surface parameters on noise level variation within a single site and surface type

Revisiting the observed high variability of porous asphalt already on the state highway network [3], we now believe this to be principally due to variations in surface thickness [15,18], with a secondary contribution from texture depth. This is not easily proven retrospectively across the full highway network due to the absence of existing thickness measurements and the difficulty of performing the measurements post-construction. Nonetheless, the observed variation in $L_{CPX:P1,80}$ on the network is consistent with the current findings for thickness variation, having already excluded texture depth and a number of construction parameters as being the primary cause [18].

CONCLUSIONS

Through a structured programme of research (Figure 1), the factors that influence the tyre/road noise emission of porous asphalt have been better understood, and in many cases quantified. Asphalt thickness dominates tyre/road noise variability of porous asphalts, but has been harnessed to produce thicker and much quieter road surfaces. Surface texture depth (measured as MPD) also has a significant effect on noise level, and can be initially controlled through the aggregate sizing. Selecting the (thus far) optimal combination of a 7 mm aggregate and constructing a 50 mm thick porous asphalt surface results in a high-performance low-noise surface that is at least 4 dB quieter than standard NZ porous asphalt.

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