Developing a Durable Quiet Road Surface

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Road traffic noise can have a significant impact on the quality of life for residents close to major road networks. One of the most effective measures for reducing the noise from road traffic, particularly on high-speed roads, is to ensure the use of a low noise road surface. Research on pavement construction and the measurement of its acoustic properties has shown that significant noise reductions can be achieved through the use of certain road surface types. However certain low noise road surfaces do not exhibit the desired durability associated with more traditional pavements, leading to costly and disruptive maintenance regimes.
This article looks at the mechanisms involved in tyre/road noise generation and how these interact with various road surface properties including a brief overview of some common surface types. It then goes on to explain how these concepts informed the development of an asphalt surfacing material with enhanced durability and good acoustic performance without compromising safety. Progress in testing the resulting Premium Asphalt Surfacing System (PASS) is outlined, including the completion of a successful network trial.

Keywords: Asphalt, road surface, low noise pavement, tyre/road noise.

1 Introduction

Road traffic noise can have a significant impact on the quality of life for residents close to major road networks[1]. One of the most effective measures for reducing the noise from road traffic, particularly on high-speed roads, is to ensure the use of a low noise road surface. Research on pavement construction and the measurement of its acoustic properties has shown that significant noise reductions can be achieved through the use of certain road surface types[2]. However certain low noise road surfaces do not exhibit the desired durability associated with more traditional pavements, leading to costly and disruptive maintenance regimes[3].

As such Highways England, the Mineral Products Association and Eurobitume UK have come together to fund collaborative work into developing an asphalt surfacing material with enhanced durability without compromising safety or increasing noise levels[4, 5].

This article looks at the mechanisms involved in tyre/road noise generation and how these interact with various road surface properties including a brief overview of some common surface types. It then goes on to explain how these concepts informed the development of a new Premium Asphalt Surfacing System (PASS) and summarises the progress made towards a safe and durable low noise surfacing material including the completion of a successful network trial.

2 Tyre Road Noise Generation

The mechanisms of tyre/road noise generation are often divided into three classes covering impacts and shocks, aerodynamic processes and adhesion effects.

Impacts and shocks describe the interaction forces between the tyre tread and the road surface. The tread block is compressed and is said to be snapping out as it leaves the road surface and returns to its uncompressed state and this tends to generate noise below 1 kHz.

Aerodynamic processes include the compression and decompression of air trapped between tyre tread blocks as it passes over the road and this process, called air pumping, tends to generate noise above 1 kHz. Theoretically, this process is a significant source of tyre/road noise for smooth, non-porous surfaces which have fewer avenues for the dissipation of the compressed air.

Adhesion effects include frictional forces between the tyre and road surface causing vibrations in the tyre which are then dissipated by the tyre slipping on the road surface. These noise generating mechanisms are amplified by the local geometry of the tyre and road surface, at the rear of the contact patch (the area where the tyre touches the surface forming a horn like geometry), and this is known as the horn effect. It can result in substantial amplification of the noise above 1 kHz.

The relative importance of these different mechanisms varies between tyre types and surface designs. As well as the generation of noise, surface design can influence noise propagation. For example, porous road surfaces can result in destructive interference between the direct sound wave and that which penetrates the surface layer and is reflected back towards the receiver. In addition, porous surfaces mitigate the amplification of noise caused by the horn effect.

Below we discuss some important road surface properties and how they influence tyre/road noise before giving a brief overview of the properties of some common surface types.

2.1 Road Surface Profile

A road surface profile can be visualised by taking a virtual cross section of the pavement and considering how the top layer of this cross section appears. It will consist of a continuous series of peaks and troughs which may be randomised or reasonably well defined depending on the pavement type. This profile shape can be interpreted in terms of the summation of a number of sinusoidal variations of different amplitudes and wavelengths. Each sinusoidal variation is called a waveform and the associated amplitudes and wavelengths are referred to as texture amplitudes and texture wavelengths.

Research has shown that increasing texture amplitudes at wavelengths between 0.5 mm and 10 mm reduces air pumping noise as the air between the surface and tyre is released more smoothly[3]. However, research has also shown that increasing texture amplitudes at wavelengths between 10 mm and 500 mm increases low-frequency noise as a result of higher vibration levels in the tyre carcass.

In addition, the way the texture is applied can have an effect. Research has indicated that noise levels associated with surfaces with transverse texture (i.e. a relatively regular profile across the width of the road surface) are higher than those associated with surfaces with random texture even if the texture amplitudes are similar[2]. This is down to the synchronised forces in the transverse texture enhancing the associated tyre vibrations.

As well as texture amplitudes and wavelengths, road surface profile may be referred to as having either a positive or negative texture. Positive texture refers to a surface where ridges protrude above the plane of the surface whereas negative texture refers to a surface which is largely smooth save for some voids between the aggregate. In general positive texture encourages higher levels of vibration (and therefore noise) in the tyre than negative texture.

2.2 Road Surface Durability

Achieving good durability is often in conflict with attaining low noise and therefore creating a surface that performs well in both areas is a key challenge in pavement design.

The durability of asphalt surfacing may be defined as the ability of the surfacing material to resist degradation in service (such as fretting, cracking and delamination) due to changes in the chemical and mechanical properties of the material. Not only is good surface durability desirable in terms of increasing the lifetime of the surface it also has a beneficial impact on traffic noise compared with another surface with poor durability. For example, traffic can wear down the texture amplitudes associated with shorter texture wavelengths, increasing aerodynamic noise. Porous surfaces are particularly susceptible to degradation as the high void content can result in the surface becoming clogged, reducing acoustic absorption and causing the surface layer to break apart[6].

There are a number of factors to consider in achieving good surface durability. Firstly the asphalt mixture, typically a combination of aggregates, fines, filler and bituminous binder, needs to be balanced. The ideal mixture has the right amount of air voids (gaps between the materials) and a good compatibility between the components in terms of their physical and chemical properties.

Typically an in situ air void range between 2% and 6% is ideal for dense asphalt concrete[4]. A lower air void content is not conducive to a quiet surface and a higher air void content is not conducive to good durability as moisture enters into the voids and leads to fretting and cracking of the pavement.

In addition to considering the risk from moisture damage, winter maintenance practices also need to be considered. The effect of de-icing fluids on asphalt pavements has been reported as causing degradation and disintegration of asphalt pavements[7, 8]. Improving the properties of binders and/or aggregate may reduce or even eliminate the problem.

2.3 Other Road Surface Properties

The environmental noise from traffic is also influenced by the absorption of the sound generated and one of the key parameters in this regard is porosity. Porosity is a measure of the fraction of the volume of voids to the overall volume and, with respect to road surfaces the residual air void content is the fraction of voids open to the air in a given volume of pavement mix.

For tyre/road noise, increased porosity reduces air pumping and generally increases sound absorption, which in turn reduces the horn effect. There are also other parameters which influence sound absorption including the thickness of the porous layer, airflow resistance and tortuosity (a measure of the curved/meandering nature of the air path through the surface layer).

These parameters have complex and interdependent relationships with the air flow through the surface and the frequencies which are mostly absorbed[9, 10]. Research in the area of porous surfaces has shown that porosity decreases as the surface becomes clogged.

Skid resistance requires a degree of surface texture amplitude over a wide range of texture wavelengths. Achieving the desired texture amplitudes for skid resistance at the texture wavelengths that do not adversely impact the noise generation is the key to having a low noise surface that meets the necessary safety requirements.

Rolling resistance and noise are more closely related and reducing texture amplitudes at certain wavelengths tends to be beneficial for both properties[11].

2.4 Road Surface Types

Current road surfaces each contain their own combinations of properties discussed above leading to varying levels of acoustic and structural performance in practice. Hot Rolled Asphalt (HRA) for example often uses a 20 mm pre-coated chipping and has been widely used in the UK for many years. It is a durable surface that can last over 20 years; however, it results in higher levels of traffic noise than most other randomly textured surfaces including thin surface course systems and porous asphalt.

Thin surface course systems have been used in the UK since the late 1990s and encompass a variety of bituminous products with a surface layer less than 50 mm deep. These surfaces tend to be classified either according to their surface thickness or in terms of the aggregate size used. The nominal aggregate size used in these surface layers is in the range 6-14 mm and the open and smooth surface texture lends itself to low noise performance. In general thinner layers and smaller aggregate sizes result in quieter surfaces with less durability and greater deterioration in acoustic performance over time[2].

Porous asphalt surfaces can be constructed with either a single layer or two layers usually around 40 mm thick; sound absorption is achieved by a gap-graded aggregate distribution resulting in a high void content. They are common low noise surfaces in Denmark and the Netherlands and their acoustic properties have been investigated in several studies[12, 13, 14, 15]. They are not commonly laid in the UK however as they do not exhibit good durability because of the rapid ageing of the binder and the clogging of the voids. The surface also requires more frequent salting in winter conditions and surface repairs are more problematic[3]. Reported measurements indicate that high initial noise benefits, around 5 dB quieter than some thin surfaces, are achievable but that the clogging of the voids in the surface leads to most of this benefit disappearing over the first 5-6 years of the surface's life. Also, noise levels are reported to increase by around 3.5 dB in wet weather and the surface takes longer than other surfaces to dry out[16].

3 Developing a Durable Quiet Surface

3.1 Stage 1: Concept Generation

Initial work focused on developing new and innovative asphalt surfacing materials with significantly enhanced durability, whilst balancing other performance demands such as noise, skid resistance and safety. The major factors considered were:

- Understanding issues and failure mechanisms.
- Performance requirements.
- Assessment criteria.
- Mix design and specification.
- Construction techniques.

A workshop was organised in June 2015 drawing upon leading experts and international experience. In this workshop, the participants were challenged to come up with ideas for the next generation of asphalt surfacing for use on Highways England's motorway and all-purpose trunk road network that will increase durability without compromising the current performance.

Ideas presented in the workshop were collated into broad concept groups and an initial high-level evaluation of each concept was undertaken against durability, ease of implementation and likely relative cost.

Several ideas generated at the workshop related to the category of "good practice". The key factors to be considered for potential options were:

- The mix design process.
- A better understanding of aggregate packing.
- Constructability-Improving workmanship/operational upskilling/training.
- Substrate condition.
- The bond between layers.
- Improved safety and joint workmanship.
- Temperature control and prevention of mix segregation.

The dual layer Premium Asphalt Surfacing Systems (PASS) was the top idea amongst a range of other options[3]. The concept is based on a low voided, dense body of material with improved surface characteristics.

3.2 Stage 2: Laboratory Testing

The mix design explored aggregate packing theories to produce the PASS[17]. The desired properties for the PASS include resistance to rutting, long-term durability, improved skid resistance and reduced noise properties. The packing characteristics are determined by several factors that include the shape, strength and texture of the aggregates.

Other factors include the aggregate gradation and compaction effort applied. For example, cubical particles form a denser configuration in comparison to flat and elongated particles whilst smooth particles slide together more easily than those with a rough surface texture. To better understand aggregate packing, it is important to establish what particles form the coarse aggregate structure and which ones fit into the voids created within the structure.

A binder for the PASS was selected which allowed for easy compaction under adverse weather conditions and had sufficient flexibility against surface cracking and did not compromise the desired texture of the surface course.

3.3 Stage 3: Demonstration Trial

Following laboratory tests a pilot scale demonstration was undertaken at Alrewas Quarry, Staffordshire in June 2016, see Figure 1. The PASS samples showed optimal packing of aggregates and laying characteristics were very similar to those of a thin surface course. The demonstration trial showed that the PASS material was relatively easy to batch with no problems encountered at the asphalt plants. The obtained in situ air voids was around 4%.

During the laboratory and field assessments, the test results were benchmarked against the UK Specification for Highway Works (SHW) Clause 942 for Thin Surface Course Systems. The results found that the new PASS material showed mechanical properties at least similar to, or better than that of the Clause 942 reference[3].

Figure 1: Laying the PASS at Alrewas Quarry.

3.4 Stage 4: Road Network Trial

The next phase of work involved laying the PASS mix on Highways England's road network. The road network trial involved the installation of two PASS mixes (PASS 1 and PASS 2) targeting 50 mm nominal thickness for the mixtures. The same equipment and procedure used in the installation of typical thin surface course materials were utilised for the PASS trial. Following installation, the PASS appeared to be dense with a high coarse aggregate content showing good interlocking properties.

The major advantage of the PASS material is the fact that the design is based on closely controlling the amount of in situ air voids. This parameter is aimed at helping to improve the in service durability of the PASS mixtures. The skid test results showed encouraging values for the asphalt mixtures. The mechanical test results on cores recovered from these sections showed performance at least comparable to, or better than, the result obtained from the Alrewas trial[4].

The Statistical Pass-By (SPB) measurement is the most frequently used procedure in the UK for assessing the influence of road surfaces on vehicle noise emissions. During an SPB measurement, the maximum pass-by noise levels and speeds of individual vehicles selected from the traffic stream are measured at a reference distance from the centre of the vehicle lane and these data are used to infer the acoustic performance of the road surface[18, 19].

The SPB method was used in assessing the noise properties of the PASS mixtures following the road trial, see Figure 2, to obtain a Road Surface Influence (RSI) which describes the acoustic performance of the surface relative to a standard Hot Rolled Asphalt (HRA) surface. The obtained value for the PASS from this survey was -5.7 dB(A) which compares well with the acoustic performance of existing low noise surfaces and meets the requirement of SHW Clause 942 for "very quiet surfacing".

Figure 2: Noise testing on the highways england road network.

These results point towards the PASS being a very promising surface for achieving low noise and good durability but the key test will be how the surface stands up to the next few years of use. In addition to further testing of the PASS material on the trial site as it is ages, recommendations have been made to:

- Develop guidance documents and specifications for the design, testing and use of these next generation asphalt mixtures
- Develop a more advanced assessment of in-situ density that isolates the effects of surface texture. These are important parameters required in order to produce durable PASS mixtures within the design air void target limits of 2%-6% and texture values between 1.0 mm and 1.4 mm.
- Make use of a mobile load simulator to better understand the long-term performance of the mixture, relative to a control thin surface.
- Measure the wet skidding resistance of the mixture.
- Look into using different aggregate sources and suppliers.

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