NANOPHONE®: Innovative open-graded asphalt concrete 0/4mm for improving noise reduction

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ABSTRACT

A recent study regarding living conditions indicates that 25% of the rural population is dissatisfied with the noise generated by road transportation. This rate reaches 66% in urban areas.
In this context, Eiffage has developed a new generation of open-graded asphalt for a very thin layer of so-called Nanophone® or BBTM (0/4mm), with a 0/4 mm grading curve and containing polymer-modified bitumen. This wearing course relies on the use of the finest gradation (size of the coarsest aggregate = 4 mm) and makes it possible to obtain high acoustic performances (low acoustic emission and strong noise absorption capacity) due in particular to a specific grading curve and a rate of optimized void content.

The implementation of a 2 to 3 cm thick asphalt mix of 0/4 mm with a fine and regular texture leads to very satisfactory performances in terms of macro texture, Sideways Force Coefficient and Braking Force Coefficient.

In situ measurements, carried out in line with the European standard NF EN ISO 11819-1, indicate that this new generation of asphalts presents acoustic performances higher than 2 to 3 dB(A) compared to the most efficient French wearing course (porous asphalt 0/6 mm), and near 8 dB(A) compared to traditional dense asphalt wearing course 0/10 mm.

Other measurements, consisting in evaluating the pavement noise impact on an existing infrastructure with the French standard NF S 31-085, show that this innovative asphalt composition allows a reduction of 50% of noise pollution (road traffic divided by two) compared to the traditional dense asphalt wearing course 0/10 mm.

KEYWORDS: asphalt concrete 0/4mm - noise reduction – sound absorption –voids – skid resistance

1. INTRODUCTION

The citizens are attentive to their health and environment. These are important elements of their heritage.
The disturbance caused by noise pollution is one of the most important effects of poor environmental health. Approximately 80 million people in Europe are exposed to noise levels exceeding 65 dB (A) and 175 million to nuisances in so-called "grey" areas (= potentially harmful noise) which do not provide sufficient acoustic comfort.

A recent French study regarding living conditions indicates that 25% of the rural population is dissatisfied with the noise generated by road transportation. This rate reaches 66% in urban areas.

In this context, EIFFAGE Travaux Publics has developed a new generation of open-graded asphalt for a very thin layer of so-called Nanophone® or BBTM (0/4mm) with low environmental impact, particularly in terms of noise emission.

This article describes the technical and environmental advantages of this BBTM 0/4mm wearing course developed by EIFFAGE Travaux Publics. This innovative material relies on the use of the finest gradation (size of the coarsest aggregate = 4 mm) and optimized void content to reduce the rolling resistance of vehicles and ensure enhanced acoustic performance (low emission and high noise absorption capacity).

The specific mixture design of this asphalt combined with its easy implementation as well as a fine and regular texture provides an excellent level of security and comfort for the user. These sustainable mechanical and acoustic performances, including the use of polymer-modified bitumen, offer a solution to noise reduction for road residents and road networks managers.

2. INNOVATIVE OPEN-GRADED ASPHALT CONCRETE NANOPHONE® (BBTM 0/4mm)

The decrease in nominal maximum particle size seems crucial to reduce noise pollution related to road transportation [1], [14], [15].

By adapting the surface characteristics (suitable aggregates allow for a fine and open surface texture), it is possible to ensure a good level of skid resistance while reducing noise emissions as well as rolling resistance, and therefore the consumption of vehicles.
Moreover, high void content in the wearing course promote satisfactory noise absorption.
Also, the use of a very workable mixture combined with a managed lay off contributes to obtaining an optimized surface texture and a good evenness. Thus, it is possible to consider a significant reduction in rolling resistance and fuel consumption (figure 1) while maintaining an excellent level of comfort for the road users.

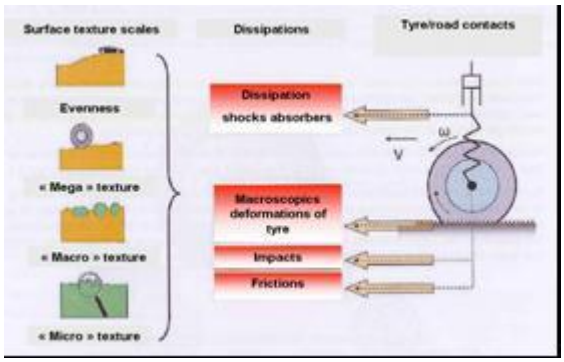

Figure 1: Contribution of the different scales of texture to the rolling resistance [1].

The sustainability of the mechanical and acoustic characteristics of the BBTM 0/4mm wearing course is ensured by the use of appropriate aggregates and high-performance polymer-modified bitumen.

2.1 Grading curve

The first feature of Nanophone ® is based on its grading curve. The size of the coarsest aggregate blend is limited to 4 mm. Thus, the final asphalt is fine and has a significant amount of void content, including through incorporation in a high proportion of aggregates 2/4mm.
As noted in the literature [1], the size of aggregates, the energy transmitted to the pneumatic shocks, indentation and pumping phenomena are directly related (see figure 2).

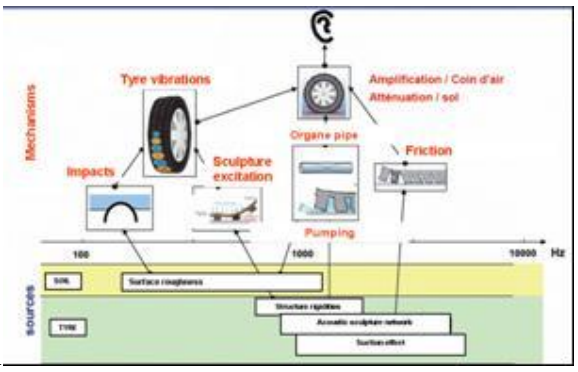

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Figure 2: Mechanisms and sources of noise.

The reduction in nominal maximum particle size 6mm to 4mm brings about a reduction in the amplitude of the local pressure variations of tyre/road contacts while maintaining the depth of the macrotexture. Thus, the number of contact points is increased which helps to obtain a good skid resistance.

The combination of a fine and regular surface texture with high void content (>25%), led to obtaining high acoustic absorption and reducing the sound contribution related to the pavement-tyres contacts.

Several campaigns of noise measurements from different asphalts allowed us to identify the mix design parameters affecting the absorption and sound emissions.
We have been able to establish a specific grading curve for the Nanophone® (table 1) and an optimum void content as shown in chapter 2.3.

In all cases aggregates should be conform to the specifications mentioned in the French standard EN13043 [3] concerning their use in wearing courses

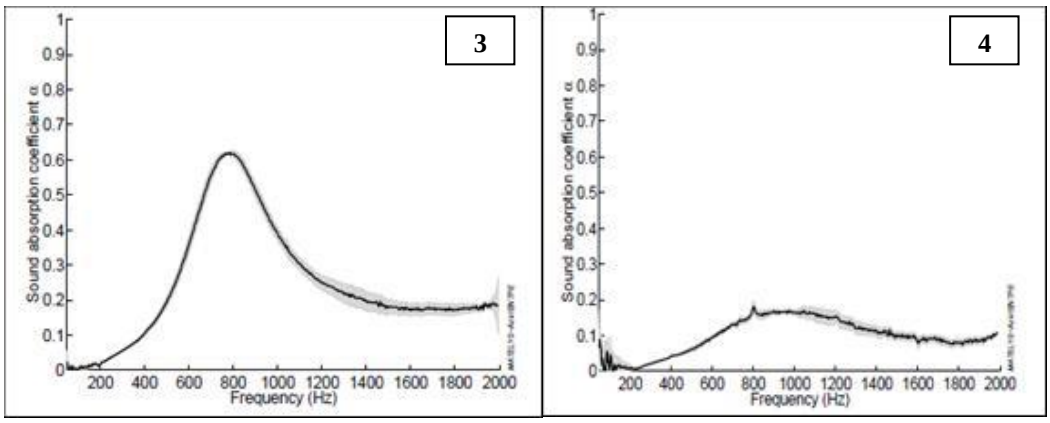
Table 1: Grading curve elements.

Sieve (mm)	Passing (%)
4	85 - 95
2	20 - 30
0.063	5,5 - 7

2.2 Relationship between acoustic performances in laboratory and air void content

The research and laboratory trials (compaction test with shear press and wheel tracking test) have shown that the void content for the BBTM 0/4mm should ideally fall between 25% and 30%.

For example, figures 3 and 4 present acoustic performances determined with two open-graded asphalt mixtures, BBTM 0/6mm and the innovative BBTM 0/4 mm grading curves, produced with similar aggregates and binders. The sound absorption coefficient (α) was measured using Kundt's tube.



Comparative measurements of acoustic absorption using Kundt's tube:
Figure 3: Innovative open-graded BBTM 0/4mm (void content = 27.5% and thickness = 2 cm).
Figure 4: Standard open-graded BBTM 0/6mm (void content = 18.2% and thickness = 2.5 cm).

The results indicate that the open-graded asphalt with a 0/4mm grading curve containing 27.5% air voids presents a better sound absorption coefficient than the 0/6mm grading curve formula containing 18.2% air voids.
A factor 3 is nearly observed between the respective absorption coefficients of the two asphalts.

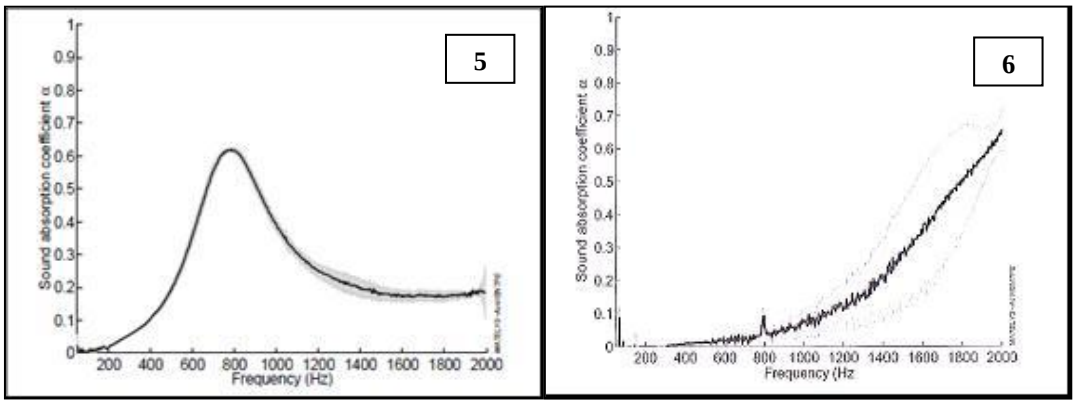
2.3 Binders

In order to ensure the sustainability of the physical and mechanical characteristics of BBTM 0/4mm, the formulas are systematically composed with polymer (styrene-butadiene-styrene) -modified bitumen.

Their excellent characteristics (elasticity, resistance behaviour, granular cohesion and conservation of adhesion) help improve the performance and durability of asphalt concrete in very thin layers under all traffic and weather conditions. We have observed that the optimal polymer rate in the binder necessary to conserve the wearing course properties is between 3% and 5%, with total binder content superior to 5.1%.

2.4 Implementation thickness

The study of the sound absorption coefficient using Kundt's tube allowed us to optimize the mixture's design and the implementation thickness. Indeed, the trials show that when thickness increases, the acoustic absorption coefficient drops to the lower frequencies. We have established that a thickness between 2.5 cm and 3 cm is optimum for the open-graded asphalt BBTM 0/4mm to absorb in a balanced way all the frequencies between 800 Hz and 2000 Hz. Those frequencies are considered the most disturbing to the human ear. Figures 5 and 6 present an illustration of the impact of implementation thickness on sound absorption at different frequencies.



Examples of acoustic Spectra using Kundt's tube with different implementation thicknesses:
Figure 5: Open-graded BBTM 0/4mm with thickness = 2 cm
Figure 6: Open-graded BBTM 0/4mm with thickness = 4 cm

3. DEVELOPMENT AND LARGE SCALE ROADWORKS (2008 – 2011)

To date, several projects have been made. We will quote, for example, the following achievements.

3.1 Implementation in an agglomeration (traffic = 19,000 vehicles a day including 3% of trucks)

In this site (figure 7), 23 500 m² of the BBTM 0/4mm were implemented (thickness = 2.5 cm) in replacement of a noisy asphalt 0/10mm with a continuous grading curve.

Figure 7: Worksite in a French Mediterranean city.

3.2 Implementation in highways (traffic = 2000 trucks a day)

28 000 m² of the A43 highway pavement (figures 8 and 9) was covered by 2.5 cm of the BBTM 0/4 in order to reduce noises generated by traffic and increase the residents living comfort.

Figure 8: Laying of equipment.
Figure 9: Compaction equipment.

For the same reasons, 16 000 m² of the BBTM 0/4mm were implemented (thickness = 2.5 cm) on A41 highway pavement to replace a noisy asphalt 0/10mm with a continuous grading curve.

Figure 10: Overview of the worksite
Figure 11: Appearance of the BBTM 0/4mm surface texture.

3.3 Rural area (traffic = 150 to 300 trucks a day)

In this case (figure 12 and 13), at the request of the residents, a very noisy cold micro asphalt was covered by the innovative BBTM 0/4mm (3 100 m²) on a French alpine road.

Figure 12: Compaction equipment.
Figure 13: Appearance of the BBTM 0/4mm surface texture.

4. ACOUSTIC PERFORMANCE

The acoustic performance of several BBTM 0/4mm wearing courses has been measured in accordance with European and French standards [6] |7] [8], and the note no. 20 of the French Committee for Technical Roads (C.F.T.R.) [5]. Some of the acoustic measurement results are presented in tables 2 to 4.

Table 2: Measurements of the open-graded BBTM 0/4mm sound emissions in accordance with the European standard EN ISO 11819-1 [6].

Method	Worksite	Results
Pass-by method with isolated vehicle at 90 km/h, EN ISO 11819-1 - [$L_{véh}$]	French alpine road	**BBTM 0/4mm (void content = 21%) :** → 4 months after implementation : 69.3 to 70.6 dB(A) → 15 months after implementation : 66.7 dB(A)

As shown in table 2, measurements at 90 km/h from category 1 vehicles (cars) in accordance with the European standard EN 11819-1 [6] are ranked from 66.7 to 70.6 dB (A). This value indicates a higher level of performance than that of the pavement until the most recent efficient wearing courses: open-graded asphalt concrete 0/6mm in a very thin layer and porous asphalt 0/6mm.

Thus, we can observe an increase in acoustic performance: -2.6 dB(A) between the two trials campaign. This improvement is due to the strip of binder leaving a better noise absorption by air voids contained in the layer.

Table 3: Measurements of the traffic noise reduction (French standard NF S 31-085 [8]) due to the innovative BBTM 0/4mm implementation.

Method	Worksite	Results
Characterization and measurement of road traffic noise NF S 31-085 - [LAeq measured between 6 pm and 22 pm]	Urban area	**. Former top layer (5% to 10% void content) = 70.6 dB(A)** (0/10mm continuous grading curve asphalt concrete) **. New BBTM 0/4mm (18% to 25% void content) = 66.9 dB(A)** **. Noise reduction with BBTM 0/4mm = -3.7 dB(A)**

In the case of table 3, the measurements were performed in front of a building. The traffic noise perceived by the people has been reduced by more than 50% after replacement of the former wearing course (continuous grading curve 0/10mm) by the BBTM 0/4mm.

On the other hand, several measurements collected from different sites show that the reduction of noise emissions may reach 4.1 dB (A).

Table 4: Statistical Pass-By measurements with the European standard EN ISO 11819-1 [6].

Method	Worksite	
Statistical pass-by method EN ISO 11819-1 - [SPB statistical index, included cars and trucks]	A41 highway	**. Former top layer (4% to 9% void content) = 81.3 dB(A)** (continuous grading curve asphalt concrete 0/14mm) **. New BBTM 0/4mm (20% to 24% void content) :** 1 month after implementation = 78.0 dB(A) 9 months after implementation = 77.2 dB(A) **. New continuous grading curve asphalt concrete (BBSG) 0/10mm (5% to 8% void content) :** 1 month after implementation = 80.4 dB(A) **. Noise reduction :** New BBTM 0/4mm vs Former top layer : -3.3 dB(A) after 1 month and -4.1 dB(A) after 9 months New BBTM 0/4mm vs new BBSG 0/10mm: -2.4 dB(A) after 1 month

The measurements presented in table 4 confirm the attenuation of road traffic noise due to the replacement of the open-graded asphalt concrete 0/14mm by BBTM 0/4mm material.
This noise reduction is also significant compared to a same ageing continuous grading curve 0/10 mm (BBSG) with lowest voids content.
As shown in table 2, we can observe an increase in the acoustic performances related to the aging of the layer.

5. SURFACE TEXTURE

Pavement surface macro texture depth measurements, so-called P.M.T, have been carried out in accordance with the European standard NF EN 13036-1 [3] in all open-graded asphalt concrete 0/4mm operations.

The P.M.T. average measurements, based on all the products implemented, is 0.90 mm (min value = 0.76 mm, max value = 1.21 mm).

These values comply with the requirements of the French standard NF P 98-150-1 [10] for open-graded asphalt concrete 0/6mm in a very thin layer (BBTM 6) which requires 0.7 mm minimum for 90% of the controlled points.

6. SKID RESISTANCE

Several Nanophone® top layers were analyzed to determine the Sideways Force Coefficient (CFT) [12] and Braking Force Coefficient (CFL) [13].

6.1 Sideways Force Coefficient (CFT)

The measurements were carried out with the S.C.R.I.M. device (Sideway Force Coefficient Routine Investigation Machine) in accordance with the French standard NF P 98-220-4 (12, 1996) [12].

The axis of the measurement wheel is equipped with a sensor system allowing the evaluation of the tyre/pavement "N" reaction, inferred from the extent of the effort cashed by the measuring wheel hub and the "P" assumed constant vertical load imposed on the ground through the measuring wheel.
The coefficient of transverse friction (CFT) measured by the SCRIM is proportional to N on P.
The device, equipped with a standard special tyre, makes an angle of approximately 20 ° to the direction of the vehicle.

The material is presented in figures 14 and 15.

Figure 14: Sideway Force Coefficient Routine Investigation Machine for the CFT measurement.
Figure 15: Device for measuring (wheel and water injection)

The sideway friction coefficient (CFT) measured at 60 km/h is 0.72.

The measurements show that the increase of tyre / pavement contact points due to smaller aggregates improves skid resistance.

6.2 Breaking Force Coefficient (CFL)

The measurements were made with the ADHERA device in accordance with the French standard NF P 98-220-2, 1994) [13].
A car type wheel, on which a fixed vertical load is applied, is pulled at constant speed by a tractor vehicle which simultaneously sprays water on the pavement. The wheel is prevented from rotating along a distance of 20 m and the average torque ensuring balance with the friction torque exerted by the pavement on the tire is then measured.
The material is presented in figure 16.

Figure 16: Device ADHERA for measuring the Sideways Force Coefficient (C.F.L.) on the pavement.

The Sideways Force Coefficient (CFL) measured at speeds of 40-90 km/h is respectively 0.59 and 0.48 (Figure 17).

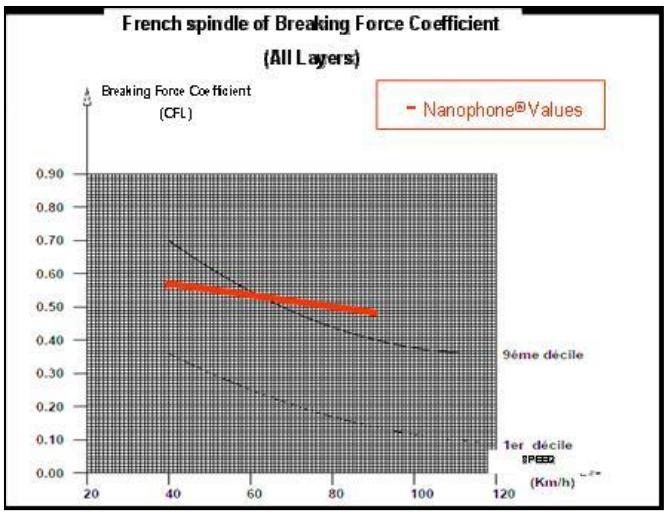


Figure 17: Example of Breaking Force Coefficient (CFL) measured from BBTM 0/4mm wearing course (9 months after implementation).

In accordance with the French pavement guide specifications CARAT (Road Pavement Skid Resistance / pavement CR25edited by the French Public Works Research Laboratory [11]), the results of the measurements enable the classification of the BBTM 0/4mm as high-performance open-graded asphalt concrete in a very thin layer.

7. CONCLUSIONS

Nanophone ® is a new open-graded asphalt 0/4mm in very thin layer with very good acoustic performances due to the specific aggregate blend 0/4mm.

The reduction of the coarsest aggregate size (from 0/6 mm to 0/4 mm) in addition to high void content, enhances the acoustic absorption and helps reduce the acoustic emission due, in part, to tyre/pavement impact.
The acoustic measurements show that this innovative BBTM 0/4mm leads to a superior level of performance (minimum acoustic gain is 2,4 dB(A), representing more than 50% noise reduction) than the other French asphalts concrete evaluated. This gain can reach 4,1 dB(A) in comparison to former continuous wearing courses 0/14mm.

Furthermore, the specific mixture is extremely fluid and easy to implement, which in turn leads to a suitable surface texture (mega texture, macro texture and evenness).
These characteristics, combined with suitable aggregates, support a good level of skid resistance.

Moreover, the innovative formulation of the BBTM 0/4mm with polymer-modified bitumen allows sustainable mechanical and acoustic performances as shown by several measurements.

The implementation of the BBTM 0/4mm doesn't require specific laying equipment for open-graded asphalt concrete 0/6mm in a very thin layer, apart from compliance with the usual laying rules.
Several innovation protocols were signed for a 5-year period with highway managers in order to ensure the thorough and regular technical follow-up to the BBTM 0/4mm. The technical follow-up could be extended up to an additional seven-year period.

With regard to overall performance and the layers' durability, this type of product will be made available where necessary to significantly reduce transportation noise and the "black point traffic noise" identified in all countries.

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