

The Search for the Best Concrete Surface Texture Relative to Noise and Skid Resistance in Québec

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Abstract

Concrete pavements under the ministère des Transports du Québec (MTQ) are located on the highest trafficked roads in the province, often in urban areas. In the late 1990s, the MTQ noted a skid resistance problem for most of the concrete pavements rebuilt since 1994. The texture specified at the time for the new pavements was the result of dragging an Astroturf mat on the surface of the fresh concrete. This produced a low noise pavement, but skid resistance measurements were disappointing. Since 2000, the MTQ has specified the transverse tining on fresh concrete; this technique is known to provide better skid resistance. However, it is sometimes noisier and complaints were recorded in some areas. It was also found that skid resistance issues still occurred because of the limestone coarse aggregate used in almost all concrete pavements since 1994. It has been banned since 2003. Since 2004, to counter the noise effect, the longitudinal tining technique has been increasingly used by MTQ project engineers. Various other techniques were tested on new slabs such as exposed aggregate, shot-blasting and grinding. All our experimental sections were subject to tire-pavement noise measurement by our custom-made equipment.

Introduction

The mission of the ministère des Transports du Québec (MTQ) is to ensure, throughout Québec, the mobility of people and goods through safe and efficient transport systems, which contribute to the economic, social and sustainable development of Québec. The policy on pavement noise, adopted in 1998, also sets out the position of the MTQ in relation to pavement noise, and essentially aims to reduce the noise generated by the use of road transport infrastructure in order to help achieve the government's environmental and land use objectives. It goes without saying that the two criteria, user safety and pavement noise, must be met for all types of pavement whether flexible or rigid. The designer's challenge is considerable, especially when the project is in an urban environment and traffic is very high, since it must combine both criteria.

This paper will present the steps followed by the MTQ, the experiences and the results in finding a concrete texture that will combine the durability of skid resistance with the lowest possible noise level. The aim of this research is to select the best option for Québec roads and, therefore, the safest for all users.

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The textures used since 1994 in Québec will first be presented, as well as the history of skid resistance and pavement noise. MTQ skid resistance measurements will then be detailed relative to the apparatus used and the results obtained on several sections tested for both new pavements and maintenance techniques. MTQ noise measurements will also be detailed relative to the apparatus and results for rigid and flexible pavements. These two characteristics will then be analysed together to determine the best compromise for concrete pavement texture in Québec.

Context

History of concrete pavement textures and skid resistance at MTQ since 1994. From 1994 to 1999, the technique used on **fresh concrete** was to drag an Astroturf mat to give texture to rigid pavements. However, the skid resistance was rapidly lost over time. To correct this problem, transverse tining has been added to the Astroturf since 2000. To ensure an acceptable skid resistance and noise level, the spacing needs to be random (between 16 and 38 mm) and the depth has to be between 3 and 6 mm. Despite the use of transverse tining, the higher skid resistance has not been maintained over time compared to Astroturf only. The loss of skid resistance is related to the nature of the coarse aggregate used at that time (dolomite and limestone), which were more sensitive to polishing. Moreover, autoroute 20 (Ste-Julie/Boucherville) and autoroute 15 (Boisbriand) have deep transverse tining (about 10 mm), good aggregates, a better skid resistance over time, but are especially loud. Some complaints were recorded due to the noisy texture. As a result, the section on autoroute 15 was overlaid with asphalt in 2005. Since 2004, longitudinal tining is rather used to minimise the noise. The longitudinal tining technique is added to the Astroturf with the following characteristics: the depth is between 3 and 6 mm, the width is 3 mm and the spacing is 19 mm.

In 2004, different exposed aggregate textures were tried as well as longitudinal tining, especially on autoroute 40 (Montreal/Kirkland/Dorval). The exposed aggregate technique consists of applying a set retarder onto the fresh concrete then protecting it with a waterproof membrane. Several hours later, the mortar, which has not yet set, is washed away to expose the aggregate.

In 2005, again on autoroute 40, shot-blasting was tried on the newly constructed slab. It consists of projecting a steel abrasive media at high speed onto the concrete surface. The abrasion clears the mortar on top of the aggregate to a depth of up to 6 mm.

In 2008, the Next Generation Concrete Surface (NGCS) technique has been tried on autoroute 15 (St-Jérôme). This technique is usually done in a two-pass diamond grinding operation that resembles a combination of a flush grinding and a longitudinal grooving. The flush grinding is mainly used to correct the transverse profile with spacing between the blades of 0.6 mm and a width of 3.2 mm. The texture is given by the grooving, with spacing of 12.7 mm, a width of 3.2 mm and a depth between 3.2 to 4.8 mm.

For the **maintenance techniques**, shot-blasting was widely used in 2004 and 2005 on most highways that had an Astroturf texture. Longitudinal grooving has been tried on a 500 meter section in 2007, and shot-blasting and grinding have been tried respectively in 2009 and in 2010 on autoroute 440 (Laval). The grinding used on that project has a uniform blade spacing of 3.3 mm. This kind of grinding is a little different from the conventional grinding, which has lesser spacing between the blades.

Finally, when used on concrete later in the maintenance cycle, an asphalt overlay requires a specific thin gap-graded asphalt mix with a thickness of about 50 mm. The bonding between the asphalt overlay and concrete needs to be excellent to withstand the high shear stresses at the interface. A clean surface and the good type of tack coat are essential.

Pictures of different concrete pavement textures are shown on Figure 1. Table 1 presents the projects done since 1994 by their year of completion as well as their location and texturing.

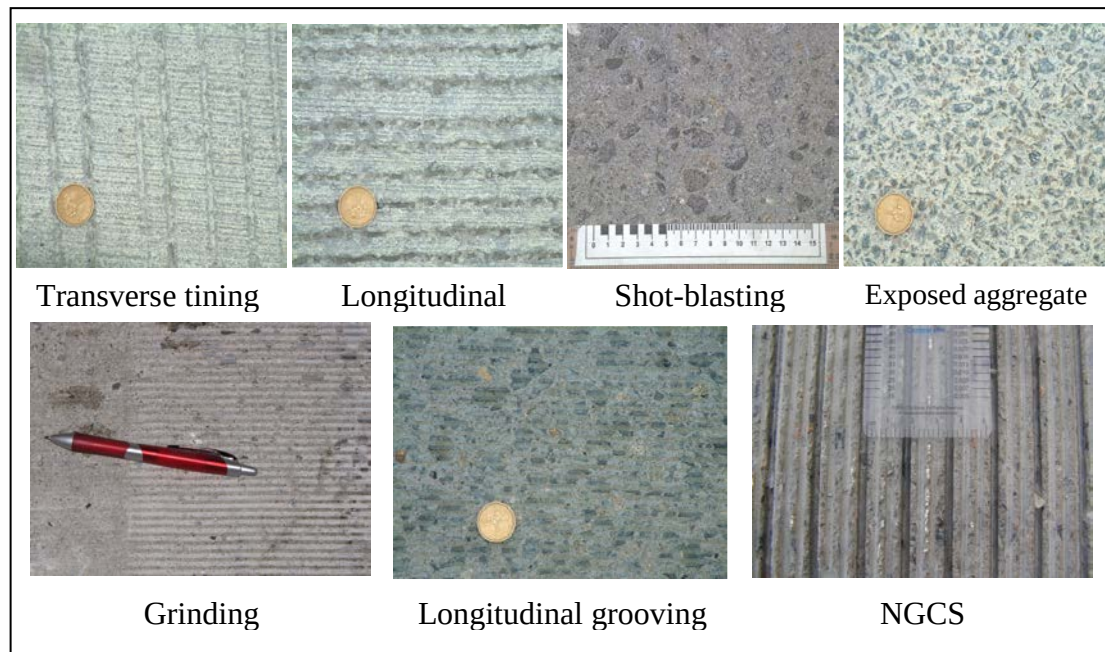


Figure 1: Different textures of rigid pavements

Table 1: Concrete pavement projects in Québec since 1994

Year	Autoroute	City	Texture (Construction)	Maintenance
1994	15	Montréal	Astroturf	2005: shot blasting
1994, 1997-1998	440	Laval	Astroturf	2007: longitudinal grooving* 2009: shot-blasting* 2010: grinding*
1995, 1997	40	Vaudreuil	Astroturf	2004-2005: shot- blasting
1998	Souigny Blvd	Montréal	Astroturf	2005: shot-blasting
1998-1999	40	Anjou	Astroturf	2004-2005: shot-blasting
2000-2001	13	Laval	Transverse tining	
2001-2002	20	Ste-Julie /Boucherville	Deep transverse tining	
2002	15/132	La Prairie	Astroturf	
2002-2003	15	Boisbriand	Deep transverse tining	2005: asphalt overlay
2003-2006	40	Montréal /Kirkland / Dorval	* Transverse tining, exposed aggregate, shot-blasting and longitudinal tining	
2005	10	Brossard	Transverse tining	
2005	13	Montréal	Transverse tining	
2007-2008	13	Boisbriand	Longitudinal tining	
2007-2010	15	St-Jérôme /Mirabel /Blainville	* Longitudinal tining 2008: NGCS, exposed aggregate	
2009	Souigny Blvd	Montréal	Longitudinal tining	
2009-2011	30	St-Constant	Longitudinal tining	
2010-2011	40	L'Assomption	Longitudinal tining	
2010-2011	132/20	Longueuil	Longitudinal tining	
2010-2011	20	St-Apollinaire	Longitudinal tining	
2011	40	Anjou / East Montréal	Longitudinal tining	

*Experimental 500 meter sections only

History of tire-pavement noise. There are two principal methods to measure traffic generated noise: statistical pass-by (SPB) and close-proximity (CPX). The first determines what a resident perceives, but is only punctual, since it depends on the topography, background noise and weather conditions. The second measures the noise directly at the tire-pavement contact. It doesn't represent what a resident would perceive, but is more appropriate for comparing different pavement textures (Rasmussen et al. 2007).

In Québec, the need for a tire-pavement noise apparatus was first discussed in 2004. The principal goal of the MTQ was to compare the different textures, especially of concrete pavements, since there were some concerns about the noise. Therefore, the first CPX-method apparatus was functional in 2005, but the concept evolved to achieve a final product in 2009.

The SPB method is used by the Island of Montréal DOT and collaborations compare both measurements.

In 2004, the University of Auburn, Alabama, came to measure noise with their National Center for Asphalt Technology (NCAT) apparatus. Also, the Cement Association of Canada (CAC) has commissioned the American Concrete Pavement Association (ACPA) since 2006, to assess the noise measurement of our experimental sections with the On-Board Sound Intensity (OBSI). These results have also helped in the development of our own apparatus.

Concrete pavement skid resistance development

Skid resistance. The skid resistance between the tire and the pavement depends on several parameters: the friction conditions (normal load, trajectory, and speed of the vehicle), the tire characteristics, the weather and the surface characteristics (macrotexture, microtexture and surface contamination).

The macrotexture is the relief created by the aggregate on the concrete surface. It plays an important role in the drainage of water at the tire-pavement contact and prevents hydroplaning. It is influenced by the shape, angularity and size of the aggregate. It is possible to measure the macrotexture with the sand patch test (ASTM E 965) to obtain the mean texture depth (MTD) or continuously with an optical laser (TM2) to obtain the mean profile depth (MPD). The sand patch height should be higher than 0.60 mm to be considered acceptable. The profile measured with the TM2 should be higher than 0.50 mm (Thébeau and Pouliot 2007).

Both MTD and MPD were measured simultaneously on some of our sections. Results are shown in table 2. The sand patch test is a punctual measure and can only give an indication since the texture may vary throughout the section. Both MTD and MPD for Astroturf texture do not meet the requirements. The MPD for the longitudinal tining is significantly lower than the MTD. Because the longitudinal texture is not always perfectly aligned, there is an error associated with the optical laser going inside or between the tining.

Table 2 : MTD and MPD value for different concrete pavement sections

Results per year (mm)		2002		2004		2005	
Location	Texture	MTD	MPD	MTD	MPD	MTD	MPD
Aut. 15, Montréal (1994)*	Astroturf	0,31	0,32	0,22	0,17	0,30	0,35
Aut. 440, Laval (1994)	Astroturf	0,25	0,29			0,27	0,33
Aut. 440, Laval (1997)	Astroturf	0,24	0,29				0,30
Aut.40, Vaudreuil (1997)	Shot-blasting			0,37	0,25		
Aut. 40, Anjou (1999)*	Astroturf		0,53				0,64
Aut.15, Boisbriand (2002)	Transverse tining			0,81	1,09		
Aut.40, Montréal, CRCP (2004)	Transverse tining			0,85	0,81		
Aut.40, Montréal, CRCP (2004)	Transverse tining			0,93	0,9		
Aut.40, Montréal, CRCP (2004)	Exposed aggregate			0,77	0,81		
Aut.40, Montréal, CRCP (2004)	Exposed aggregate			1,65	1,34		
Aut.40, Montréal, CRCP (2004)	Longitudinal tining			0,71	0,38		

*Shot-blasting in 2005

Microtexture is related to small asperities on the surface of the aggregate. It is influenced by the mineralogy and the texture of the coarse aggregate as well as the paste associated with the fine aggregate. It significantly affects braking distances on wet surface and the maintenance of the trajectory in curves. The microtexture of a pavement is evaluated with the SCRIM device, presented next. The microtexture of an aggregate can be measured in the laboratory by the aggregate resistance to polishing test (LC 21-102) which provides a Polished Stone Value (PSV) measured by a shotblasting method. The PSV must be greater than 0.45 according to the standard (NQ 2560-114) or greater than 0.50 on highways with high traffic according to specifications. This requirement excludes several aggregates, generally limestone and dolomite (Thébeau and Pouliot 2007).

SCRIM apparatus. The microtexture of a highway is evaluated using the SCRIM apparatus that provides a transverse friction coefficient on wet surface. The Sideway-force Coefficient Routine Investigation Machine (SCRIM) is used in England to measure skid resistance of highways. It is the only apparatus of its kind in North America. The apparatus consists of a test wheel, a load cell, a water pump, an hydraulic pump and an electronic system. **Error! Reference source not found..** The principle of the test is to measure the sideway-force coefficient, which will be referred to as the Sideway Force Coefficient (SFC). The SFC is generated by the test wheel which is driven at an angle of 20 degrees from the longitudinal axle of the road (see Figure 2). It is calculated using Equation 1. For safety reasons, tests are conducted at a speed of 60 km/h (about 37 mph). Measurements are taken in the right wheel path and a water projection of 1.0 mm is made on the pavement in front of the test wheel.

Critical thresholds of the SFC are closely related to the speed limits, the pavement type (divided or single), the radius of curvature, the vertical slope and the presence of an intersection, a roundabout, a crossing or a pedestrian crossing (PIARC 2003). For all types of road, the MTQ requires a SFC greater than or equal to 55 at a test speed of 60 km/h. In some cases, such as on divided highways without intersection with a straight and a flat profile, a SFC between 40 and 55 may be acceptable. Finally, a SFC under 40 requires a specific investigation and a possible

corrective action that takes into account the macrotexture, geometry of the road, speed limits and traffic flow (Thébeau and Pouliot 2007).

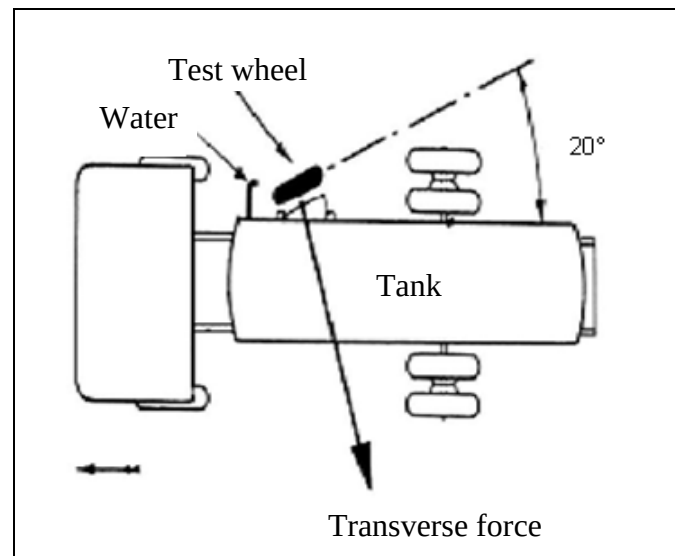


Figure 2: Principle of measurement and calculation of the SFC

$$\text{SFC} = \frac{\text{Transverse force} \times 100}{\text{Vertical mass}} \quad \text{Equation 1}$$

Test sections. The MTQ is following 11 test sections on new pavements where different textures were made including longitudinal and transverse tining, exposed aggregate (5-10 mm, 5-14 mm and 5-20 mm coarse aggregate), shot-blasting and the NGCS. In addition, several test sections using different maintenance techniques are followed: shot-blasting, longitudinal grooving and grinding.

Results on new pavements. The surveys conducted since 1994 showed a significant decrease of the SFC over time on some concrete highways. Prior to 2000, the texture method used for the new pavements involved dragging an Astroturf mat on the surface of the fresh concrete and the aggregates used were also more sensitive to polishing. Results of SFC for different textures are shown on Figure 3. Sections paved in 1994 and 1995 show a decrease in the SFC below 40 after 7 years. Those sections were made with dolomite and limestone coarse aggregate. To improve the skid resistance, transverse tining has been added to the Astroturf on fresh concrete since 2000. However, this addition was still not enough given the poor nature of the aggregate. Since 2003, dolomite and limestone have been banned in concrete pavements. It is therefore possible to see an increase of the SFC for the 2003 and 2004 projects on Figure 3, where a combination of a tining texture and a better aggregate can maintain a higher SFC over time, even if the traffic is significantly higher. It is also possible to see the tendency of the SFC to increase after 15 and 16 years. This could be explained by the loss of paste around the aggregate, making it more exposed. This tendency will be followed in our future test sections.

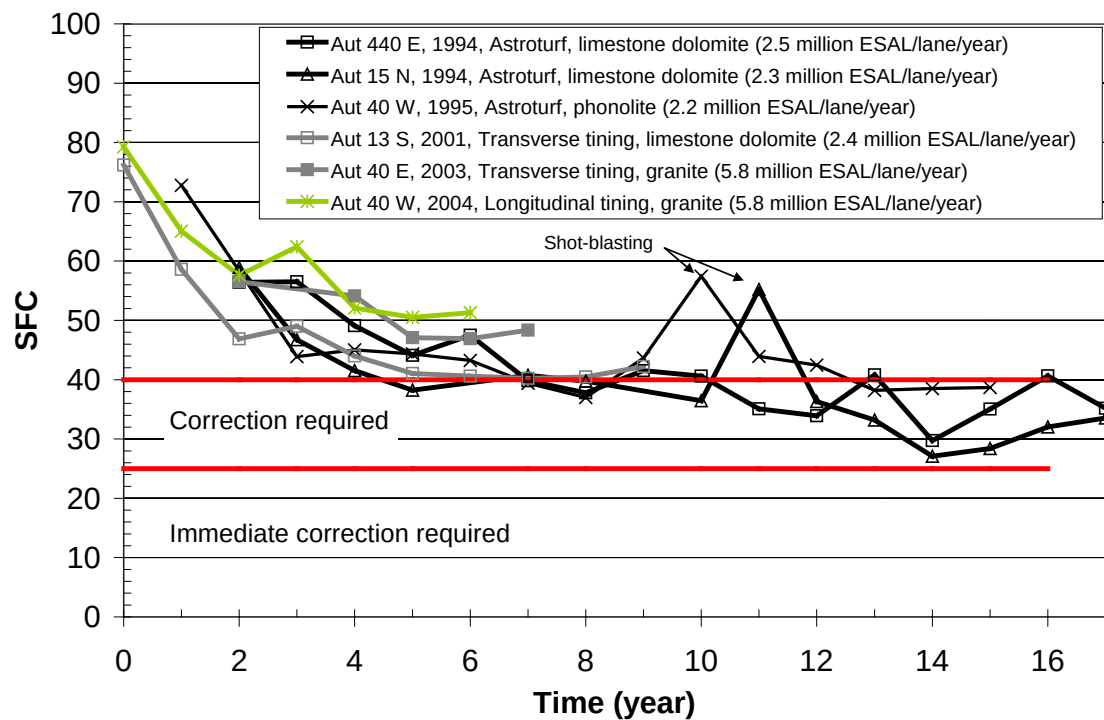


Figure 3: SFC of different textures

From 2004, longitudinal and transverse tining as well as exposed aggregate were tried in Montréal on autoroutes 15 and 40. In 2008, the NGCS has also been tried on autoroute 15. The results in Figure 4 show a generally higher SFC for those new textures (more than 65) compared to Astroturf only (less than 60, Figure 3) within the first years. After the first years, the SFC tends to stabilize at less than 40 for the Astroturf and at around 50 for the other textures. After several years, the SFC is similar for longitudinal and transverse tining, exposed aggregate (5-14 mm) and shot-blasting for autoroute 40. Only exposed aggregate using 5-20 mm aggregate shows a lower SFC after 6 years of life. For autoroute 15, all textures show similar SFC, except for the NGCS, which shows promising results. Despite its low traffic, the skid resistance on autoroute 15 seems to decrease faster. The quality of the aggregates used may explain this difference between autoroutes 40 and 15. However, in both cases, the SFC decreases rapidly within the first two years, but tends to stabilize after that.

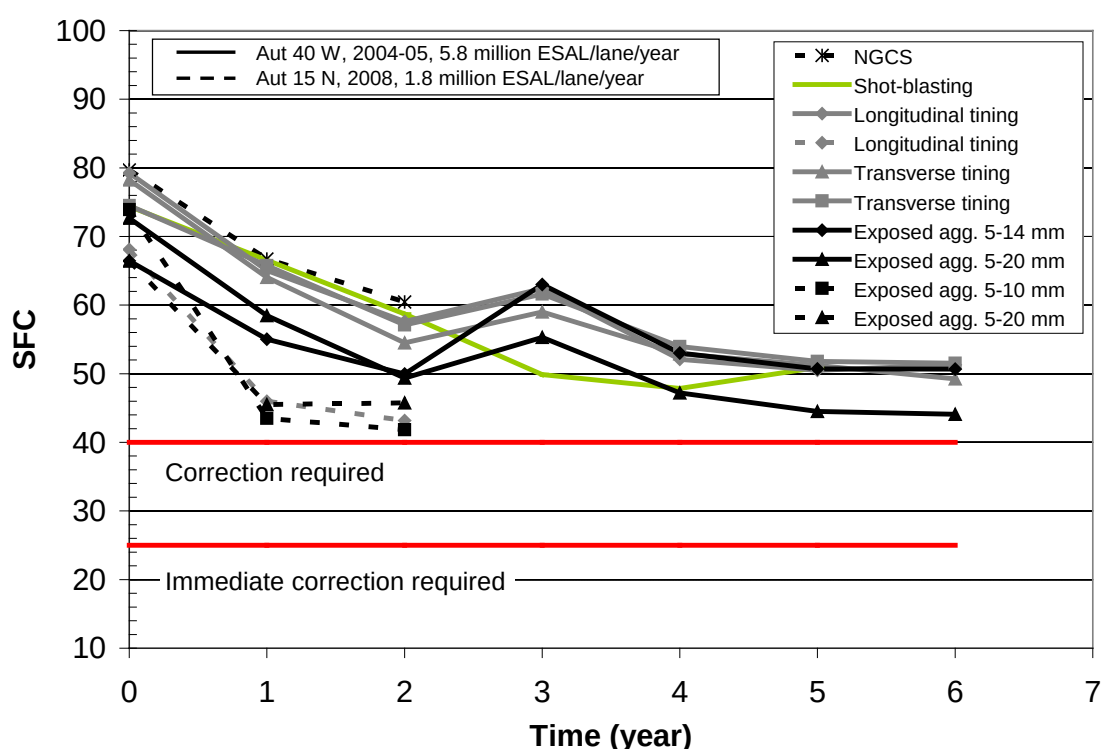


Figure 4: SFC evolution for different textures on new pavements

Pavement maintenance results. Maintenance has been performed to improve the skid resistance of existing concrete slabs. In 2004 and 2005, many of the projects completed between 1994 and 1999 with Astroturf and dolomite and limestone coarse aggregate were shot-blasted. In Figure 3, it is possible to see that the SFC on autoroute 15 and 40 increased after maintenance, but returned to their initial value after only one year. It was the same result for the other sections where shot-blasting was done regardless of the traffic. In 2007, a longitudinal grooving was done on a 1994 project. Results in Figure 5 show the gain related to the maintenance on both center and left lanes. However, the longitudinal grooving was not done deep enough in this project to reach the bottom of the ruts, especially in the center lane (most trafficked lane) where the ruts were about 6.6 mm deep. The ruts on the left lane were about 3.7 mm deep. Even if these are normal values for a 17 years old section, a grinding should have been done prior to the longitudinal grooving to remove the ruts, since the longitudinal grooving is about 3 to 5 mm deep. This phenomenon is visible as it is possible to see that the left lane, which has lower rut depths, reaches a higher SFC. It is also possible to see that the SFC increases after the longitudinal grooving. This could be caused by the wear of the edge of the grooving over time. In 2010, a project was done where the grinding was deeper than the ruts; however, there was no grooving. Like shot-blasting, there was a loss of the SFC after one year.

This is why the MTQ plans to move on to NGCS for maintenance contracts. This technique uses a grinding to first remove the ruts, followed by longitudinal grooving for an optimal texture.

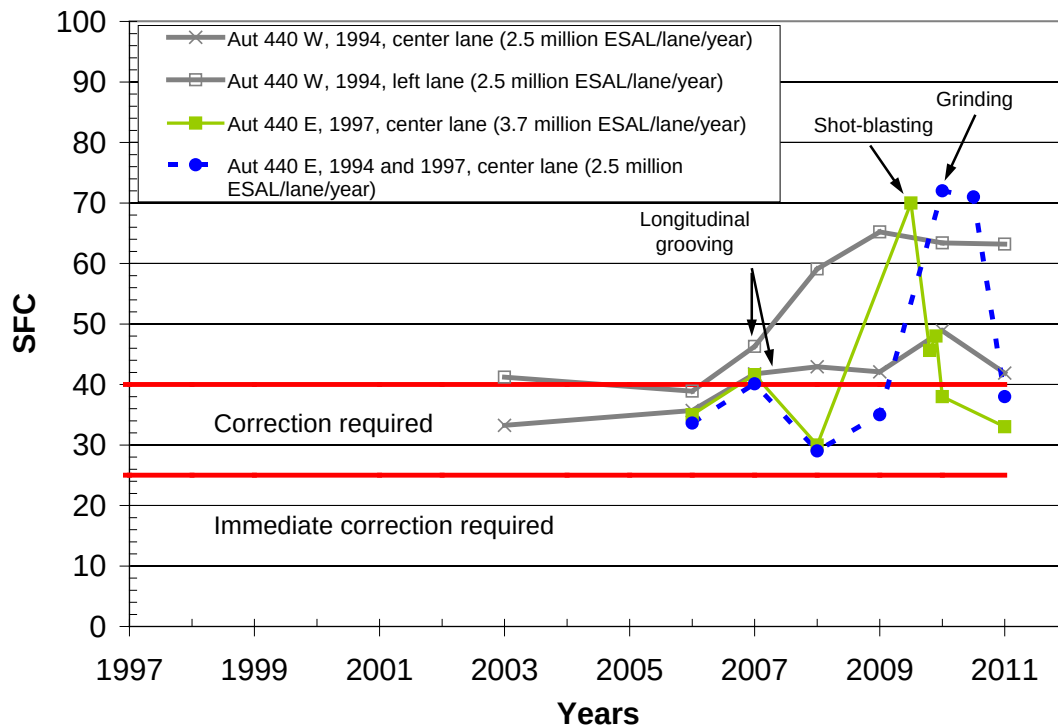


Figure 5: SFC evolution for different pavement maintenance techniques on autoroute 440 (Laval)

Pavement noise measurements

Tire-pavement noise. There are many traffic sources that can produce noise: power units, tire-pavements and aerodynamics. Noise related to aerodynamics only applies to very high speeds that are not reached on highways. Power unit noise applies, especially while accelerating, but does not increase with speed, unlike tire-pavement noise. The moment the power unit noise becomes lower than the tire-pavement noise is called “the crossover speed”. For a car, this speed is reached at around 32 to 48 km/h during acceleration, which is the worst case. For a truck, this speed is about 80 km/h during acceleration, or between 56 and 80 km/h while cruising. It is, therefore, possible to accept that on highways, tire-pavement noise dominates (Rasmussen et al. 2007).

The mechanisms that generate tire-pavement noise are as follows (Rasmussen et al. 2007):

- “tread impact”, which is the radial vibration or the direct individual impact of the tire on the pavement, like a hammer;
- “air pumping”, which is air compression that escapes thousands of times, the pressure relief causing the noise;
- “stick-slip”, where the tire loses momentarily its friction and slip, also called tangential movements;
- and “stick-snap”, which is a suction effect that creates adhesion between the tire and the pavement.

All of these can also be amplified by other mechanisms that will modify certain frequencies.

In order of importance, texture, porosity and stiffness of a pavement affect tire-pavement noise. The textures that are repeated every 10 to 150 mm are most likely to affect noise. For a quiet pavement, you need a small negative texture (maximum 10 mm spacing and 5 mm deep with small aggregates). The porosity is the percentage of air of a surface. It manages to absorb sound and prevent it from spreading into the air, especially when over 20%. Moreover, the greater the porosity, the less contact between the tire and the pavement there is. The stiffness of a pavement has little effect, but the more it approaches that of a tire, the less noise it will produce (Rasmussen et al. 2007).

RDA apparatus. In 2005, the MTQ developed a Road Dynamic Audiometer (RDA) to measure tire-pavement noise using the CPX method. The apparatus was based on draft standard ISO/CD 11819-2 and evolved into a satisfactory product in 2009. At first, the frame supporting the microphones was fixed on the vehicle body. To prevent the microphones from moving on the vertical axis, it was decided to use a new frame fixed to the wheel axle in 2006. This bigger and more complex frame created some vibrations and increased the noise level. Some modifications and improvements were made from 2007 and a Chevrolet Uplander has been dedicated exclusively to tire-pavement noise measurements since 2009. The tire used is similar to the type A specified by the ISO standard.

As shown in Figure 7, the microphones are installed near the left rear tire and fixed on the vehicle body, similarly to the 2005 concept. The result is an arithmetic average of the 3 A-weighted sound pressure levels of the 3 microphones installed at angles of 45°, 90° and 135°. Results are corrected for a reference speed of 100 km/h and a temperature of 20°C. According to the ISO standard, no test is conducted if winds are greater than 15 km/h since open-air microphones are used.

In this case, nothing is done to reduce the background noise. However, the NCAT has made measurements on some of our sections with their CPX Trailer in 2005. Their CPX Trailer has an acoustical enclosure that can prevent the interference of unwanted noise. Their results were between 10 and 12.8 dBA lower than the RDA results, which would represent the background noise (Pouliot et al. 2006). This seems to be consistent with the value of 10 dBA prescribed by the ISO 11819-2 draft standard. However, further analyses related to frequencies are required as well as other comparison since our apparatus has changed since 2005.

Since 2006, the OBSI also made measurements on some of our sections. Their CPX apparatus is similar to the RDA, but measures sound intensity instead of sound pressure, which allows removing sound coming from certain directions, thus keeping only what is produced by tire-pavement contact. Results from both apparatus are shown in Figure 6 for 2009 data. Even if OBSI's microphones are located closer to the tire, RDA sound levels are about 3.3 dBA higher. The standard deviation is smaller for the RDA, which indicates that its measurements are affected by something more constant. Several factors may explain these differences, like the wind turbulence or the different type of tire used by the two organisations. Moreover, the MTQ measures the entire project while OBSI only measures a short section. However, the ranking has a similar trend for most sections.

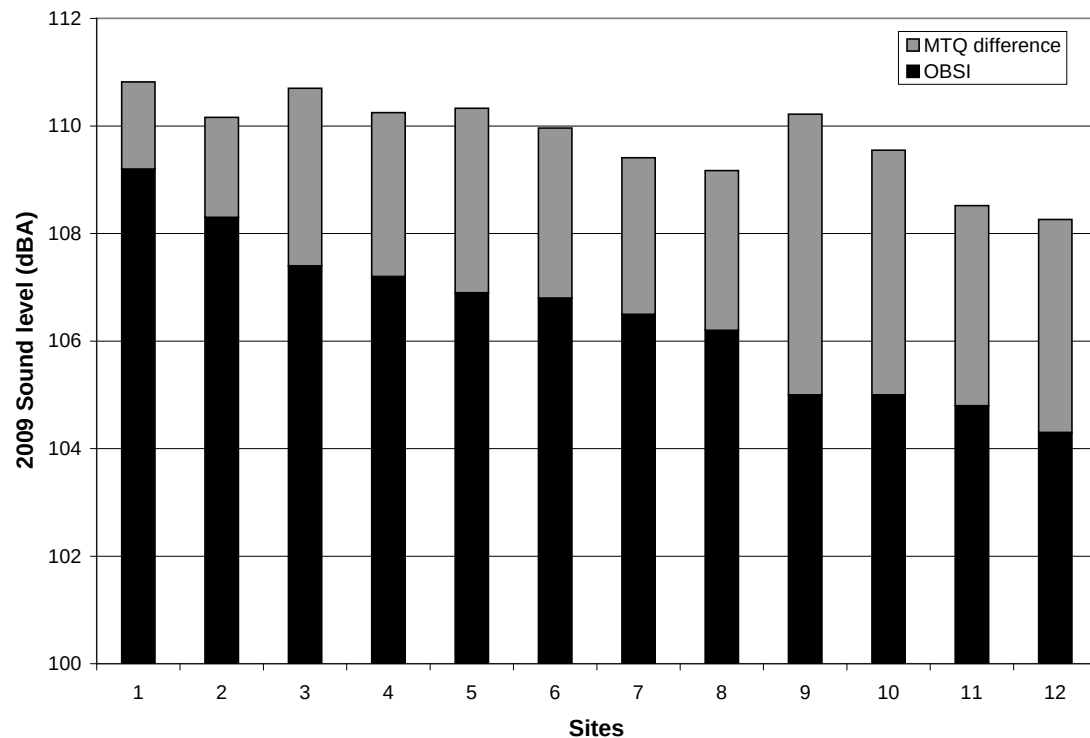


Figure 6 : OBSI and MTQ level for different site location and texture



Figure 7: Road Dynamic Audiometer

Noise. Noise is actually a sound, which is simply a small change in air pressure. This pressure is often converted into a logarithmic scale in units of decibels (dB) to fit our hearing. Frequency describes how fast these changes in air pressure occur. In addition to sound levels, frequencies from 315 to 4000 Hz using third-octave-band resolution are also analysed. Because the human ear is not equally sensitive to all frequencies, an A-filter is applied, resulting to an A-weighted sound pressure level (dBA) (Rasmussen et al. 2007).

It is important to know that two sounds having the same sound pressure level in dBA will not necessarily be perceived the same way depending on their frequencies distribution. Therefore, an analysis of both the sound pressure level and the frequencies are required. Moreover, when more than one source is present, it is not possible to simply add the decibels. For example, doubling the volume of traffic is

equivalent to increasing the noise by approximately 3 dBA. Two sources of 70 dBA will then produce the equivalent of 73 dBA.

Test sections. Different asphalt and concrete pavements were tested and results of their A-weighted sound pressure level are reported in Figure 9. The texture and their respective ages are reported on the vertical axis. Stone-mastic asphalt (SMA), open-graded (OG), thin open-graded (Thin-OG), dense-graded (DG), micromilling (MM) and microsurfacing (MS) were among the flexible pavements tested. Transverse tining, longitudinal tining, longitudinal grooving, exposed aggregate, shot-blasting and the NGCS were among the rigid pavements tested. The different textures for flexible pavements are also shown in Figure 8. For rigid pavements, textures were shown previously in Figure 1.

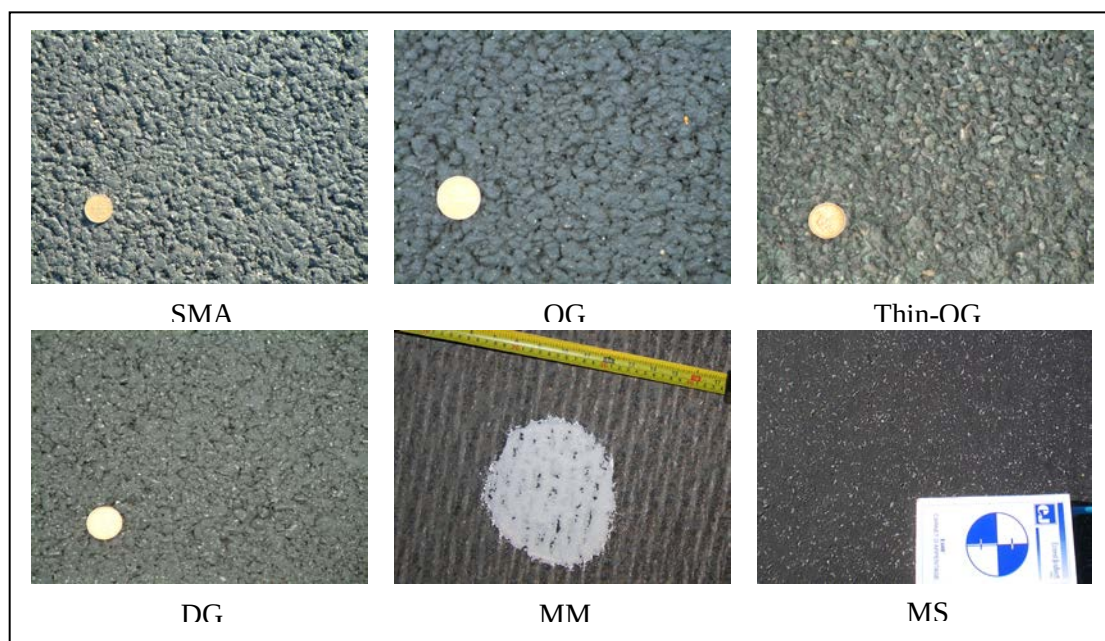


Figure 8: Different textures of flexible pavements

Results. Results from our first measurements show that concrete pavements are in general louder, but some textures show promising results. Transverse tining and shot-blasting are the louder rigid pavement textures while longitudinal tining and grooving are the quieter. The NGCS is also giving promising results. Exposed aggregate is in the middle. However, some previous studies began looking at the frequencies and showed that exposed aggregate, longitudinal tining and shot-blasting didn't have the disturbing peak at 1000 Hz, associated to the transverse tining (Pouliot et al. 2006). It is, therefore, possible that even if shot-blasting was found to be louder than transverse tining, it would maybe not be perceived that way by users. Further studies need to be made with frequencies.

For flexible pavements, young pavements seems to be quieter, the thin-OG and OG being the quietest. MS was expected to be the loudest flexible pavement according to its positive texture, but MM and SMA of about the same age were found to be louder. After a couple of years, the asphalt overlay seems to be loud, probably because of the reflective cracking in the overlay, originated from the JPCP transverse joints.

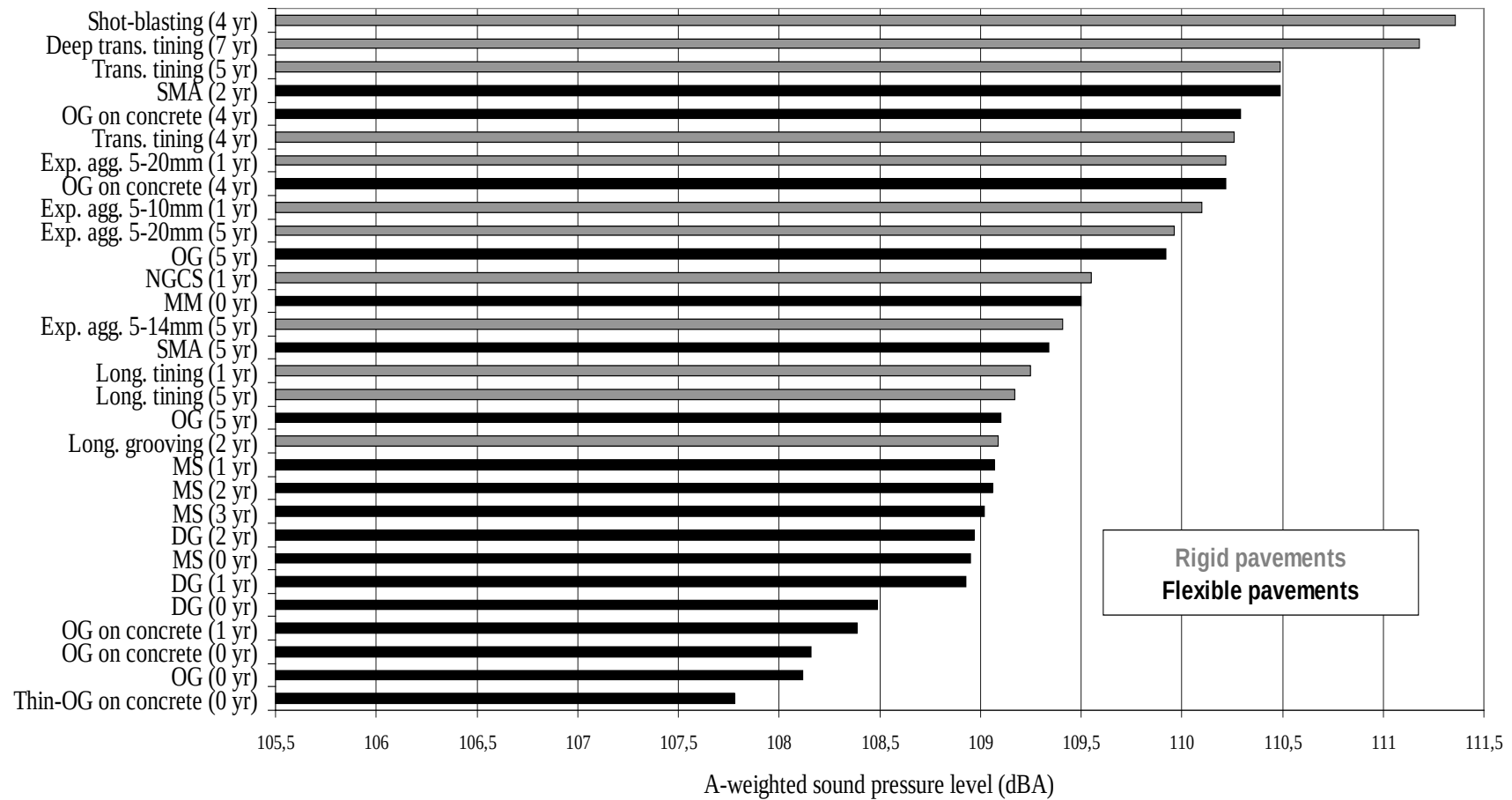


Figure 9: A-weighted sound pressure level for different pavements in Québec

For the future, the next step would be to study the evolution of tire-pavement noise over time for the same test section. It will be interesting to see how a concrete pavement evolves compared to a flexible pavement. The noise of a flexible pavement tends to increase over time because its macrotexture closes, leading to less noise absorption, unlike concrete pavement texture that becomes less deep, resulting in less noise amplification (Sandberg and Ejsmont 2002). Some tire-pavement noise measurements have also been made on some of our sections in collaboration with the CAC and the ACPA since 2006. Those results will also help to evaluate the evolution of noise over time.

What is, to date, the best concrete pavement texture compromise?

At the beginning of the 1990s, only the skid resistance issue was a concern. About 10 years ago, the pavement noise issue was added to the skid resistance issue. We have tried to put into relation the tire-pavement noise and the skid resistance results. Only data measured in 2009 for both characteristics were used: no real relation has been found. Other variables have to be taken into account like the frequencies, the age, as well as the macrotexture that are quite important to characterize a pavement. However, it is possible to observe some tendencies. The results in Figure 10 show that for rigid pavement, shot-blasting and transverse tining are among the loudest pavements with a low SFC. Longitudinal tining is quieter, but does not show a really better skid resistance. On the other hand, longitudinal grooving and the NGCS are quieter while having a good SFC. However, the value reported for the longitudinal grooving is for the left lane, which showed better results than the center lane. Exposed aggregate sometimes show a good SFC, but is still a little louder than the NGCS.

For flexible pavements, MM seems to be the optimal choice, having a good SFC while being quiet. MS has a wide range of SFC values, not always depending on the age.

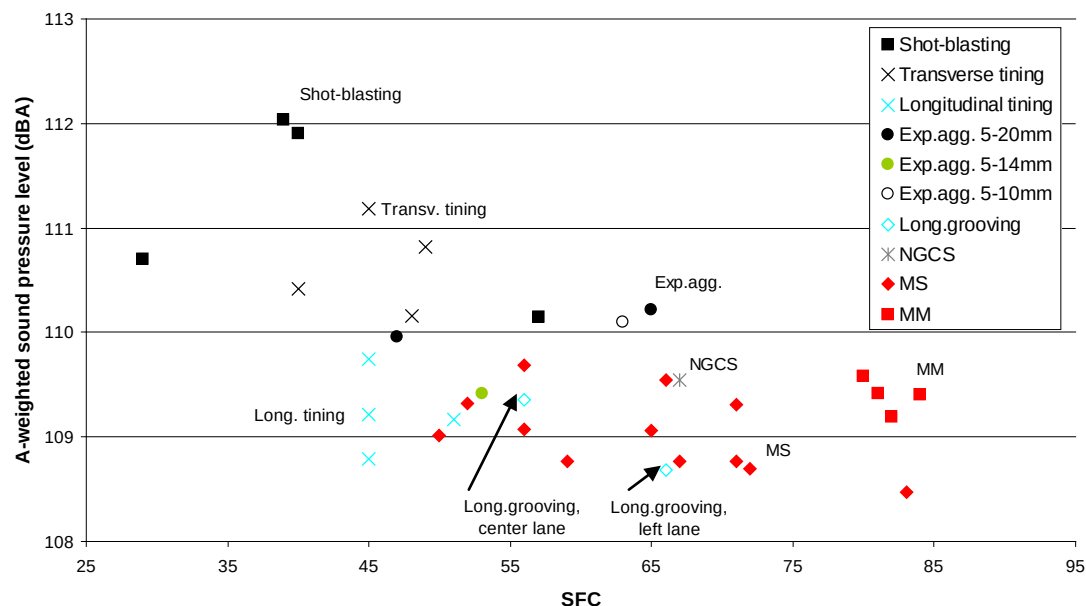


Figure 10: Sound level in function of the SFC

Conclusion

To find a texture that combines the durability of skid resistance and the lowest possible noise level, the MTQ has followed several test sections where both measurements were made.

In regard to skid resistance, the MTQ has noted a decrease of the skid resistance on some projects completed using the Astroturf mat and dolomite and limestone coarse aggregate in the 1990s. The following measures were adopted to counter this problem:

- The limestone and dolomite coarse aggregate were banned;
- Transverse and longitudinal tining was added to the Astroturf.

Except for the Astroturf, the other textures show similar results, but the maintenance techniques have been disappointing. Only the NGCS seems to show promising results.

In regard to noise, transverse tining and shot-blasting were the louder rigid pavement textures while longitudinal tining and grooving were the quieter. The NGCS is also giving promising results. Exposed aggregate is in the middle.

Therefore, where the noise level is an issue, longitudinal tining is currently the texture that is recommended for new pavements. For maintenance techniques, the MTQ currently recommends NGCS for its high SFC and low noise level.

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