New ISO Test Track Specification for Measuring Tire and Vehicle Noise

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International standard ISO 10844 is applicable to test tracks used for evaluating vehicle exterior (pass-by) noise. The objective of the standard is to provide a high degree of reproducibility between different test tracks. Toward that objective, the standard specifies properties of the test track to (a) ensure that noise propagation is not significantly affected by the surface, and (b) minimize the variability of tire-pavement noise generation. There are significant changes in the methods of measuring the pavement’s acoustic absorption and texture properties compared with the 1994 version of the standard. Acoustic absorption affects noise propagation over the surface, and the standard now requires the two-microphone impedance tube method measured in situ. Pavement texture affects tire-pavement noise generation, and the standard now specifies laser-based profiling methods. Advantages and benefits of the new test methods are described along with practical techniques to help ensure valid measurements. The article also explores the possibility of supplementing ISO 10844 measurements with standard tire-pavement noise testing using the on-board sound intensity (OBSI) method. This additional test provides a direct measure of the tire-pavement noise response, which can be compared to the pavement texture being used as an indirect indicator of this response. The OBSI method also allows for a measure of the variability of tire-pavement noise along the length of the test track (spatial variability).

ISO 10844 applies to test tracks used for measuring exterior vehicle and tire noise. It is required by ISO 362, which is one of the main standards governing vehicle pass-by noise. The objective of ISO 10844 is to control the reproducibility of noise measurements on test tracks; i.e., reduce the variability of noise measurements on tracks at different sites. A new version of ISO 10844 was released in early 2011 with the intention of better achieving this objective.

The properties of the test track that affect noise are of two types:

• Source-related properties – those that affect the amount of noise emitted by a vehicle traveling on the track.
• Path-related properties – those that affect the propagation of noise to the measuring microphone.

Properties in the first group include pavement texture, which is a significant factor in generating tire-pavement noise. Tire-pavement noise is generated through tire-to-pavement contact; therefore, the standard contains requirements on the evenness of the pavement to control bumps or dips that would change the geometry of the tire contact patch as a vehicle moves. In addition, the sound absorption property of the pavement affects the amount of noise generated at the tire-pavement interface.

The second group includes the general layout and geometry of the pavement over the propagation area. In addition, the sound absorption property of the pavement affects source-to-microphone propagation paths that include reflections off the pavement surface.

This article discusses the improvements in ISO 10844:2011 and our experiences applying this latest version to conformity tests of noise test tracks, the equipment needed, and conformity test process. Emphasis is placed on the new methods for measuring acoustic absorption and texture. We conclude with some suggested supplemental measurements that may help further develop our understanding and control of the variability in tire-pavement noise from test tracks.

What’s New in the 2011 Version?

The significant changes from the 1994 version of the standard to the 2011 version can be grouped into three categories: construction, measurement methods, and metrics and limits. In regard to construction, the updated version allows for asphalt mixtures with polymer-modified binder that can be tailored for the local climate and environment. This allows for tracks with pavements more resistant to surface wear and extends the stability of the texture over time. In addition, the aggregate (sand and gravel) blend must meet the sieving (sizing) curve specified in the standard. In the earlier version, the sieving curve was informative.

In the category of measurement methods, three new methods are specified:

• For quantifying texture in the megatexture to unevenness range (flatness of the surface), it is specified to follow standard EN 13036-7, which employs a 3-meter straightedge and gap gage to determine surface evenness.
• The measurement of texture in the megatexture to macrotexture ranges is changed from using the volumetric patch method (sand patch method) to using a Class DE texture profilometer defined in ISO 13473-3. This change represents a shift from a subjective, operator-dependent method to a more objective and modern approach.
• Acoustic absorption measurements are performed in situ with an impedance tube conforming to ISO 13472-2. The prior version of the 10844 standard relied on either indirectly measuring void content or a bench-top impedance tube, both involving the removal of core samples; this is destructive to the pavement.

Several metrics and associated limits are updated in the new version. Objective requirements controlling surface evenness and smoothness (grade, cross slope, and irregularity) are added. The texture metric is also changed from mean texture depth (MTD) to mean profile depth (MPD). Of particular significance, however, is that there are now lower and upper bounds placed on the MPD (the older standard had a lower limit only). Finally, sound absorption now has a requirement for each one-third-octave band from 315 to 1600 Hz and separate requirements for the drive lane and propagation area.

Overall, the updates improve the standard with respect to better control of the surface geometry, texture, and sound absorption.

Summary of Requirements

Basically, an ISO 10844 noise test track consists of a drive lane with propagation areas on each side. Figure 1 shows the configuration, size, and free space radius required by the standard. Other properties covered by the standard include:

Geometry.
• Step between drive lane and propagation area
• Gradient (longitudinal slope) and cross fall (transverse slope)
• Irregularity (texture at wavelengths longer than 0.5 m)

Surface Properties.
• Surface texture (MPD)
• Sound absorption coefficient
• Sieving curve

To ensure the geometry, surface texture, and absorption are homogeneous over the test track, there is a homogeneity requirement placed on these properties. Both the average of all the samples and 80% of the samples must meet the requirements. In addition, the standard provides for acceptance testing (new construction) and intervals for periodic checking as the test track ages. Tables 1

and 2 summarize the requirements, including frequency of checking, areas of application (drive lane and propagation area), and homogeneity. Other general construction requirements are that the surface pavement must be dense asphalt, and the thickness of the top wearing course must be greater than or equal to 30 mm.

**Conformity Testing**

This section describes the measurement methods, equipment, and procedures for checking conformity of a test track to the standard.

**Measurement Grid and Points.** The first step is to define a transverse grid with 5-meter intervals on which to base the measurement points. An initial grid line is chosen randomly within ±2.5 m of the microphone line. From this first line, a transverse grid is established at 5-meter intervals along the entire length of the drive lane (including drive-lane extensions). Figure 2 shows an example layout of the transverse grid and measurement points.

In the drive lane, a measurement point is located at each grid line but on alternating sides of the centerline. The distance from the measuring point to the centerline is randomized so that the points are not longitudinally aligned.

In the propagation areas on each side of the drive lane, at least two measurement points are selected at random locations. In addition, a measurement point is selected close to the microphone line and in front of the microphone location (between the microphone location and drive lane centerline). This results in a total of at least six measurement locations in the propagation areas.

**Step, Gradient, and Cross-Fall.** Slopes are measured using standard surveying methods and equipment, such as a laser level on tripod and graduated rod (see Figure 3). The elevation at key positions is measured along each transverse grid line, at the outside boundaries of the propagation areas, at the joints between drive lane and propagation areas, and at the drive-lane centerline. If there is a step between the drive lane and propagation area, then the elevation on each side of the step is measured. From this set of elevation measurements, the following is calculated:

- Gradient (longitudinal slope) of the drive lane along the centerline and along each edge.
- Cross fall in the drive lane at all the transverse grid lines.
- Cross fall in the propagation area at the transverse grid lines that traverse the propagation area.
- Step heights of the joints between drive lane and propagation areas.

Elevation profiles can be plotted to visualize the general slope of the test track (see Figure 4).

**Irregularity.** Irregularity is measured using the straightedge test defined by EN 13036-7. This method requires a calibrated straightedge three meters long accompanied by a wedge-shaped gage calibrated in 1-mm increments (see Figure 5). The measurement procedure is straightforward. The straightedge is laid on the pavement with the measuring edge on the surface. The wedge gage is then used to locate the greatest gap between the straightedge and the surface.
and pavement, and the gap is recorded to the nearest 1 mm. The pavement surface must be clear of loose grit and debris that could lift the straightedge off the surface and bias the measurement.

The irregularity is measured at all the established points. The straightedge should be positioned on the pavement in each of the longitudinal and transverse directions so that it is centered at the measurement point. However, for the transverse direction at points in the drive lane, the straightedge should be centered across the drive lane. For points close to the track boundaries, the straightedge should be offset from the center so that the entire length of the straightedge remains within the track boundaries.

**Surface Texture.** ISO 10844:2011 requires the methods, equipment, and analyses of texture to follow the ISO 13473 series of standards. First, a brief introduction to the relevant parts of these standards.

A texture profile is a two-dimensional representation of a surface: one dimension is distance along the pavement (longitudinal or transverse) and the second dimension is amplitude or elevation of the surface. ISO 13473-1\(^6\) describes a test method to calculate the MPD of a pavement surface from the measured texture profile.

ISO 13473-3\(^4\) specifies requirements for texture profile-measuring devices (profilometers). Classifications are made with respect to accuracy and the capability for measurements within various texture wavelength ranges (micro-, macro-, and mega-texture, for example). ISO 10844:2011 requires a Class DE profilometer, which means it must evaluate texture wavelengths in the range from 2.5 to 200 mm and a sampling interval less than or equal to 1 mm.

ISO 13473-4\(^7\) describes methods for conducting spectral analysis of pavement texture profiles. Spectral analysis is routinely performed on acoustic signals sampled in the time domain (units are seconds), and transformed to the frequency domain (units are cycles/second or Hz). For the case of pavement texture, the signal is sampled in the spatial domain (units are mm) and then transformed to spatial frequency (units are cycles/meter) or wave number (units are meter/cycle). Spectral analysis of the texture is done to calculate a quantity, ENDT. ENDT is an estimate of the difference in tire-pavement noise level generated by the track under test relative to a track with a reference surface. Since it is a level quantity, ENDT has units of dB. ENDT is not a requirement of ISO 10844:2011 but is included as an appendix and encouraged to be measured, with results communicated to the standards working group.

Most profilometers meeting these requirements use a laser-based distance sensor. The Transtec Group employs a robotic-based profilometer (RoboTex) using a line laser rather than a spot laser (Figure 6). Use of a line laser results in a three-dimensional surface profile, with distance across the laser line as the third dimension. The system is capable of sampling at a rate of 1000 Hz at 100 points across the width of the laser line as it travels down the drive lane at approximately 0.5 m/s. The result is a pavement texture measurement with a spatial resolution of about 0.5 mm longitudinally by 1.0 mm transversely and a height resolution of 0.01 mm. Figure 7 shows a sample result of the three-dimensional texture profile along a 100-mm wide swath of pavement surface.

The robotic profilometer allows for a continuous measurement of the profile in each wheel track for the entire length of the drive lane. Following the methods specified in ISO 10844, the profiles are divided into 5-meter segments, and an MPD is determined for each segment.

**Sound Absorption.** The previous version of the standard, ISO 10844:1994, required that the sound absorption coefficient of the track surface be measured using the standing-wave method of ISO 10534-1\(^8\) on core samples extracted from the pavement. However, ISO 10534-1, developed mainly for measuring sound absorption coefficient of acoustic materials, allows the use of a range of impedance tube diameters and lengths that lead to inconsistent results. By contrast, the new ISO 10844:2011 mandates that the track sound absorption properties be measured using the procedures and equipment specified in ISO 13472-2,\(^7\) which is based on the two-microphone method of ISO 10534-2. ISO 13472-2 specifies the diameter and length of the impedance tube within close tolerances and recommends a procedure to seal between the track surface and the impedance tube. Recent reports document the use of ISO 13472-2 for *in situ* measurements of asphalt and concrete road surfaces.\(^10-11\)

Figure 8 shows an impedance tube with USB-powered data acquisition system known as ACUPAVE built according to ISO 13472-2 by Spectronics, Inc., USA. A key element in the system is the pavement attachment fixture. This fixture must seal well with the impedance tube and with the pavement surface so that sound does...
not leak out and ambient sound does not leak in. Typically, sealing between the fixture and the pavement is made by using a flexible sealant like modeling clay or putty. Figures 9 and 10 show how the pavement attachment fixture is used with a flexible sealant.

A performance test in which the sound absorption is measured with the tube mounted on a 10-mm thick plate is used to determine the reference (or baseline) sound absorption of the system. ISO 13472-2 requires that the baseline sound absorption of the system be less than 3% in each one-third-octave band from 315 to 1600 Hz. Figure 11 shows the impedance tube configured for the baseline absorption measurement.

ISO 13472-2 also requires that a relative phase and magnitude calibration of the microphones be performed prior to any measurements. This is done by inserting a piece of sound-absorbing material in the impedance tube followed by a microphone swapping procedure like that used in the measurement of sound absorption of acoustic materials by the two-microphone method of ISO 10534-2. Figure 12 shows a piece of sound absorbing material placed in the pavement fixture prior to attaching the impedance tube for the microphone calibration step.

The baseline sound absorption is subtracted from the measured pavement absorption to obtain the corrected sound absorption of the pavement. Figure 13 shows sample sound absorption results for a dense-grade asphalt pavement. Tables 1 and 2 show the maximum permissible values of corrected sound absorption required for conformance to ISO 10844:2011 in each one-third-octave band from 315 to 1600 Hz.

Supplemental Measurements

One objective of the ISO 10844 standard is to control the generation of tire-pavement noise from the test surface. The standard implicitly assumes that MPD is the pavement texture quantity that is the significant factor in tire-pavement noise generation. However, research has shown that MPD does not always correlate well with tire-pavement noise generation and that other texture metrics can correlate better.12-14 In addition, there is now a standardized method for directly measuring tire-pavement noise, the on-board sound intensity (OBSI) method. This section discusses other texture metrics and the OBSI method as recommended supplements to the ISO 10844 MPD measurement.

Texture Metrics. For a texture metric to predict tire-pavement noise, the metric should quantify texture in a manner that relates to how it interacts with a tire. Figures 14a and 14b illustrate the classic example of two pavement surface profiles that are upside down versions of each other. That is, the profile of 14b is profile 14a just flipped over about a horizontal axis. It is easy to envision how a tire traversing across Profile 14a will quietly roll over the deep indentations, while on Profile 14b, the tall, sharp peaks will excite the tire tread and generate noise. The texture of Profile 14a is predominantly negative (downward directed), while Profile 14b is predominantly positive (upward directed). However, MPD does not fully capture the magnitude of positive-directed versus negative-directed textures and, therefore, is not optimum for predicting tire-pavement noise generation.

To capture positive- versus negative-directed texture characteristics, more fundamentally relevant metrics are available. An
Figure 16. Tire-pavement noise versus distance for two noise test tracks.

Figure 17. Noise, mean profile depth, and texture skew for Track A overlaid using relative linear vertical scale.

eample is the statistical quantity skew, which is based on the third moment about the mean. The profile in Figure 14a (with negative texture) has negative skew. The profile in Figure 14b (with positive texture) has positive skew. An example of a test track having MPD and skew with contrasting degrees of correlation to tire-pavement noise is presented under “Noise Variation and Correlation to Texture.”

In addition to skew, ISO 13565-215 describes alternative texture metrics that further recognize positive and negative texture. In this standard, the profile is transformed into a profile-bearing curve and divided into three regions: peaks, core, and valleys. From these regions, various parameters are derived, including reduced peak height ($R_{pk}$), core roughness depth ($R_{h}$), and reduced valley depth ($R_{vl}$).

Additional metrics can be determined using bridging filters that are based on how flexible tire tread blocks impregnate pavement texture.16 We suggest evaluating these and other alternative texture metrics, which can be reported along with MPD to further develop and refine the capability of using texture metrics to control tire-pavement noise of the test track.

**Direct Measurement.** The OBSI test is a method of quantifying tire-pavement noise by measuring sound intensity on board the moving test vehicle at fixed locations relative to a tire mounted in a specific axle position. The procedure uses two measurement locations, one near the leading edge of the tire contact patch and a second near the trailing edge. The intent is to include the noise generated by both of those sources (see Figure 15). Sound intensity is measured rather than sound pressure, because the directional characteristic of the intensity probe allows it to focus toward the noise source of interest (near the edges of the contact patch) while reducing background noise from other directions (such as engine, exhaust, and wind noise).

OBSI as a test procedure is well developed and standardized as AASHTO TP-76.17-18 Significant factors controlled during the standardized test procedure include the vehicle speed (the standard prefers 60 mph, or 97 kph), the test tire (16-inch standard reference test tire, or SRTT, specified by ASTM F 249319), and the applicable frequency range (third-octave bands from 400 to 5000 Hz). Sound intensity measured at the leading and trailing-edge positions are A weighted, time averaged over the length of the pavement tested, and combined into a single result. The OBSI result is reported as an overall level and in third-octave bands. This method is a direct measure of the tire-pavement noise, and results allow for various pavements and textures to be directly compared. The authors suggest the OBSI level be measured and reported along with other ISO 10844 results to help further understand and establish the reproducibility of tire-pavement noise generation from noise test tracks.

**Noise Variation and Correlation to Texture.** The standard OBSI test procedure specifies averaging time coincident with the length of the pavement tested. However, by using shorter averaging times, the tire-pavement noise level as a function of distance along the test section can be obtained. Such results can be used to demonstrate the variation (or homogeneity) of the tire-pavement noise within a test track.

Figure 16 shows the OBSI level as a function of distance for two ISO 10844 test tracks using an averaging time of 0.5 seconds. The absolute levels cannot be compared, because these tests were conducted at different vehicle speeds — 45 mph (72 kph) and 60 mph (96 kph). However, the variation within each track is clearly identified. For each track, the variation in tire-pavement noise is within 1 dB. Track A, however, has a bias at one end of the track, with a trend toward higher tire-pavement noise levels at a distance of 40 meters and beyond. Noise from Track B goes through a 0.8-dB oscillation over the first half of its length. This type of data reveals that both tracks have relatively constant noise generation (±0.2 dB) over only half of their track length.

Tire-pavement noise level as a function of distance also allows for correlation to texture. Figure 17 shows superimposed plots of noise (OBSI) and two texture metrics (MPD and skew). In this case, texture skew correlates to noise better than MPD. This illustrates how MPD alone is not the optimum texture metric for predicting tire-pavement noise.

**Conclusions**

The 2011 version of standard ISO 10844 is significantly improved over the prior 1994 version in terms of fulfilling the objective of controlling the reproducibility of noise measurements across test tracks. It has stronger controls on test track surface evenness, texture, and sound absorption. The standard is now more up to date with recent measurement methods for surface profiling, in situ impedance tube apparatus, and the two-microphone method for sound absorption.

This article offers supplemental metrics for texture and methods for direct measurement of tire-pavement noise to help further understand and control the variation of test track performance.

**References**


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