Road Surface Absorption Measurement System
WA-1599

March 2013
Yunseon Ryu(Yoo)

Sound Absorption
Absorber

- Absorber is a porous material, cellular or fibrous structure
- Activities inside the material include:
  - Viscous dissipation
  - Fibrous rub against each other
  - Sound energy transformed to thermal energy

Performance is expected in terms of:

**Sound Absorption Coefficient (α)**

\[
\alpha = \frac{\text{Sound energy absorbed}}{\text{Sound energy incident}}
\]

Where, \( \alpha \) = By a surface \((I_i - I_r)\)

On that surface \((I_i)\)

---

Absorber (continued)

- Coefficient varies from zero (0) to one (1)

Performance is a function of frequency
- Performed generally with the increase in frequency

- Performance improves with the increase in thickness
  - Material thickness: At least 1/10 wavelength of sound to justify the use (i.e., offer any benefit)
  - Material thickness: ¼ wavelength of sound to be effective
Absorption effect of various parameters

- Effect of porosity
- Effect of thickness
- Effect of density
- Effect of airspace between the absorber and the wall
- Effect of facing
  - No facing
  - Impervious membrane facing
  - Perforated facing
- Effect of perforation

Qualitative effect of various factors
Standardization

International Organization for Standardization
American Society for Testing and Materials

The Standards

- **Reverberation Room Method**
  - ASTM C 423-99a: Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method

- **Standing Wave Impedance Tube Method**
The Standards (Cont.)

- **Two-microphone Impedance Tube Method**

The Standards (Cont.)

- **Free-field Method**

- **Spatial Fourier Transform Method**
  - No known standard available. Not even on draft level.
The Two-microphone Method

An Overview

- Broadband Random Noise Excitation
- Measurement of Sound Pressure (FFT)
- Calculation of Transfer Functions

Reflection Factor:
\[ R = \frac{H_1 - H_i}{H_1 - H_r} e^{i 2 \pi s / \lambda} \quad [-] \] where
- \( H_1 \): Frequency Response Function (FRF)
- \( H_i \): FRF associated with the incident component
- \( H_r \): FRF associated with the reflected component
- \( \lambda \): Wavelength
- \( s \): Microphone distance to sample [m]

Absorption Coefficient:
\[ \alpha = 1 - |q| \] [-]

Normalized Impedance Ratio:
\[ \frac{z}{\rho c} = \frac{1 + R}{1 - R} \] [ ]
- \( \rho \): Impedance of the Air
Working Frequency Range

● Lower working frequency \( f_l \) limited by:
  - The frequency resolution of the analysis system
  - The frequency response of the loudspeaker
  - The spacing between the microphones
    » \( 0.05*\lambda_i < s \Rightarrow f_l > 0.05*\text{c}_0/s \) (ISO 10534-2)
    » \( 0.01*\lambda_i < s \Rightarrow f_l > 0.01*\text{c}_0/s \) (ASTM E 1050)

Working Frequency Range

● Upper working frequency \( f_u \) limited by:
  - The cross section of the tube
    » \( d < 0.58*\lambda_u \Rightarrow f_u < 0.58*\text{c}_0/d \) (Circular tube) (ISO 10534-2)
    » \( d < 0.586*\lambda_u \Rightarrow f_u < 0.586*\text{c}_0/d \) (Circular tube) (ASTM E 1050)
    » \( d < 0.50*\lambda_u \Rightarrow f_u < 0.50*\text{c}_0/d \) (Rectangular tube) (ISO and ASTM)
  - The spacing between the microphones
    » \( s < 0.45*\lambda_u \Rightarrow f_u < 0.45*\text{c}_0/s \) (ISO 10534-2)
    » \( s <= 0.40*\lambda_u \Rightarrow f_u <= 0.40*\text{c}_0/s \) (ASTM E 1050)

The upper working frequency is chosen to avoid the occurrence of non-plane wave mode propagation and to assure accurate phase detection

\[ \text{c}_0 = 343.2\sqrt{T/293} \]
The Tube

- The tube must be long enough to cause plane wave development:
  - \( x_{\text{ms}} > d \) (minimum)
  - \( x_{\text{ms}} > 3d \) (recommended)

- The spacing (l) between sample and closest microphone must be long enough to avoid proximity distortions to the acoustic field:
  - Non-structured layer: \( l > d/2 \)
  - Semi-lateral structured layer: \( l > d \)
  - Strongly asymmetrical layer: \( l > 2d \)

\( x_{\text{ms}} \): The distance between source and closest microphone [m]

The Microphones

- They must be placed in the plane wave field
- Their membrane diameter should be small in relation to their spacing to reduce the influence of their acoustic centers:
  - \( d_{\text{mic}} < 0.2s \)
- Their membrane diameter should be small to minimize high frequency spatial averaging across the diaphragm face:
  - \( d_{\text{mic}} << \lambda_u \)

\( d_{\text{mic}} \): The diameter of the microphone
Specifications of Impedance Tube 4206

<table>
<thead>
<tr>
<th>Tubes</th>
<th>d : Diameter [mm][in]</th>
<th>l : Length [mm][in]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Meas. Tube</td>
<td>29 (1.1)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Medium Meas. Tube</td>
<td>63.5 (2.5)</td>
<td>200 (17.4)</td>
</tr>
<tr>
<td>Large Meas. Tube</td>
<td>100 (3.9)</td>
<td>440 (17.4)</td>
</tr>
<tr>
<td>Small Sample Holder</td>
<td>29 (1.1)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Medium Sample Holder</td>
<td>63.5 (2.5)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Large Sample Holder</td>
<td>100 (3.9)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Small Ext. Tube</td>
<td>29 (1.1)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Large Ext. Tube</td>
<td>100 (3.9)</td>
<td>200 (7.9)</td>
</tr>
</tbody>
</table>

**Frequency Range**

- Large Tube: 50Hz to 1.6kHz
- Medium Tube: 100Hz to 3.2kHz
- Small Tube: 500Hz to 6.4kHz

**Zero Absorption**

- 50Hz to 4kHz: <4%
- 5kHz to 6.4kHz: <10%

Calculated in 1/3-octave band

**Types of Errors**

- Random Errors
- Bias Errors
  - Measurement distance from specimen
  - Different acoustic and geometric centers of microphones
  - Uncorrected phase and amplitude mismatch
  - Data acquisition and computational errors
- Preparation and installation of test specimen (largest error)
- Time Aliasing
- Tube Attenuation
Leakage

Leakage occurs if the tube is not 100% airtight

- **Low frequency leakage can occur at:**
  - The mounting of the sample holder to the tube
  - The backplate in the sample holder

- **High frequency leakage can occur at:**
  - The microphone mountings and the microphones themselves

- **Leakage can be eliminated by:**
  - A proper mechanical construction of the tube and microphones
  - The use of “O-rings”, where moving parts

---

System Configuration (Portable)
Road Surface Absorption Measurement System
WA-1599

ISO Track Layout

Free field (over reflecting plane) conditions

Not drawn to scale

Minimum of 3m wide
And 40m long

7.5m from road centreline

Microphones positioned 1.2m above ground directed horizontally normal to track centreline

Drive Lane

Propagation area

Test Area 20m

Mic Right

Mic Left

50 m
4.2 Surface properties of the propagation area
The surface of the propagation area shall exhibit a sound absorption value not exceeding 10 % on the average of the measurement points in any one-third-octave band between 315 Hz and 1 600 Hz when measured according to 5.3.

NOTE 1 The measure is realized on the site without taking cores
NOTE 2 Absorption level is the corrected result according to ISO 13472-2.
Location and number of measurement points are given in 4.4.

4.3 Surface properties of the drive lane
The surface of the drive lane:

a) shall be dense asphalt concrete and shall exhibit a sound absorption not exceeding 8 % of the measurement points in any one-third-octave band between 315 Hz and 1 600 Hz when measured according to 5.3.

4.4 Proving the requirements

For sound absorption, texture, geometrical and stiffness compliance, the first point shall be chosen randomly (not on the same axis) and the subsequent measurements shall be performed at 5 m intervals to cover the whole track.

All measurements shall be made along the total length of the drive lane in each wheel track.

For checking the surface properties of the propagation area, take at least two measurements randomly chosen on each side.

In addition, sound absorption of the propagation area shall be measured at both sides of the drive lane at half way of the microphone location in the vicinity of the line PP'.

ISO 10844
ISO 10844 "Acoustics – Specification of test tracks for the purpose of measuring noise emitted by road vehicles and their tyres”
ISO 13472-2


Part 2: Spot method for reflective surfaces

5.4 Impedance tube

5.4.1 Tube diameter

The diameter of the tube shall be (100 ± 1) mm. The tube shall have a circular cross-section, be straight with a uniform cross-section (variations in diameter no greater than 0.2 %) and with smooth, non-porous walls, without holes or slits and rigid so as to prevent unwanted loss of sound energy.

NOTE 1 Not meeting the diameter requirement affects the frequency range. The upper frequency at a given diameter, \( f_u \), is given by the equation:

\[
f_u = 0.58* c_0 / d
\]

where

- \( c_0 \) is the speed of sound, in metres per second;
- \( d \) is the diameter, in metres, of the tube.

NOTE 2 Loss of energy due to vibrations of the walls is generally prevented by using a metal tube with a thickness of at least 5 % of the tube diameter.

The tube shall have a small ventilation hole in the vicinity of the loudspeaker so as to prevent build-up of static pressure inside the tube.
ISO 13472-2

5.6 In-situ test fixture between impedance tube and test surface

Similar to a detachable holder (ISO 10534-2:1998, 4.7), an in-situ test fixture shall be fitted in such a way as to avoid air flowing between the end of the tube opposite the sound source and the surface to be measured. Any air leakage through this interface appears as absorption in the measurement results. The in-situ test fixture, like the detachable holder, shall conform to the interior shape and dimensions of the main part of the impedance tube. The connecting joint of the in-situ test fixture shall be finished carefully and shall exhibit no slit or hole. The use of a sealant, such as an O-ring, is required for sealing it to the main part of the impedance tube. Additionally, a groove shall be cut in the in-situ test fixture on the specimen side to accept a bead of sealing material such as water-soluble modeling clay, for sealing the fixture to the road.

Practically, the in-situ test fixture should have a larger outer diameter than the main part of the tube. The additional diameter is not used in the measurement, but this additional portion aids in stability when the system is mounted upright (see Annex C).

The sealing material shall fill irregularities due to surface texture but shall not penetrate into the surface and shall not spread out on the surface.

Measurement points:
For sound absorption, texture, geometrical compliance, the first point shall be chosen randomly (not on the same axis) on each side at the vicinity of the line PP’ and the subsequent measurements shall be performed at 5 m intervals to cover the whole track.

ISO 13472-2

8. Measurement and analysis procedure

The measurement shall be carried out as follows:

a) check the road surface and meteorological conditions to ensure compliance with the specifications in Clause 7 — if these conditions are not met, the measurement cannot be carried out;

b) switch on the system for at least 15 min;

c) perform the microphone calibration procedure (6.2);

d) perform the reference measurement with a totally reflective surface (6.3);

e) place the measuring equipment on site as specified in 7.1, apply the sealant carefully in order to suppress measuring errors due to leakage, and check the correctness of the sealing visually or audibly;

f) perform the measurement: if online monitoring of the result is possible, proceed with averaging until a stable result is obtained — if this is not possible, averaging over 50 sweeps or bursts is recommended;

g) refer to ISO 10534-2 for procedures for measurement and calculation of both the sound pressure reflection factor and the sound absorption coefficient from the transfer function and tube geometry;

h) then compute the road surface sound absorption coefficient in one-third-octave bands (6.6);

i) repeat the measurements on at least four required positions and calculate the mean value and the standard deviation in each one-third-octave band;

j) compile the test report (see Clause 10 and Annex D).
An Overview

- Broadband Random Noise Excitation
- Measurement of Sound Pressure (FFT)
- Calculation of Transfer Functions

Reflection Factor:

\[ R = \frac{H_1 - H_i}{H_1 + H_i} \quad [-] \]

- \( H_1 \): Frequency Response Function (FRF)
- \( H_i \): FRF associated with the incident component
- \( H_r \): FRF associated with the reflected component
- \( k \): Wave number
- \( s \): Microphone to sample distance [mm]
- \( r \): Spacing between the microphones [mm]

Absorption Coefficient:

\[ \alpha = 1 - |R|^2 \]

Normalized Impedance Ratio:

\[ \frac{s}{ρc} = \frac{1 + R}{1 - R} \quad [-] \]

\( ρ \): Impedance of the Air [ ]

\[ \beta = \frac{H_1}{H_2} \]

\( H_1 \): Transfer Function between two microphones

\( R \): Reflection Coefficient

\( α \): Absorption Coefficient

\[ \alpha = 1 - |R|^2 \]

\( P_1 \), \( P_2 \): Sound Pressure

\( s \), \( h \): Spacing between microphones and sample

Sound Source

Signal Generator & Amplifier

Stationary Random Signal

Analyzer

Test Sample

\( P_1 \), \( P_2 \): Sound Pressure

\( P_r \): Reference Sound Pressure

\( H_1 \): Frequency Response Function (FRF)

\( H_i \): FRF associated with the incident component

\( H_r \): FRF associated with the reflected component

\( k \): Wave number

\( s \): Microphone to sample distance [mm]

\( r \): Spacing between the microphones [mm]
System Configuration

- Microphones 4187
  with Preamp 2670
- Power Amplifier WB3514
- PULSE LAN-XI 3160-A
- PC with PULSE software incl.
  Material Testing 775B-N

Specifications of Tube WA 1599

- Working Frequency Range:
  1/3 Octave Analysis: 250 – 1,600 Hz Center frequency
  Narrow Band: 220 – 1,800 Hz
- Diameter of tube: 100 mm
- Shape of section: Circular