Designation: E1050 – 19

Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System[1]

This standard is issued under the fixed designation E1050; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the use of an impedance tube, two microphone locations, and a digital frequency analysis system for the determination of normal incidence sound absorption coefficients and normal specific acoustic impedance ratios of materials.

1.2 *Laboratory Accreditation*—A procedure for accrediting a laboratory for performing this test method is given in Annex A1.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C384 Test Method for Impedance and Absorption of Acoustical Materials by Impedance Tube Method

C634 Terminology Relating to Building and Environmental Acoustics

E548 Guide for General Criteria Used for Evaluating Laboratory Competence (Withdrawn 2002)[3]

2.2 *ISO Standards:*

ISO 10534-1 Acoustics—Determination of Sound Absorption Coefficient and Impedance or Admittance—Part 1: Impedance Tube Method[4]

ISO 10534–2 Acoustics—Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes—Part 2: Transfer-Function Method[4]

2.3 *ANSI Standards:*[4]

ANSI/ASA S1.11 Octave-Band and Fractional-Octave-Band Analog and Digital Filters

3. Terminology

3.1 *Definitions*—The acoustical terminology used in this test method is intended to be consistent with the definitions in Terminology C634.

NOTE 1—Historical literature regarding the measurement of normal incidence absorption coefficients referred to "transfer function" measurements; however, the term arises from Laplace transform theory and is not strictly rigorous when the initial conditions have a non-zero value. The term "frequency response function" arises from more general Fourier transform theory (**1**).[5] This test method shall retain the use of the former term although not technically correct. Users should be aware that modern FFT analyzers may employ the latter terminology.

3.2 *Symbols:* The following symbols are used in Section 8 (Procedure):

3.2.1 $b\rho c$—normal specific acoustics susceptance ratio.

3.2.2 c—speed of sound, m/s.

3.2.3 $g\rho c$—normal specific acoustic conductance ratio.

3.2.4 G_{11}, G_{22}—auto power spectra of the acoustic pressure signal at microphone locations 1 and 2, respectively.

3.2.5 G_{12}—cross power spectrum of the acoustic pressure signals at microphones locations 1 and 2.

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[1] This test method is under the jurisdiction of ASTM Committee E33 on Building and Environmental Acoustics and is the direct responsibility of Subcommittee E33.01 on Sound Absorption.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[5] The boldface numbers in parentheses refer to the list of references at the end of this test method.

3.2.6 H—transfer function of the two microphone signals corrected for microphone response mismatch.

3.2.7 $\bar{H}$—measured transfer function of the two microphone signals.

3.2.8 H^I, H^{II}—calibration transfer functions for the microphones in the standard and switched configurations, respectively.

3.2.9 $\bar{H}_c$—complex microphone calibration factor.

3.2.10 j—equals $\sqrt{-1}$.

3.2.11 k—equal $2\pi f/c$; wave number, m^{-1}.

3.2.11.1 *Discussion*—In general the wave number is complex where $k = k' - jk''$. k' is the real component, $2\pi f/c$ and k'' is the imaginary component of the wave number, also referred to as the attenuation constant, Nepers-m^{-1}.

3.2.12 l—distance from the test sample to the centre of the nearest microphone, m.

3.2.13 $r/\rho c$—normal specific acoustic resistance ratio.

3.2.14 R—complex acoustic reflection coefficient.

3.2.15 s—centre-to-center spacing between microphones, m.

3.2.16 $x/\rho c$—normal specific acoustic reactance ratio.

3.2.17 $y\rho c$—normal specific acoustic admittance ration.

3.2.18 $z/\rho c$—normal specific acoustic impedance ratio.

3.2.19 a—normal incidence sound absorption coefficient.

3.2.20 φ—phase of the complex transfer function, radians.

3.2.21 φ_R—phase of the complex acoustic reflection coefficient, radians.

3.2.22 ρ—density of air, kg/m^3.

3.3 *Subscripts, Superscripts, and Other Notation*—The following symbols, which employ the variable X for illustrative purposes, are used in Section 8:

3.3.1 X_c—calibration.

3.3.2 X_i—imaginary part of a complex quantity.

3.3.3 X_r—real part of a complex quantity.

3.3.4 X^I, X^{II}—calibration quantities measured with microphones placed in the standard and switched configurations, respectively.

3.3.5 $\bar{X}$—measured quantity prior to correction for amplitude and phase mismatch.

3.3.6 $|X|$—magnitude of a complex quantity.

4. Summary of Test Method

4.1 This test method is similar to Test Method C384 in that it also uses an impedance tube with a sound source connected to one end and the test sample mounted at the other end. The measurement techniques for the two methods are fundamentally different, however. In this test method, plane waves are generated in the tube using a broad band signal from a noise source rather than a discrete sinusoid from an oscillator. The decomposition of the stationary sound wave pattern into forward- and backward-traveling components is achieved by measuring sound pressures simultaneously at two spaced locations in the tube's side wall. Calculations of the normal-incidence absorption coefficients for the acoustical material are performed by processing an array of complex data from the measured transfer function.

4.2 The quantities are determined as functions of frequency with a resolution determined by the sampling rate of a digital frequency analysis system. The usable frequency range depends on the diameter of the tube and the spacing between the microphone positions. An extended frequency range may be obtained by using tubes with various diameters and microphones spacings.

4.3 This test method is intended to provide a much faster measurement technique than that of Test Method C384.

5. Significance and Use

5.1 This test method can be applied to measure sound absorption coefficients of absorptive materials at normal incidence, that is, 0°. It also can be used to determine specific impedance and admittance ratios. The properties measured with this test method are useful in basic research and product development of sound absorptive materials.

5.2 Normal incidence sound absorption coefficients can be quite useful in certain situations where the material is placed within a small acoustical cavity close to a sound source, for example a closely-fitted machine enclosure.

5.3 This test method allows one to compare relative values of sound absorption when it is impractical to procure large samples for accurate random-incidence measurements in a reverberation room. Estimates of the random incidence absorption coefficients can be obtained from normal impedance data for locally-reacting materials (**2**).

NOTE 2—The classification, "locally-reacting" includes fibrous materials having high internal losses. Formulas have been developed for converting sound absorption properties from normal incidence to random incidence, for both locally-reacting and bulk-reacing materials (**3**).

5.4 Measurements described in this test method can be made with high precision, but these measurements may be misleading. Uncertainties of greater magnitude than those from the measurements may occur from other sources. Care should be exercised to sample nonuniform materials adequately (see 11.1).

6. Apparatus

6.1 The apparatus is a hallow cylinder, or tube, with a test sample holder at one end and a sound source at the other. Microphone ports are mounted at two or more locations along the wall of the tube. A two channel digital frequency analysis system is used for data acquisition and processing.

6.2 *Tube:*

6.2.1 *Construction*—The interior section of the tube may be circular or rectangular with a constant dimension from end-to-end. The tube shall be straight and its inside surface shall be smooth, nonporous, and free of dust to maintain low sound attenuation. The tube construction shall be massive so sound transmission through the tube wall is negligible.

NOTE 3—The tube can be constructed from materials including metal, plastic, cement, or wood. It may be necessary to seal the interior walls with a smooth coating in order to maintain low sound attenuation for plane waves.

6.2.2 *Working Frequency Range*—The working frequency range is:

$$f_l < f < f_u \tag{1}$$

where:

f = operating frequency, hertz,
f_l = lower working frequency of the tube, hertz, and
f_u = upper working frequency of the tube, hertz.

6.2.2.1 The lower frequency limit depends on the spacing of the microphones and the accuracy of the analysis system. It is recommended that the microphone spacing exceed one percent of the wavelength corresponding to the lower frequency of interest.

6.2.2.2 The upper frequency limit, f_u, and the corresponding wavelength, λ_u, depends on the diameter of the tube and upon the speed of sound.

6.2.3 *Diameter*—In order to maintain plane wave propagation, the upper frequency limit (4) is defined as follows:

$$f_u < K\,c/d \quad or \quad d < K\,c/f_u \tag{2}$$

where:

f_u = upper frequency limit, hertz,
c = speed of sound in the tube, m/s,
d = diameter of the tube, m, and
K = 0.586.

6.2.3.1 For rectangular tubes, *d* is defined as the largest section dimension the tube and *K* is defined as 0.500. Extreme aspect rations greater than 2:1 or less than 1:2 should be avoided. A square cross-section is recommended.

6.2.3.2 It is best to conduct the plane wave measurements well within these frequency limits in order to avoid cross-modes that occur at higher frequencies when the acoustical wave length approaches the sectional dimension of the tube.

6.2.4 *Length*—The tube should be sufficiently long as plane waves are fully developed before reaching the microphones and test specimen. A minimum of three tube diameters must be allowed between sound source and the nearest microphone. The sound source may generate nonplane waves along with desired plane waves. The nonplane waves usually will subside at a distance equivalent to three tube diameters from the source. If measurements are conducted over a wide frequency range, it may be desirable to use a tube which provides multiple microphone spacings or to employ separate tubes. The overall tube length also must be chosen to satisfy the requirements of 6.4.3, 6.5.3, and 6.5.4.

6.2.5 *Tube Venting*—Some tube designs are such that, during installation or removal of the test specimen, large temporary pressure variation may be generated. This may induce microphone diaphragm deflection. The potential for damage to a microphone diaphragm due to excessive deflection may be reduced including a pressure relief opening in the tube. This may be accomplished by drilling a small hole, 1 to 2 mm through the wall of the tube. It is recommended to locate the tube vent near the sound source, away from microphone locations, and to seal the vent during acoustic measurements.

6.3 *Test Specimen Holder:*

6.3.1 *General Features*—The specimen holder may either be integrated with the impedance tube or may be a separate, detachable extension of the tube. Provision must be made for mounting the specimen with its face in a known position along the tube axis and for placing a heavy backing plate behind the specimen. For some measurements it may be desirable to maintain an airspace of known dimensions between the specimen and the backing plate. One such arrangement may be to simulate a suspended ceiling tile.

6.3.2 *Detachable Holder*—As a detachable unit, the holder must make an airtight fit with the end of the tube opposite the sound source. The holder must conform with the interior shape and dimensions of the main part of the impedance tube. The connecting joint must be finished carefully and the use of a sealant, such as petroleum jelly or silicone grease, is recommended for sealing.

6.3.3 *Integral Holder*—If the sample holder is in an integral part of the impedance tube, it is recommended to make the installation section of the tube accessible for mounting of the specimen by a removable cover. The mating surfaces must be finished carefully, and the use of a sealant is recommended for sealing.

6.3.4 *Circular Holder*—For circular tubes, it is recommended to make the specimen accessible from both the front and back end of the sample holder. It is possible then to check the position and flatness of the front surface and back position. Holders may be constructed from a rigid, clear material, such as acrylic, to facilitate inspection.

6.3.5 *Rectangular Holder*—With rectangular tubes, it is recommended to install the specimen from the side, making it possible to check the fitting and the position of the specimen in the tube and to check the position and flatness of the front surface.

6.3.6 *Backing Plate*—The backing plate of the sample holder shall be rigid and shall be fixed tightly to the tube since it serves to provide a sound-reflective termination in many measurements. A metal plate having a minimum thickness of 20 mm is recommended.

6.4 *Sound Source:*

6.4.1 *Kind and Placement*—The sound sources should have a uniform power response over the frequency range of interest. It may either be coaxial with the main tube or joined to the main tube by means of a transition having a straight, tapered, or exponential section (see Fig. 1).

6.4.2 *Isolation*—The sound source and transition shall be sealed and isolated from the tube to minimize structure-borne sound excitation of the impedance tube. If a direct radiator loudspeaker is utilized, it shall be contained in a sound-isolating enclosure in order to avoid airborne flanking transmission to the microphones (see Fig. 1).

6.4.3 *Termination*—Resonances of the air column in the impedance tube may arise if the mechanical impedance of the loudspeaker membrane or diaphragm is high. In this case, it is recommended to apply a porous absorber coating or lining inside either the impedance tube near the loudspeaker or inside