



Standard Test Method for Measurement of Ultrasonic Attenuation Coefficients of Advanced Ceramics by Pulse-Echo Contact Technique¹

This standard is issued under the fixed designation C 1332; 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 describes a procedure for measurement of ultrasonic attenuation coefficients for advanced structural ceramic materials. The procedure is based on a broadband buffered piezoelectric probe used in the pulse-echo contact mode and emitting either longitudinal or shear waves. The primary objective of this test method is materials characterization.

1.2 The procedure requires coupling an ultrasonic probe to the surface of a plate-like sample and the recovery of successive front surface and back surface echoes. Power spectra of the echoes are used to calculate the attenuation spectrum (attenuation coefficient as a function of ultrasonic frequency) for the sample material. The transducer bandwidth and spectral response are selected to cover a range of frequencies and corresponding wavelengths that interact with microstructural features of interest in solid test samples.

1.3 The purpose of this test method is to establish fundamental procedures for measurement of ultrasonic attenuation coefficients. These measurements should distinguish and quantify microstructural differences among solid samples and therefore help establish a reference database for comparing materials and calibrating ultrasonic attenuation measurement equipment.

1.4 This test method applies to monolithic ceramics and also polycrystalline metals. This test method may be applied to whisker reinforced ceramics, particulate toughened ceramics, and ceramic composites provided that similar constraints on sample size, shape, and finish are met as described herein for monolithic ceramics.

1.5 This test method sets forth the constraints on sample size, shape, and finish that will assure valid attenuation coefficient measurements. This test method also describes the instrumentation, methods, and data processing procedures for accomplishing the measurements.

1.6 This test method is not recommended for highly attenuating materials such as very thick, very porous, rough-surfaced monolithics or composites. This test method is not recommended for highly nonuniform, heterogeneous, cracked, defec-

tive, or otherwise flaw-ridden samples that are unrepresentative of the nature or inherent characteristics of the material under examination.

1.7 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

C 1331 Test Method for Measuring Ultrasonic Velocity in Advanced Ceramics with the Broadband Pulse-Echo Cross-Correlation Method²

E 664 Practice for Measurement of Apparent Attenuation of Longitudinal Ultrasonic Waves by Immersion Method³

E 1316 Terminology for Nondestructive Examinations³

E 1495 Guide for Acousto-Ultrasonic Assessment of Composites, Laminates, and Bonded Joints³

2.2 ASNT Document:

Recommended Practice SNT-TC-1A for Nondestructive Testing Personnel Qualification and Certification⁴

2.3 Military Standard:

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification⁵

2.4 *Additional references are cited in the text and at end of this test method.*

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *acoustic impedance (Z)*—a property (**1**)⁶ defined by a material's density, ρ , and the velocity of sound within it, v , where $Z = \rho v$.

3.1.2 *attenuation coefficient (α)*—decrease in ultrasound intensity with distance expressed in nepers (Np) per unit

² Annual Book of ASTM Standards, Vol 15.01.

³ Annual Book of ASTM Standards, Vol 03.03.

⁴ Available from the American Society for Nondestructive Testing, 1711 Arlington Ln., Columbus, OH 43228.

⁵ Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

⁶ The boldface numbers in parentheses refer to a list of references at the end of this standard.

¹ This test method is under the jurisdiction of ASTM Committee C-28 on Advanced Ceramics and is the direct responsibility of Subcommittee C28.02 on Design and Evaluation. Current edition approved March 10, 1996. Published May 1996.

length, herein, $\alpha = [\ln(I_0/I)]/d$, where α is attenuation coefficient, d is path length or distance, I_0 is original intensity and I is attenuated intensity (2).

3.1.3 *attenuation spectrum*—the attenuation coefficient, α , expressed as a function of ultrasonic frequency, f , or plotted as α versus f , over a range of ultrasonic frequencies within the bandwidth of the transducer and associated pulser-receiver instrumentation.

3.1.4 *back surface*—the surface of a test sample which is opposite to the front surface and from which back surface echoes are returned at normal incidence directly to the transducer.

3.1.5 *bandwidth*—the frequency range of an ultrasonic probe, defined by convention as the difference between the lower and upper frequencies at which the signal amplitude is 6 dB down from the frequency at which maximum signal amplitude occurs. The frequency at which the maximum occurs is termed the *center frequency* of the probe or transducer.

3.1.6 *broadband transducer*—an ultrasonic transducer capable of sending and receiving undistorted signals over a broad bandwidth, consisting of thin damped piezoelectric crystal in a buffered probe (search unit).

3.1.7 *buffered probe*—an ultrasonic search unit as defined in Terminology E 1316 but containing a delay line or buffer rod to which the piezoelement, that is, transducer consisting of a piezoelectric crystal, is affixed. The buffer rod separates the piezoelement from the test sample (see Fig. 1).

3.1.8 *buffer rod*—an integral part of a buffered probe or search unit, usually a quartz or fused silica cylinder that provides a time delay between the excitation pulse from the piezoelement and echoes returning from a sample coupled to the free end of the buffer rod.

3.1.9 *free surface*—the back surface of a solid test sample interfaced with a very low density medium, usually air or other gas, to assure that the back surface reflection coefficient equals 1 to a high degree of precision.

3.1.10 *frequency (f)*—number of oscillations per second of ultrasonic waves, measured in megahertz, MHz, herein.

3.1.11 *front surface*—the surface of a test sample to which the buffer rod is coupled at normal incidence (designated as test surface in Terminology E 1316).

3.1.12 *inherent attenuation*—ultrasound energy loss in a solid as a result of scattering, diffusion, and absorption. This standard assumes that the dominant inherent losses are due to Rayleigh and stochastic scattering (2) by the material microstructure, for example, by grains, grain boundaries, and mi-

cro pores. Measured ultrasound energy loss which, if not corrected, may include losses due to diffraction, individual macroflaws, surface roughness, couplant variations, and transducer defects.

3.1.13 *reflection coefficient (R)*—measure of relative intensity of sound waves reflected back into a material at an interface, defined in terms of the acoustic impedance of the material in which the sound wave originates (Z_0) and the acoustic impedance of the material interfaced with it (Z_i), where $R = [(Z_i - Z_0)/(Z_i + Z_0)]^2$.

3.1.14 *test sample*—a solid coupon or material part that meets the constraints needed to make the attenuation coefficient measurements described herein, that is, a test sample or part having flat, parallel, smooth, preferably ground/polished opposing (front and back) surfaces and having no discrete flaws or anomalies that are unrepresentative of the inherent properties of the material.

3.1.15 *transmission coefficient (T)*—measure of relative intensity of sound waves transmitted through an interface, defined in terms of the acoustic impedance of the material in which the sound wave originates (Z_0) and the acoustic impedance of the material interfaced with it (Z_i), where $T = (4Z_i Z_0)/(Z_i + Z_0)^2$ so that $R + T = 1$.

3.1.16 *wavelength (λ)*—distance that sound (of a particular frequency) travels during one period (during one oscillation), $\lambda = v/f$, where v is the velocity of sound in the material and where velocity is measured in cm/ μ s, and wavelength in cm, herein.

3.2 Other terms used in this test method are defined in Terminology E 1316.

4. Summary of Test Method

4.1 This test method describes a procedure for determining a material's inherent attenuation coefficient and attenuation spectrum by means of a buffered broadband probe operating in the pulse-echo contact mode on a solid sample that has smooth, flat, parallel surfaces.

4.2 The procedure described in this test method involves digital acquisition and computer processing of ultrasonic echo waveforms returned by the test sample. Test sample constraints, probing methods, data validity criteria, and measurement corrections are prescribed herein.

5. Significance and Use

5.1 This test method is useful for characterizing material microstructure or measuring variations in microstructure that occur because of material processing conditions and thermal, mechanical, or chemical exposure (3). When applied to monolithic or composite ceramics, the procedure should reveal microstructural gradients due to density, porosity, and grain variations. This test method may also be applied to polycrystalline metals to assess variations in grain size, porosity, and multiphase constituents.

5.2 This test method is useful for measuring and comparing microstructural variations among different samples of the same material or for sensing and measuring subtle microstructural variations within a given sample.

5.3 This test method is useful for mapping variations in the attenuation coefficient and the attenuation spectrum as they

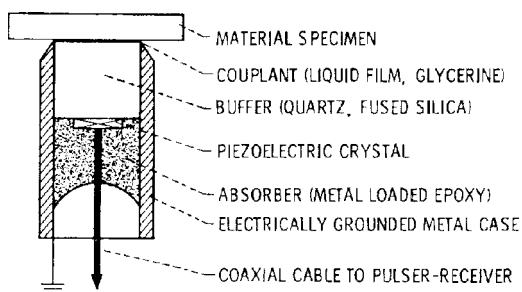


FIG. 1 Cross Section of Buffered Broadband Ultrasonic Probe

pertain to variations in the microstructure and associated properties of monolithic ceramics, ceramic composites and metals.

5.4 This test method is useful for establishing a reference database for comparing materials and for calibrating ultrasonic attenuation measurement equipment.

5.5 This test method is not recommended for highly attenuating monolithics or composites that are thick, highly porous, or that have rough or highly textured surfaces. For these materials Practice E 664 may be appropriate. Guide E 1495 is recommended for assessing attenuation differences among composite plates and laminates that may exhibit, for example, pervasive matrix porosity or matrix crazing in addition to having complex fiber architectures or thermomechanical degradation (3). The proposed ASTM Standard Test Method for Measuring Ultrasonic Velocity in Advanced Ceramics (C 1331) is recommended for characterizing monolithic ceramics with significant porosity or porosity variations (4).

6. Personnel Qualifications

6.1 It is recommended that nondestructive evaluation/examination personnel applying this test method be qualified in accordance with a nationally recognized personnel qualification practice or standard such as ASNT SNT-TC-1A, MIL STD 410, or a similar document. The qualification practice or standard used and its applicable revision(s) should be specified in a contractual agreement.

6.2 Knowledge of the principles of ultrasonic testing is required. Personnel applying this test method shall be experienced practitioners of ultrasonic examinations and associated methods for signal acquisition, processing, and interpretation.

6.3 Personnel shall have proficiency in computer programming and signal processing using digital methods for time and frequency domain signal analysis. Familiarity with the Fourier transform and associated spectrum analysis methods for ultrasonic signals is required.

7. Apparatus

7.1 The instrumentation and apparatus for pulse-echo contact ultrasonic attenuation coefficient measurement should

include the following (see Fig. 2). Appropriate equipment can be assembled from any of several suppliers.

7.1.1 *Buffered Probe*, meeting the following requirements:

7.1.1.1 The probe should have a center frequency that corresponds to an ultrasonic wavelength that is less than one fifth of the thickness, d , of the test sample.

7.1.1.2 The probe bandwidth should match the bandwidth of received echoes. This may require transducer bandwidths of from 50 to 200 MHz.

7.1.1.3 The probe should be well constructed, carefully selected, and shown to be free of internal defects and structural anomalies that distort received echoes.

7.1.1.4 The frequency spectra of the first two echoes returned by the free end of the buffer should be essentially gaussian (bell shaped).

7.1.2 *Buffer Rod*, with length that results in a time delay ≥ 3 times the interval between two successive echoes from the back surface of the test sample. This imposes a limit on the test sample thickness if the buffer rod length is fixed or predetermined by design.

7.1.3 *Couplant*, meeting the following requirements:

7.1.3.1 The couplant should be a fluid such as glycerine or an ultrasonic gel that will not corrode, damage, or be absorbed by the test sample or part being examined.

7.1.3.2 The couplant film or couplant layer thickness should be much less than the ultrasound wavelength in the couplant at the probe's center frequency.

7.1.3.3 Ideally, to avoid echo distortions, the acoustic impedance of the couplant should be between that of the buffer rod material and test sample (5). With fluid couplants, just reducing the couplant layer thickness is usually more practical than impedance matching by changing the fluid. For example, if glycerine is used between a fused quartz buffer and a steel sample, the couplant layer thickness should be less than 1 μm .

7.1.3.4 Dry coupling, for example, with an elastomer or thin deformable polymer film, may be used provided that echo distortions or phase inversions are avoided by acoustic impedance matching (5) and by substantially reducing the couplant layer thickness.

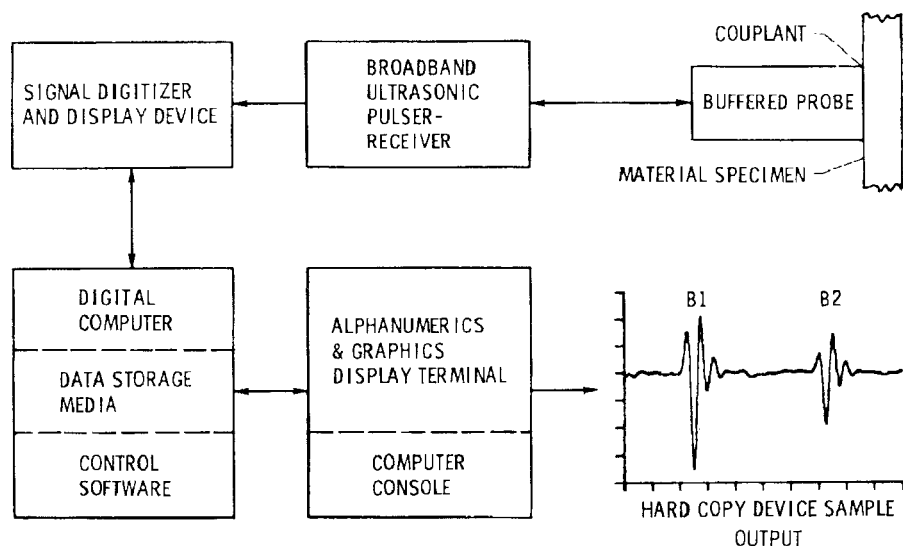


FIG. 2 Block Diagram of Computer System for Ultrasonic Signal Acquisition and Processing for Pulse-Echo Attenuation Measurement