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Standard Practice for Measuring Ultrasonic Velocity in Materials[1]

This standard is issued under the fixed designation E494; 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.

This specification has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This practice covers a test procedure for measuring ultrasonic velocities in materials with conventional ultrasonic pulse echo flaw detection equipment in which results are displayed in an A-scan display. This practice describes a method whereby unknown ultrasonic velocities in a material sample are determined by comparative measurements using a reference material whose ultrasonic velocities are accurately known.

1.2 This procedure is intended for solid materials 5 mm [0.2 in.](0.2 in.) thick or greater. The surfaces normal to the direction of energy propagation shall be parallel to at least ±3°. Surface finish for velocity measurements shall be 3.2 µm [125 µin.](125 µin.) rms or smoother.

NOTE 1—Sound wave velocities are cited in this practice using the fundamental units of metres per second, with inches per second supplied for reference in many cases. For some calculations, it is convenient to think of velocities in units of millimetres per microsecond. While these units work nicely in the calculations, the more natural units were chosen for use in the tables in this practice. The values can be simply converted from m/s to mm/µs by moving the decimal point three places to the left, that is, 3500 m/s becomes 3.5 mm/µs.

1.3 Ultrasonic velocity measurements are useful for determining several important material properties. Young's modulus of elasticity, Poisson's ratio, acoustic impedance, and several other useful properties and coefficients can be calculated for solid materials with the ultrasonic velocities if the density is known (see Appendix X1).

1.4 More accurate results can be obtained with more specialized ultrasonic equipment, auxiliary equipment, and specialized techniques. Some of the supplemental techniques are described in Appendix X2. (Material contained in Appendix X2 is for informational purposes only.)

NOTE 2—Factors including techniques, equipment, types of material, and operator variables will result in variations in absolute velocity readings, sometimes by as much as 5 %. Relative results with a single combination of the above factors can be expected to be much more accurate (probably within a 1 % tolerance).

1.5

1.5 The values stated in SI units are to be regarded as standard.

1.6 *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:*[2]

C597 Test Method for Pulse Velocity Through Concrete
E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments
E543 Specification for Agencies Performing Nondestructive Testing
E797 Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method
E1316 Terminology for Nondestructive Examinations

2.2 *ASNT Documents:*[3]

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

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Method.
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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] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

***A Summary of Changes section appears at the end of this standard.**

ASNI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *AIA Document:*[4]

NAS-410 Certification and Qualification of Nondestructive Testing Personnel

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology E1316.

4. Summary of Practice

4.1 Several possible modes of vibration can propagate in solids. This procedure is concerned with two velocities of propagation, namely those associated with longitudinal (v_l) and transverse (v_t) waves. The longitudinal velocity is independent of sample geometry when the dimensions at right angles to the beam are very large compared with beam area and wave length. The transverse velocity is little affected by physical dimensions of the sample. The procedure described in Section ~~7~~ 8 is, as noted in the scope, for use with conventional pulse echo flaw detection equipment only.

5. Significance and Use

5.1 This practice describes a test procedure for the application of conventional ultrasonic methods to determine velocity in materials wherein unknown ultrasonic velocities in a material sample are determined by comparative measurements using a reference material whose ultrasonic velocities are accurately known.

5.2 Although not all methods described in this practice are applied equally or universally to all velocity measurements in different materials, it does provide flexibility and a basis for establishing contractual criteria between users, and may be used as a general guideline for preparing a detailed procedure or specification for a particular application.

5.3 This practice is directed towards the determination of longitudinal and shear wave velocities using the appropriate sound wave form. This practice also outlines methods to determine elastic modulus and can be applied in both contact and immersion mode.

6. Basis of Application

~~5.1The~~6.1 The following items are subject to contractual agreement between the parties using or referencing this practice:

~~5.2~~6.2 *Personnel Qualification*—If specified in the contractual agreement, personnel performing to this practice shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ASNI/ASNT-CP-189, SNT-TC-1A, NAS-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

~~5.3~~

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

~~6.~~

7. Apparatus

~~6.1The~~7.1 The ultrasonic testing system to be used in this practice shall include the following:

~~6.1.1~~7.1.1 *Test Instrument*—Any ultrasonic instrument comprising a time base, transmitter (pulser), receiver (echo amplifier), and an A-scan indicator circuit to generate, receive, and display electrical signals related to ultrasonic waves. Equipment shall allow reading the positions of A_k, A_s, A_t, A_l(defined in ~~7.1.4~~ 8.1.4 and ~~7.2.4~~8.2.4), along the A-scan base line within ±0.5 mm ~~[0.020 in.].~~(0.020 in.). For maximum accuracy, the highest possible frequency that will present at least two easily distinguishable back echo reflections, and preferably five, shall be used.

~~6.1.2~~7.1.2 *Search Unit*—The search unit containing a search unit that generates and receives ultrasonic waves of an appropriate size, type and frequency, designed for tests by the contact method shall be used. Contact straight beam longitudinal mode shall be used for longitudinal velocity measurements, and contact straight beam shear mode for transverse velocity measurements.

~~6.1.3~~

7.1.3 *Couplant*—For longitudinal velocity measurements, the couplant should be the material used in practice, for example, clean light-grade oil. For transverse velocity measurements, a high viscosity material such as resin or solid bond shall be used. In some materials isopolybutene, honey, or other high-viscosity materials have been used effectively. Most liquids will not support transverse waves. In porous materials special nonliquid couplants are required. The couplant must not be deleterious to the material.

~~6.1.4~~

7.1.4 *Standard Reference Blocks*:

[4] Available from Aerospace Industries Association of America, Inc. (AIA), 1250 Eye St., NW, Washington, DC 20005.

~~6.1.4.1~~

7.1.4.1 *Velocity Standard*—Any material of known velocity, that can be penetrated by the acoustical wave, and that has an appropriate surface roughness, shape, thickness, and parallelism. The velocity of the standard should be determined by some other technique of higher accuracy, or by comparison with water velocity that is known (see Appendix X2.5 and Appendix X4). The reference block should have an attenuation similar to that of the test material.

~~6~~7.1.4.2 For horizontal linearity check, see Practice E317.

~~7.~~

8. Procedure

~~7.1~~

8.1 *Longitudinal Wave Velocity*—Determine bulk, longitudinal wave velocity (v_l) by comparing the transit time of a longitudinal wave in the unknown material to the transit time of ultrasound in a velocity standard (v_k).

~~7~~8.1.1 Select samples of each with flat parallel surfaces and measure the thickness of each to an accuracy of ±0.02 mm ~~[0.001 in.]~~(0.001 in.) or 0.1 %, whichever is greater.

~~7~~8.1.2 Align the search unit over each sample and obtain a nominal signal pattern (see Fig. 1) of as many back echoes as are clearly defined. The time base (sweep control) must be set the same for both measurements.

~~7~~8.1.3 Using a scale or caliper measure the distance at the base line between the leading edge of the first back echo and the leading edge of the last back echo that is clearly defined on the known and unknown sample. For better accuracy, adjust the amplitude of the last back echo by means of the gain control to approximately the same height as the first back echo, after the position of the leading edge of the first back echo has been fixed. This allows more accurate time or distance measurements. The position of the leading edge of the last back echo is then determined. The signal has traversed a distance twice the thickness of the specimen between each back echo. The signal traversing the specimen and returning is called a round trip. In Fig. 1 the signal has made six round trips between Echo 1 and Echo 7. Count the number of round trips from first echo used to the last echo measured on both samples. This number will be one less than the number of echoes used. Note that the sample thickness, number of round trips, and distance from front to last back echo measured need not be the same.

~~7.1.4~~

8.1.4 Calculate the value of the unknown velocity as follows:

$$v_l = (A_k\, n_l\, t_l\, v_k)/(A_l\, n_k\, t_k) \quad (1)$$

where:

A_k = distance from first to *N*th back echo on the known material, m ~~[in.],~~(in.), measured along the baseline of the A-scan display,

n_l = number of round trips, unknown material,

t_l = thickness of unknown material, m ~~[in.],~~ (in.),

v_k = velocity in known material, m/s ~~[in./s],~~ (in./s),

A_l = distance from the first to the *N*th back echo on the unknown material, m ~~[in.],~~(in.), measured along the baseline of the A-scan display,

n_k = number of round trips, known material, and

t_k = thickness, known material, m ~~[in.].~~(in.).

NOTE 3—The units used in measurement are not significant as long as the system is consistent.

~~7.2~~

8.2 *Transverse Velocity*—Determine transverse velocity (v_s) by comparing the transit time of a transverse wave in an unknown material to the transit time of a transverse wave in a material of known velocity (v_t).

~~7~~8.2.1 Select samples of each with flat parallel surfaces and measure the thickness of each to an accuracy of ±0.02 mm ~~[0.001 in.]~~(0.001 in.) or 0.1 %, whichever is greater.

~~7~~8.2.2 Align the search unit (see Fig. 1) over each sample and obtain an optimum signal pattern of as many back echoes as are clearly defined. The time base (sweep control) must be the same for both measurements.

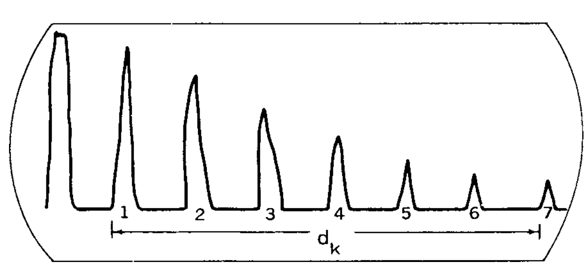

FIG. 1 Initial Pulse and 7 Back Echoes

78.2.3 Using a scale or caliper measure the distance at the base line between the leading edge of the first back echo and the leading edge of the last back echo that is clearly defined on the known and unknown sample. For better accuracy, adjust the amplitude of the last back echo by means of the gain control to approximately the same height as the first back echo, after the position of the leading edge of the first back echo has been fixed. This adds high-frequency components of the signal which have been attenuated. Then determine the position of the leading edge of the last back echo. Count the number of round trips from first echo used to the last echo measured on both samples. This number will be one less than the number of echoes used. Note that the sample thickness, number of round trips, and distance from first to last back echo measured need not be the same.

7.2.48.2.4 Calculate the value of the unknown velocity as follows:

$$v_s = (A_t\, n_s\, t_s\, v_t)/(A_s\, n_t\, t_t) \quad (2)$$

where:

A_t = distance from first to Nth back echo on the known material, m [in.],(in.), measured along the baseline of the A-scan display,
n_s = number of round trips, unknown material,
t_s = thickness of unknown material, m [in.], (in.),
v_t = velocity of transverse wave in known material, m/s [in./s], (in./s),
A_s = distance from the first to the Nth back echo on the unknown material, m [in.],(in.), measured along the baseline of the A-scan display,
n_t = number of round trips, known material, and
t_t = thickness, known material, m [in.].(in.). (See Note 3).

8.

9. Report

8.1The9.1 The following are data which should be included in a report on velocity measurements:

8.1.19.1.1 *Longitudinal Wave*:

8.1.1.1
9.1.1.1 A_k=__________m [in.]
8.1.1.2 = __________*m (in.)*
9.1.1.2 n_1 = __________
8.1.1.3
9.1.1.3 t_1=__________m [in.]
8.1.1.4 = __________*m (in.)*
9.1.1.4 v_k=__________m/s [in./s]
8.1.1.5 = __________*m/s (in./s)*
9.1.1.5 A_1=__________m [in.]
8.1.1.6 = __________*m (in.)*
9.1.1.6 n_k = __________
8.1.1.7
9.1.1.7 t_k=__________m [in.]
8.1.1.8 = __________*m (in.)*
9.1.1.8 v_1 (using Eq 1)=___m/s [in./s]
8.1.2*(using Eq 1) = ___m/s (in./s)*

9.1.2 *Transverse Wave*:

8.1.2.1
9.1.2.1 A_t=__________m [in.]
8.1.2.2 = __________*m (in.)*
9.1.2.2 n_s = __________
8.1.2.3
9.1.2.3 t_s=__________m [in.]
8.1.2.4 = __________*m (in.)*
9.1.2.4 v_t=__________m/s [in./s]
8.1.2.5 = __________*m/s (in./s)*
9.1.2.5 A_s=__________m [in.]
8.1.2.6 = __________*m (in.)*
9.1.2.6 n_t = __________
8.1.2.7
9.1.2.7 t_t=__________m [in.]
8.1.2.8 = __________*m (in.)*
9.1.2.8 v_s (using Eq 2)=___m/s [in./s]

~~8.1.3Horizontal linearity~~
~~8.1.4Test frequency~~
~~8.1.5Couplant~~
~~8.1.6~~*(using Eq 2) = ___m/s (in./s)*
9.1.3 Horizontal linearity
9.1.4 Test frequency
9.1.5 Couplant
9.1.6 *Search unit*:
~~8.1.6.1Frequency~~
~~8.1.6.2Size~~
~~8.1.6.3Shape~~
~~8.1.6.4Type~~
~~8.1.6.5Serial number~~
~~8.1.7Sample geometry~~
~~8.1.8~~
9.1.6.1 Frequency
9.1.6.2 Size
9.1.6.3 Shape
9.1.6.4 Type
9.1.6.5 Serial number
9.1.7 Sample geometry
9.1.8 *Instrument*:
~~8.1.8.1Name~~
~~8.1.8.2Model number~~
~~8.1.8.3Serial number~~
~~8.1.8.4Pertinent control settings~~

~~9.~~

9.1.8.1 Name
9.1.8.2 Model number
9.1.8.3 Serial number
9.1.8.4 Pertinent control settings

10. Keywords

~~9~~10.1 measure of ultrasonic velocity; nondestructive testing; ultrasonic properties of materials; ultrasonic thickness gages; ultrasonic velocity

APPENDIXES

(Nonmandatory Information)

X1. FORMULAS

X1.1 Using the technique of this practice will give results in some instances which are only approximate calculations. The determination of longitudinal and transverse velocity of sound in a material makes it possible to approximately calculate the elastic constants, Poisson's ratio, elastic moduli, acoustic impedance, reflection coefficient, and transmission coefficient. In this Appendix, the formulas for calculating some of these factors are as follows (see Note X1.1):

X1.1.1 *Poisson's Ratio*:

$$\sigma = [1 - 2(v_s/v_l)^2]/2[1 - (v_s/v_l)^2]$$

where:

σ = Poisson's ratio,
v_s = ultrasonic transverse velocity, m/s ~~[or in./s],~~(or in./s), and
v_l = ~~ultrasonic longitudinal velocity, m/s [or in./s].~~ultrasonic longitudinal velocity, m/s (or in./s).

X1.1.2 *Young's Modulus of Elasticity:*

~~$E=(\rho v_s^2(3v_l^2 - 4v_s^2)]/(v_l^2 - v_s^2)$~~

$$E = [\rho v_s^2 (3v_l^2 - 4v_s^2)]/(v_l^2 - v_s^2)$$

where:

ρ = density, kg/m^3~~[or lb/in.~~(or lb/in.^{3}~~], ~~),

v_l = ~~longitudinal velocity, m/s [or in./s],~~ longitudinal velocity, m/s (or in./s),

v_s = ~~transverse velocity, m/s [or in./s], and~~ transverse velocity, m/s (or in./s), and

E = Young's modulus of elasticity, N/m^2~~[or lb/in.~~(or lb/in.^{2}~~] (see Notes~~) (see Notes X1.2 and X1.3).

X1.1.3 *Acoustic Impedance* (see Note X1.3):

$$z = \rho v_l$$

where:

z = acoustic impedance (kg/m^2· s ~~[or~~(or lb/in.^{2}~~· s]).~~· s)).

X1.1.4 *Shear Modulus* (see Note X1.3):

$$G = \rho v_s^2$$

X1.1.5 *Bulk Modulus* (see Note X1.3):

$$K = \rho [v_l^2 - (4/3)v_s^2]$$

X1.1.6 *Reflection Coefficient for Energy (R)*:

$$R = (Z_2 - Z_1)^2/(Z_2 + Z_1)^2$$

where:

Z_1 = acoustic impedance in Medium 1, and

Z_2 = acoustic impedance in Medium 2.

X1.1.7 *Transmission Coefficient for Energy (T)*:

$$T = (4Z_2Z_1)/(Z_2 + Z_1)^2$$

NOTE X1.1—The dynamic elastic constants may differ from those determined by static tensile measurements. In the case of metals, ceramics, and glasses, the differences are of the order of 1 %, and may be corrected by known theoretical formulas. For plastics the differences may be larger, but can be corrected by correlation.

NOTE X1.2—Conversion factor: 1 N/m^2 = 1.4504 × 10 $^{-4}$lb/in.^{2}.

NOTE X1.3—When using pounds per cubic inch for density and inches per second for velocity, results must be divided by *g* (acceleration due to gravity) to obtain results in pounds per square inch for *E*, *G*, or *K* and also to obtain results for *Z* in pounds per square inch per second. Acceleration due to gravity (*g*) = 386.4 in./s · s.

X2. IMPORTANT TECHNIQUES FOR MEASURING ULTRASONIC VELOCITY IN MATERIALS

X2.1 Introduction

X2.1.1 Several techniques are available for precise measurement of ultrasonic velocity in materials. Most of these techniques require specialized or auxiliary equipment.

X2.1.2 Instruments are available commercially which automatically measure sound velocity or time interval or both. There is a growing list of manufacturers who make ultrasonic instruments, including pulser, receiver, and display designed specifically for making these measurements automatically or which can be used for these measurements even though designed primarily for other measurements (for example, thickness gauges).

X2.1.3 Various methods have been introduced to solve the problem of the accurate measurement of time interval or number of waves in the specimen. It would be beyond the scope of this Appendix to attempt to include all these techniques. However, it is considered of value to those using this practice to know some of these techniques. This Appendix will be useful to those who have more refined equipment or auxiliary equipment available and to those who wish more accurate results.

X2.1.4 This Appendix will include some techniques that are only suitable for the laboratory. It is only under strictly controlled conditions such as are available in the laboratory that the greatest accuracy can be achieved. Such measurements may be slow and require very carefully prepared specimens. A list of references **(1-28)**[5] is provided for more detailed information.

X2.2 Special Features Built Into the Ultrasonic Equipment

X2.2.1 Ultrasonic equipment is available that provides means adequate for the measurement of acoustic wave propagation with respect to time.

X2.3 Precision Oscilloscope

X2.3.1 An auxiliary precision cathode ray oscilloscope can be used to observe the echo pattern. Using the precision standardized horizontal display of the oscilloscope, the transit time between successive multiple back reflections is determined. Calculate velocity as follows:

[5] The boldface numbers in parentheses refer to the list of references appended to this practice.