Designation: F3004 – 13$^{\varepsilon 1}$

Standard Test Method for Evaluation of Seal Quality and Integrity Using Airborne Ultrasound[1]

This standard is issued under the fixed designation F3004; 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.

ε[1] NOTE—Reference to RR:F02-1033 was added editorially in April 2014.

1. Scope

1.1 This standard method describes the technology and testing procedures that can be used to detect seal defects in the size range of 1 mm and characterize seal quality in a variety of packaging styles using airborne ultrasound technology.

1.2 This test method does not purport to be the only method for measurement of seal quality.

1.3 Heat seals and other package components can be tested in flexible, semi-rigid and rigid packages. Only the precision and bias for flexible package seals were evaluated in a recent ILS included in the method. The precision and bias for any specific package needs to be individually determined.

1.4 On-line, real time inspection of seals can be considered particularly in the L-Scan mode.

1.5 This method provides a non-destructive, quantitative, non-subjective approach to flexible package seal inspection.

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

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:*[2]

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions:*

3.1.1 *acoustic impedance*—the product of a material's density and its acoustic velocity.

3.1.2 *airborne ultrasound*—non-contact, non-destructive ultrasound technology that allows materials to be scanned and analyzed without physical contact with the transducers. No coupling is used other than air.

3.1.3 *ultrasonic attenuation*—the decay rate of the wave as it propagates through a material. It is the combined effect of scattering and absorption.

3.1.4 *ultrasound*—sound with frequencies greater than the upper limit of human hearing which is approximately 20 kHz. Typical industrial applications use much higher frequencies in the 1–100 MHz range.

3.1.5 *ultrasound C-Scan*—multiple L-Scans which accumulates data to describe an area of interest in both X and Y dimensions.

3.1.6 *ultrasound L-Scan*—a single linear scan across one direction over the area of interest.

4. Summary of Test Method

4.1 Ultrasound has been used for inspecting a wide variety of materials as well as human health issues, based on sending and receiving ultrasonic sound waves. Airborne Ultrasound (ABUS) is a non-contact ultrasound technology that allows packages to be scanned and analyzed without making any contact with the ultrasonic transducers. Unlike contact ultrasound, ABUS does not use liquid or gel coupling to propagate sound. It may be critical to production processes to analyze a bond without changing the characteristics of the package or product in any way which may affect salability. ABUS is capable of testing packaging where continuous and complete bonding between two materials is essential or, if the bond is limited, the degree of bonding.

[1] This test method is under the jurisdiction of ASTM Committee F02 on Flexible Barrier Packaging and is the direct responsibility of Subcommittee F02.40 on Package Integrity.

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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.

4.2 ABUS is similar to most ultrasound applications in principle; however it uses air to propagate ultrasonic waves. The ABUS technology uses the transmission of ultrasonic waves to create a representative data image, allowing for quantitative evaluation of the quality of bonded materials. It has the ability to identify the size and location of defects, as well as problems with bond integrity that may or may not immediately result in leaks. The ultrasonic signal is translated by a signal processor into a quantitative data image that refers to signal strength continuously measured by the receiving ultrasonic transducer during scanning or while a sample seal moves relatively between them. The signal strength is measured in a relative value, from strongest signal capable of being transmitted through the air to no signal capable of being transmitted through the air (above the natural noise level of that frequency). Based on this scale of sound measurement, quantitative data representations of the material being scanned can be used to characterize the condition of certain materials, most specifically whether two layers of material are appropriately bonded together.

4.3 The technique and instrumentation is fundamentally very simple. An ultrasonic transducer is used to produce a signal which is subsequently passed through a sample. The transmitted signal is then received and processed by an ultrasonic signal processor. The signal strength, after passing through the sample under test and air gaps, is then compared to the strength when a non-defective sample is tested.

5. Significance and Use

5.1 This method allows for the evaluation of seal quality by passing an ultrasound signal through the sealed area of a package or item. Poorly sealed areas will not transmit as much ultrasonic energy as properly sealed areas.

5.2 This method relies on quantitative analysis of ultrasound signal strength, providing a non-subjective approach to assessing package seal quality and detecting defects.

5.3 This technique has been used for inspecting a variety of materials including flexible pouch seals, rigid tray seals and other packaging components such as affixed valves. The precision and bias for any specific package and seal configuration needs to be individually determined and validated.

5.4 The C-Scan approach is useful for laboratory applications or off-line seal inspection. The L-Scan approach can be used for on-line, real time inspection of seal quality. The sensitivity of either approach to detect a given defect size and level of severity needs to be individually determined.

5.5 Sound waves propagate at different speeds through different materials generally moving faster through more dense materials. The acoustic impedance (expressed as $g/cm^2 \cdot \mu s$) is the product of density (g/cm^3) and velocity ($cm/\mu s$). Of particular importance is the extreme difference between the impedance of air and that of any solid material. Any gap or poorly bonded area can be readily detected.

Material	Velocity (cm/μsec)	Density (g/cm^3)	Acoustic Impedance (g/cm^2-μsec)
Air (20°C, 1 bar)	0.0344	0.00119	0.000041
Water (20°C)	0.148	1.0	0.148
Polyethylene	0.267	1.1	0.294
Aluminum	0.632	2.7	1.710

6. Interferences

6.1 The sensitivity of the system to detect very slight seal defects needs to be established with mocked up samples containing these defects. The ability of these artificially produced defects to simulate defects which may be encountered in actual production must be determined.

7. Apparatus

7.1 The apparatus consists of:

7.1.1 A transducer to provide an ultrasonic signal.

7.1.2 Air gap separating the signal and detection transducers.

7.1.3 A detection transducer to measure the intensity of that signal after passing through the air gap.

7.1.4 A means to hold and transport that sample between the two transducers.

7.1.5 An Ultrasonic instrument, which integrates the hardware and software required for analyzing ultrasonic wave phenomena.

7.1.6 A computer system to collect data as to the intensity of the signal at any XY location and convert that data into a format useful to the investigator. A wide variety of data presentations are possible.

8. Reagents and Materials

8.1 No reagents or other items are used.

9. Precautions

9.1 No materials not intended to be tested, objects or body parts should be placed between the transducers or otherwise block mechanical moving parts of the test instrument.

10. Sampling

10.1 No special sampling rules apply.

11. Test Specimens

11.1 Test specimens shall be representative of the material being tested and shall be free of defects, including wrinkles, creases, and pinholes, unless these are a characteristic of the material being tested.

11.2 The specimen size and configuration shall conform to the requirements of the specific instrument used and the item under test.

12. Calibration

12.1 The instrument is calibrated in conformance to the instrument manufacturers' instructions.

13. Conditioning

13.1 Typically, no sample conditioning is required.

14. Procedure

14.1 Each specific instrument will be operated in accordance with the instrument manufacturers' instructions. Each will follow the same general steps as outlined below.

14.1.1 The sample is held in a fixture with the position of its seal or area of interest noted.

14.1.2 The sample is moved at a constant speed between the generating and receiving transducers by either moving the sample relative to the fixed transducers or by moving the transducers relative to the fixed sample.

14.1.3 The X-Y position is recorded along with the corresponding acoustic attenuation or signal strength.

14.1.4 The rate that the sample is tested shall be based on pulse rate and spot size so as to allow a defect, if present, to be detected.

14.1.5 The signal strength shall be sufficient to adequately detect defects. The sensitivity of the instrument to detect a given defect is determined by testing known defects and comparing this to known, non-defective samples.

15. Calculation

15.1 Typically, non-defective and defective samples are tested and their respective responses noted. The information generated, typically the degree of input signal attenuation, can be entered into the computer data analysis system to provide the criteria for presentation such as numeric, graphical or imagery. False color imagery has been found to be useful with various colors assigned to different levels of acoustic attenuation.

16. Report

16.1 Report the following information:

16.1.1 The data reported must be selected based on the application and the instrument employed. Typically, in normal use, the attenuation of the input signal is noted for:

16.1.1.1 No sample between transducers.

16.1.1.2 Samples without defect.

16.1.1.3 Samples with various defect levels.

16.1.2 With C-Scan applications the severity, size, shape and position of the defect can be recorded.

17. Precision and Bias

17.1 The precision of this test method is based on an interlaboratory study conducted in 2012 (see RR:F02-1033[3]). Four laboratories participated in the study, testing three different types of packaging, modified with six different intentional defects (also one non-defective). SealScan 525 systems fitted with three ultrasonic transducers, using the L-Scan technique, were used by each participant.

The total number and description of samples tested by each participant were:

3 Materials (complete layer thicknesses and material descriptions included in Research Report)

(1) PET/LDPE/FOIL/EMA (inside) sealed to itself (inside to inside) – Shown in tables below as "Foil Variable".

(2) PET/adhesive/nylon/adhesive/PP (inside) sealed to itself (inside to inside) – Shown in tables below as "All Plastic Variable".

(3) PET/LDPE (inside) sealed to Tyvek 1073B – Shown in tables below as "Tyvek Variable".

45 Samples (consisting of 15 non-defective + 30 defective)

(a) Non-defective Seal – 15 replicates

(b) 1 mm Channel – 5 replicates

(c) 3 mm Channel – 5 replicates

(d) 0.75 mm Channel – 5 replicates

(e) 2 mm Wrinkle – 5 replicates

(f) 2 mm × 2 mm Material Inclusion – 5 replicates

(g) 37 mm width Incomplete Seal – 5 replicates

3 Test Heads (SealScan 525 systems from PTI / Packaging Technologies and Inspection. Operating at 280 kHz, beam size 1.5 mm, air gap 2.5 mm, pulse rate 200 pulse/sec, scan speed 100 mm/sec)

(1) Serial number 0052565

(2) Serial number 0052594

(3) Serial number 0052595

TOTAL = 405 readings per participant.

Except for the limited number of laboratories participating, Practice E691 was followed for the study design; the details are given in RR:F02-1033.

17.1.1 *Repeatability limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "*r*" value for that material; "*r*" is the interval representing the critical difference between two test results for the same material/defect combination, obtained by

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:F02-1033. Contact ASTM Customer Service at service@astm.org.

TABLE 1 Minimum Acoustic Transmittance (Percent) – Variable A – Non-Defective Seal

Material	Average $\bar{x}$	Repeatability Standard Deviation s_r	Reproducibility Standard Deviation s_R	Repeatability Limit r	Reproducibility Limit R
"Foil Variable"	39.46	2.65	2.65	7.43	7.43
"All Plastic Variable"	39.04	0.38	0.44	1.06	1.24
"Tyvek Variable"	55.84	1.34	1.35	3.74	3.79

TABLE 2 Minimum Acoustic Transmittance (Percent) – Variable B – 1 mm Channel

Material	Average	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	s_r	s_R	r	R
"Foil Variable"	28.52	2.34	2.34	6.55	6.55
"All Plastic Variable"	28.61	2.18	2.18	6.10	6.10
"Tyvek Variable"	18.20	13.54	13.54	37.90	37.90

TABLE 3 Minimum Acoustic Transmittance (Percent) – Variable C – 3 mm Channel

Material	Average	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	s_r	s_R	r	R
"Foil Variable"	2.50	1.71	1.71	4.79	4.79
"All Plastic Variable"	2.69	2.46	2.48	6.90	6.94
"Tyvek Variable"	3.30	3.23	3.23	9.04	9.06

TABLE 4 Minimum Acoustic Transmittance (Percent) – Variable D – 0.75 mm Channel

Material	Average	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	s_r	s_R	r	R
"Foil Variable"	34.35	2.42	2.42	6.78	6.78
"All Plastic Variable"	41.64	1.36	1.43	3.81	4.00
"Tyvek Variable"	42.25	11.77	11.77	32.96	32.96

TABLE 5 Minimum Acoustic Transmittance (Percent) – Variable E – 2 mm Wrinkle

Material	Average	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	s_r	s_R	r	R
"Foil Variable"	21.49	12.24	12.24	34.27	34.27
"All Plastic Variable"	26.97	8.05	8.05	22.55	22.55
"Tyvek Variable"	14.42	9.05	9.05	25.34	25.34

TABLE 6 Minimum Acoustic Transmittance (Percent) – Variable F – 2 mm X 2 mm Material Inclusion

Material	Average	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	s_r	s_R	r	R
"Foil Variable"	17.04	10.54	10.54	29.52	29.52
"All Plastic Variable"	31.65	7.04	7.04	19.72	19.72
"Tyvek Variable"	42.78	13.66	13.66	38.24	38.24

TABLE 7 Minimum Acoustic Transmittance (Percent) – Variable G – 37mm Width Incomplete Seal

Material	Average	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	s_r	s_R	r	R
"Foil Variable"	1.89	0.60	0.64	1.69	1.80
"All Plastic Variable"	1.98	0.57	0.60	1.59	1.68
"Tyvek Variable"	1.64	0.86	0.86	2.41	2.41

the same operator using the same equipment on the same day in the same laboratory.

17.1.1.1 Repeatability limits are listed in Tables 1-7.

17.1.2 *Reproducibility limit (R)*—Two test results shall be judged not equivalent if they differ by more than the "*R*" value for that material; "*R*" is the interval representing the critical difference between two test results for the same paint, obtained by different operators using different equipment in different laboratories.

17.1.2.1 Reproducibility limits are listed in Tables 1-7.

17.1.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

17.1.4 Any judgment in accordance with statements 17.1.1 and 17.1.2 would normally have an approximate 95% probability of being correct, however the precision statistics obtained in this ILS must not be treated as exact mathematical quantities which are applicable to all circumstances and uses. The limited number of laboratories reporting replicate results guarantees that there will be times when differences greater than predicted by the ILS results will arise, sometimes with

TABLE 8 Summary of All Readings

	Material →	"Foil Variable"		"All Plastic Variable"		"Tyvek Variable"	
	Defect Category	Pass	Reject	Pass	Reject	Pass	Reject
A	Non-Defective	180 (100%)	0 (0.0%)	180 (100%)	0 (0.0%)	172 (95.6%)	8 (4.4%)
B	1 mm Channel	0 (0.0%)	60 (100%)	1 (1.67%)	59 (98.33%)	0 (0.0%)	60 (100%)
C	3 mm Channel	0 (0.0%)	60 (100%)	0 (0.0%)	60 (100%)	0 (0.0%)	60 (100%)
D	0.75 mm Channel	10 (16.7%)	50 (83.3%)	27 (45.0%)	33 (55.0%)	11 (18.3%)	49 (81.7%)
E	Wrinkle	7 (11.67%)	53 (88.3%)	8 (13.3%)	52 (86.7%)	0 (0.0%)	60 (100%)
F	Material Inclusion	1 (1.67%)	59 (98.3%)	22 (36.7%)	38 (63.3%)	25 (41.67%)	35 (58.3%)
G	Incomplete Seal	0 (0.0%)	60 (100%)	0 (0.0%)	60 (100%)	0 (0.0%)	60 (100%)

considerably greater or smaller frequency than the 95% probability limit would imply. Consider the repeatability and reproducibility limits as general guides, and the associated probability of 95% as only a rough indicator of what can be expected.

17.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

17.3 The precision statement was determined through statistical examination of all results submitted by a total of four laboratories, on three materials, with six intentional types of defect.

17.4 All individual results for each laboratory, test head, material and defect category is available in RR:F02-1033. Also included in RR:F02-1033 is a complete description of the defects tested, test heads employed, and the materials tested. Table 8 summarizes the findings from all participants.

18. Keywords

18.1 airborne ultrasound; heat seal; seal defect; seal integrity; transducer