



Standard Test Method for Evaluation of Materials, Protective Clothing and Equipment for Heat Resistance Using a Hot Air Circulating Oven¹

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1. Scope

1.1 This test method covers quantitative measurements and subjective observations that characterize the performance for evaluating the heat resistance of materials, protective clothing and equipment when exposed in a hot air circulating oven.

1.2 This test method is intended to evaluate physical changes in materials, protective clothing and equipment at a specified heat exposure.

1.2.1 The specified heat exposure in the hot air circulating oven is a combination of convective heat and radiant heat.

1.3 Materials, protective clothing and equipment are evaluated for visible changes or subjected to a material property measurement following a specified heat exposure.

1.4 This test method enables the quantitative measurement of shrinkage that occurs as a result of a specified heat exposure in a hot air circulating oven.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to other units that are commonly used for thermal testing.

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.*

NOTE 1—Flame resistant and heat resistant materials are described in a range of different standards and meet a range of different requirements. For materials tested in accordance with this test method, the applicable standard shall be used to establish preconditioning, conditioning and testing conditions and requirements.

2. Referenced Documents

2.1 ASTM Standards:²

D123 Terminology Relating to Textiles

¹ This is under the jurisdiction of ASTM Committee F23 on Personal Protective Clothing and Equipment and is the direct responsibility of Subcommittee F23.80 on Flame and Thermal.

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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.

D1776 Practice for Conditioning and Testing Textiles

E145 Specification for Gravity-Convection and Forced-Ventilation Ovens

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

F1494 Terminology Relating to Protective Clothing

2.2 AATCC Standard:

Test Method 135 Dimensional Changes in Automatic Home Laundering of Woven and Knit Fabrics³

2.3 NFPA Standards:

NFPA 1975 Standard on Station/Work Uniforms for Fire and Emergency Services⁴

3. Terminology

3.1 Definitions of Terms

3.2 For definitions of terms used in this test method, use the following documents: If the terms are related to textiles refer to Terminology **D123**; if the terms are related to protective clothing refer to Terminology **F1494**.

3.2.1 *convective heat, n*—heat transferred by the motion of a fluid.

3.2.2 *degradation, n*—a deleterious change in one or more properties of a material.

3.2.2.1 *Discussion*—In thermal testing of materials, protective clothing and equipment, degradation is a material response evidenced by a change in either or both the visual properties and the performance properties of the test specimen.

3.2.2.2 *Discussion*—Degradation generally is associated with a chemical composition change that can result in a change in a visual property, for example, color, or it can result in a change in a performance property including but not limited to strength, hand, flammability, penetration resistance, water repellency and air permeability. A test specimen that changes in one property does not necessarily change in other properties. Evidence of degradation in performance properties usually requires additional measurements related to properties of

³ Available from American Association of Textile Chemists and Colorists (AATCC), P.O. Box 12215, Research Triangle Park, NC 27709, <http://www.aatcc.org>.

⁴ Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, <http://www.nfpa.org>.

specific interest. Discoloration is a visible material response related to degradation. When discoloration is observed, it shall be reported.

3.2.3 *functionality, n*—in thermal testing of protective clothing and equipment, the continued utility of the test item as determined by an assessment of its capability to function after the heat exposure in the same manner as before its exposure to heat.

3.2.3.1 *Discussion*—This type of assessment is generally applied to items of hardware or to portions of or complete protective clothing and equipment items.

3.2.4 *ignition, n*—the initiation of combustion.

3.2.5 *protective clothing, n*—an item of clothing that is specifically designed and constructed for the intended purpose of isolating all or part of the body from a potential hazard; or, isolating the external environment from contamination by the wearer of the clothing.

3.2.6 *protective equipment, n*—a non-clothing item of equipment that is specifically designed and constructed for the intended purpose of isolating all or part of the body from a potential hazard; or, isolating the external environment from contamination by the user of the equipment.

3.2.7 *radiant heat, n*—heat communicated by energy propagated through space and transmitted by electromagnetic waves.

3.2.8 *shrinkage, n*—a decrease in one or more dimensions of an object or material.

3.3 *Definitions of Terms Related to Thermal Testing of Materials, Protective Clothing and Equipment:*

3.3.1 *deformation, n*—in thermal testing of materials, protective clothing and equipment, a material response evidenced by a change in shape of the test specimen that is irreversible at room temperature.

3.3.1.1 *Discussion*—A change in shape caused by the specified heat exposure such as distortion of woven or non woven fabrics or curling of knit fabrics shall not be identified as deformation as long as these changes are reversible at room temperature.

3.3.2 *delamination, n*—in thermal testing of materials, protective clothing and equipment, a material response evidenced by the separation of two or more layers of the test specimen in whole or in part.

3.3.3 *dripping, n*—in thermal testing of materials, protective clothing and equipment, a response evidenced by flowing of the polymer and by the formation of droplets from the flowing material.

3.3.4 *flaking, n*—in thermal testing of materials, protective clothing and equipment, a material response evidenced by the unassisted loss of visible particles of material from the test specimen when the test specimen is removed from the oven for inspection.

3.3.4.1 *Discussion*—The specimen shall not be abraded, flexed or impacted to generate flaking.

3.3.5 *hole formation, n*—in thermal testing of materials, protective clothing and equipment, the appearance of a visible aperture during the test exposure.

3.3.5.1 *Discussion*—The specimen is considered to exhibit hole formation when a visible hole is produced as a result of the thermal exposure that is approximately 3 mm (0.12 in.) in

diameter or greater, or if the hole is rectangular in shape approximately 3 mm (0.12 in.) in width and length or greater. Single threads across the hole do not reduce the size of the hole for the purposes of this test method.

3.3.6 *melting, n*—in thermal testing of materials, protective clothing and equipment, the liquefaction of material under the influence of heat.

3.3.7 *separation, n*—in thermal testing of materials, protective clothing and equipment, a material response evidenced by splitting or delaminating.

3.3.8 *splitting, n*—in thermal testing of materials, protective clothing and equipment, a material response evidenced by the test specimen breaking into two or more pieces in whole or in part.

3.3.9 *sticking, n*—in thermal testing of materials, protective clothing and equipment, a material response evidenced by the test specimen adhering to itself or to other surfaces.

3.3.9.1 *Discussion*—This test method is conducted in a manner that avoids the contact of test specimens with oven surfaces or with adjacent test specimens. However, it is still possible for test specimens to stick to the mounting hooks or clamps and this observation shall be reported. Another evaluation of sticking specific to fabrics is described in 7.2.1 and 8.3 of NFPA 1975. The NFPA 1975 test method evaluates the thermal stability of specimens by assessing the blocking of folded specimens placed between glass plates under weight inside an oven meeting the same characteristics as the oven used in this test method.

4. Summary of Test Method

4.1 The test method evaluates the heat resistance of materials, protective clothing and equipment using a hot air circulating oven.

4.2 Specimens shall be exposed in the test oven at a specified temperature for a specified oven exposure time as required by the applicable material or product specification.

4.2.1 If no material or end product specification requirements for the oven temperature and oven exposure time are provided, the oven temperature shall be 260 +8/-0°C (500 +14/-0°F) and the oven exposure time shall be 5 minutes +15/-0 seconds.

4.3 Following heat exposure, the test specimen is removed and examined for evidence of one or more of the following phenomena: ignition, melting, dripping, separation, etc., see 11.5.

4.4 If specified, test specimens are evaluated for shrinkage as a result of the convective heat exposure.

5. Significance and Use

5.1 This test method is used to evaluate the heat resistance of materials, clothing and equipment when exposed to combination of convective heat and radiant heat in a hot air circulating oven. The principal findings of this test method are observations of the specimen response to the heat exposure.

5.1.1 The majority of procedures specified in this test method apply to the evaluation of flat material specimens.

5.1.2 When evaluating non-flat materials, alternative procedures are required for mounting specimens and interpreting the effects of the heat exposure.

5.2 If specified, this test method is used for the measurement of material shrinkage following a convective heat exposure in a hot air circulating oven.

5.3 This test method is not intended to simulate the actual exposure of material, clothing or equipment in high heat conditions such as a fire environment.

6. Apparatus

6.1 *Test Oven*—The test oven shall be a horizontal-flow circulating oven with minimum interior dimensions of 610 mm by 610 mm by 610 mm such that a specimen can be suspended and be positioned at least 50 mm (2 in.) from any interior oven surface or other specimen.

6.1.1 The test oven shall have an air velocity of 0.5 m/s to 1.5 m/s at the standard temperature and pressure of 21°C at local atmospheric pressure, measured at the geometric center point of the oven.

6.1.2 The test oven shall be equipped with an oven sensing thermocouple which is used as part of the oven temperature control mechanism.

6.1.2.1 The oven sensing thermocouple shall be positioned so that it is level with the horizontal centerline of a mounted sample specimen, and the oven sensing thermocouple shall be equidistant between the vertical centerline of a mounted specimen positioned in the middle of the oven and the oven wall where the airflow enters the oven test chamber.

6.1.2.2 The oven sensing thermocouple shall be an exposed bead, Type J or Type K, No. 30 AWG thermocouple.

6.2 *Specimen Mounting*—Metal hooks or clamps shall be used to suspend the specimens in the oven.

6.2.1 If the specimens are too large to be suspended, a suitable insulating form shall be placed in the center of the oven and the specimen shall rest on the insulating form. Ceramic has been found to be an effective material for this form.

6.2.2 In the testing of some items, such as individual pieces of hardware, loops of heat-resistant thread are used to suspend the specimen.

6.3 *Optional Stretching Frame*—The optional stretching frame consists of a board with uniformly spaced pins along the perimeter at intervals of 25 mm (1 in.) to secure knit materials. Construct the stretching frame to accommodate the test specimen size specified in 9.1.1 and 9.1.2 so that the pins are located approximately 50 mm (2 in.) inward from the edges of the test specimen.

6.3.1 The optional stretching frame is permitted to be used before the knit specimen is placed in the oven for marking the specimen for shrinkage determination. The stretching frame is not used while the knit specimen is exposed in the oven. The optional stretching frame is also permitted to be used for a specified period of time after heat exposure in the oven to return knit specimens to their original dimensions. See 9.3.1 and 11.6.1.

7. Hazards

7.1 Normal precautions shall be taken for working around hot surfaces and flaming, melting or dripping test specimens.

7.2 The oven shall be properly vented to ensure that harmful vapors and gases are evacuated from the laboratory.

8. Preconditioning of Test Samples

8.1 Material samples not obtained from garments for preconditioning shall be at least 1 m² (1.2 yd²) to ensure sufficient material for the test specimen size requirements in 9.1.1 and 9.1.2. The material sample shall be representative of the material utilized in the construction of the protective clothing end product.

8.1.1 If the material width is less than 1 m (1.1 yd), the sample shall be the full width of the material and the length of the sample shall be sufficient to meet the test specimen size requirements of 9.1.1 or 9.1.2.

8.1.2 Precondition samples of protective clothing as complete items.

8.1.3 Precondition samples of protective equipment as complete items.

8.2 Precondition samples as required by the applicable material or end product specification.

8.2.1 If no material or end product specification requirements for preconditioning are provided, precondition samples according to the temperature, relative humidity and conditioning time required by Practice D1776.

8.2.2 If the test specimen form is not included in Practice D1776, condition the test specimen at 21 ± 1°C (70 ± 2°F) and 65 ± 2 % RH for eight hours.

9. Preparation of Test Specimens

9.1 After preconditioning cut test specimens to the specified size for testing.

9.1.1 Cut each material test specimen from the material sample or from the protective clothing complete item to a size of 380 ± 13 mm by 380 ± 13 mm (15 ± 0.5 in. by 15 ± 0.5 in.).

9.1.2 Smaller size material test specimens of 150 ± 6 mm by 150 ± 6 mm (6 ± 0.25 in. by 6 ± 0.25 in.) shall be acceptable for materials that are not to be subjected to shrinkage measurement.

9.1.3 For specimens (such as straps) narrower than 150 mm in one dimension, use specimens at their normal width and cut to 150 mm in length. Suspend these specimens with their long axis in a vertical direction.

9.1.4 Protective clothing test specimens are permitted to be tested in the form and size of the complete items.

9.1.4.1 Components of protective clothing, such as hardware, are permitted to be tested as individual items.

9.1.5 Test protective equipment specimens in the form and size of the complete items.

9.2 Test a minimum of three test specimens from each preconditioned sample. Testing a greater number of specimens is permitted to improve precision of test results.

9.3 Mark test specimens to be evaluated for shrinkage in accordance with AATCC Test Method 135.

9.3.1 The optional stretching frame shall be permitted to be used to mark knit fabric specimens for shrinkage determinations.

9.4 *Room Temperature Conditioning*—Unless otherwise directed by the applicable specification for the material or end product, condition test specimens, including nonwoven specimens, at a temperature of 21 ± 1°C (70 ± 2°F) and 65 ± 2 %

relative humidity, until equilibrium is reached, as determined in accordance with Practice **D1776**, or for eight hours, whichever results in the shorter conditioning time. Test specimens within five minutes after removal from conditioning.

10. Preparation and Calibration of Apparatus

10.1 At least once every twelve months, determine the temperature uniformity of the oven in accordance with Specification **E145** using the procedure in Section 4 of the Test Method for Temperature Uniformity for a Type IIB oven at 260°C (500°F) with the following exceptions: Change the time period that the temperatures of the nine thermocouples are recorded from 24 hours to four hours, and record the temperature of the nine thermocouples at least every five minutes. The maximum temperature deviation from 260°C (500°F) for each of the nine thermocouples shall be no greater than 6.5°C (11.7°F), as specified in Specification **E145** for a IIB oven.

10.1.1 During the same time period not to exceed two days during which the oven temperature uniformity is determined, confirm that the air velocity of the oven is 0.5 m/s to 1.5 m/s at the standard temperature and pressure of 21°C at local atmospheric pressure, measured at the geometric center point of the oven.

10.2 For ovens with a single temperature-sensing thermocouple, prior to commencement of testing each week, install a calibration thermocouple of equal type and performance as the oven sensing thermocouple in the center of the empty oven test chamber.

10.2.1 With the oven door closed and air circulation activated, activate the empty oven and adjust its temperature control until the oven sensing thermocouple installed as described in **6.1.2.1** the center of the oven reaches the specified testing temperature.

10.2.2 Maintain the testing temperature in center of the oven for five minutes while recording the calibration thermocouple reading and oven sensing thermocouple reading at the end of each 30 second period for the five minute duration.

10.2.3 Calculate the difference between the two thermocouple readings for each of the ten periods, and then average the ten values to determine an Average Correction Factor (ACF) in units of degrees Celsius.

10.2.3.1 The ACF is a positive number if the calibrating thermocouple is lower than the oven sensing thermocouple, and the ACF is a negative number if the calibrating thermocouple is higher than the oven sensing thermocouple.

10.2.4 Calculate the Oven Sensing Thermocouple Compensated Setting (OSTCS) by adding ACF and the specified test temperature.

10.2.5 Use the OSTCS as the test temperature.

11. Procedure

11.1 Heat the test oven and stabilize the oven sensing thermocouple temperature reading at the OSTCS for a period of not less than 30 minutes.

11.2 Suspend the specimen by metal hooks or clamps at the top of the oven and centered in the oven such that the entire specimen is not less than 50 mm (2 in.) from any oven surface, and the airflow is parallel to the plane of the specimen material.

11.2.1 Where specimens cannot be suspended by metal hooks or clamps, position the specimen in the center of the oven on a insulated form such that the entire specimen is not less than 50 mm (2 in.) from any oven surface or other specimen, and air flow is parallel to the plane of the specimen.

11.2.2 For woven material specimens, note the direction vertical or horizontal for the warp and fill directions of the material specimen. For non-woven material specimens note the direction vertical or horizontal for the machine direction and cross direction of the material specimen.

11.3 Shut off the air circulation while the oven door is open and turn on the air circulation when the oven door is closed. The total oven recovery time to the OSTCS after the door is closed shall not exceed 30 seconds.

11.4 Expose the specimen, mounted as specified, in the test oven at a specified temperature for a specified exposure time as required by the applicable material or product specification.

11.4.1 If no material or product specification requirements for the oven temperature and an oven exposure time are provided, expose the specimen, mounted as specified, to an OSTCS based on a testing temperature of 260 +8/-0°C (500 +14/-0°F) for five minutes +15/-0 seconds. Start the oven exposure time when the test thermocouple recovers to the OSTCS.

11.5 Remove the specimen from the oven immediately after the specified oven exposure time, and visually examine the test specimen for evidence of one or more of the following phenomena: ignition, deformation, degradation, delamination, melting, dripping, sticking, flaking, hole formation, separation and splitting (as defined in Section **3**).

11.6 If shrinkage determination is specified, measure the shrinkage of the test specimen in accordance with AATCC **Test Method 135**.

11.6.1 If the optional stretching frame is used, within one minute after knit material specimens are removed from the oven, use the stretching frame to pull the knit material specimen to the original specimen dimensions for one minute, and then remove the knit material specimen from the stretching frame and allow the knit material specimen to relax for one minute prior to measuring shrinkage. If the knit specimen pulls apart, tears or breaks when it is positioned on the optional stretching frame, the shrinkage shall be determined without the use of the stretching frame.

11.7 Evaluate protective clothing and equipment test specimens for functionality when a complete item is tested in the oven.

11.7.1 Evaluate zippers and other closures for functionality.

11.7.2 Evaluate seams for potential failures.

11.7.3 Evaluate hardware after the oven exposure for the ability of these items to function as used in their application in the protective clothing or equipment item.

NOTE 2—Degradation noted for **11.5** is limited to visual observation such as discoloration. Evidence of degradation in performance properties of specific interest requires additional testing of the exposed test specimens (see the two Discussions under **3.2.2**).

11.8 If specified, evaluate protective equipment specimens for distortion relative to the specific device or other reference points indicated in the protective equipment specification.

12. Report

12.1 State that the specimens were tested as directed in Test Method F2894. Describe the material, protective clothing or protective equipment samples, the method of sampling used, the preconditioning of the sample, the conditioning of the sample, the type of specimens tested, and the dimensions of the test specimens.

12.1.1 If more than three specimens are tested, report results for all test specimens.

12.2 If applicable, state the material or product specification standard used to establish test conditions and performance requirements.

12.3 Report the testing temperature and the time of exposure.

12.4 Report all observations of phenomena that occurred to the test specimens during the oven exposure. Include observations regarding ignition, deformation, degradation, delamination, melting, dripping, sticking, flaking, hole formation, separation and splitting (as defined in Section 3).

12.5 If the determination of shrinkage is specified, report the per cent shrinkage of each test specimen and the average percent shrinkage for all specimens in both the vertical and horizontal directions based on the orientation of the test specimen in the oven.

12.6 Report the functionality and any specific effect of heat for complete items of protective clothing item or equipment test specimens.

12.7 Report any other information or observation relating to the exposure conditions to assist in interpretation of the test results.

13. Precision and Bias ⁵

13.1 The precision of this test method is based on an interlaboratory study of this standard's 2011 edition, which was conducted in 2011. Eight laboratories were asked to report triplicate results, for heat resistance, using three different materials. Every "test result" reported represents an individual determination. Practice E691 was followed for the design and analysis of the data.

13.1.1 *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, obtained by the same operator using the same equipment on the same day in the same laboratory.

⁵ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:F23-1008.

13.1.1.1 Repeatability limits are listed in Tables 1 and 2.

13.1.2 *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 material, obtained by different operators using different equipment in different laboratories.

13.1.2.1 Reproducibility limits are listed in Tables 1 and 2.

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

13.1.4 Any judgment in accordance with statement 13.1.1 would have an approximate 95 % probability of being correct.

13.2 *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.

13.3 This precision statement was determined through the statistical examination of results from eight laboratories, on three materials, measured both lengthwise and widthwise. These materials were described as:

13.3.1 A: 7.5 oz/yd² woven (ripstop) fabric

13.3.2 B: 8.5oz/yd² woven (twill) fabric

13.3.3 C: 8.0 oz/yd² knit (rib) fabric

14. Keywords

14.1 convective heat; deformation; degradation; delamination; dimensional change; dripping; flaking; growth; hole formation; hot air circulating oven; ignition; melting; protective clothing; protective equipment; separation; shrinkage; splitting; sticking

TABLE 1 Dimensional Change—Lengthwise (%)

Material	Average ^A	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	S_r	S_R	r	R
A	-1.3358	0.2310	0.3412	0.6469	0.9554
B	-2.0742	0.3090	0.6684	0.8652	1.8715
C	-0.9613	0.4459	0.5488	1.2485	1.5365

^AThe average of the laboratories' calculated averages

TABLE 2 Dimensional Change—Widthwise (%)

Material	Average ^A	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	S_r	S_R	r	R
A	-1.0463	0.1258	0.2201	0.3523	0.6164
B	-1.6333	0.2184	0.4316	0.6115	1.2083
C	-0.7938	0.6066	0.8428	1.6984	2.3598

^AThe average of the laboratories' calculated averages



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