Designation: ~~D7984 – 16~~ D7984 – 21

Standard Test Method for Measurement of Thermal Effusivity of Fabrics Using a Modified Transient Plane Source (MTPS) Instrument[1]

This standard is issued under the fixed designation D7984; 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.

INTRODUCTION

This standard provides a test method for measuring the thermal effusivity of fabrics under still air conditions. Other standards, Test Methods F1868 and D1518, measure the thermal insulation of materials under steady-state conditions; however, this test method is used to measure transient heat exchange between a fabric specimen and a heated surface. It has been established that there is a strong positive correlation between the thermal effusivity and the initial perceived coldness between human skin and different materials.[2,3]

1. Scope

1.1 This test method covers the quantitative measurement of thermal effusivity of woven, knitted, or non-woven fabrics using a guarded modified transient plane source (MTPS) instrument.[4] This test method is applicable to a wide range of thicknesses; however, the thickness of the specimen must be greater than the penetration depth of the heat flux during the measurement time.

1.2 This test method is comparative since specimens of known thermal effusivity are used to calibrate the apparatus at the factory level. Thermal effusivity of the calibration specimens are confirmed through calculations that use established properties of thermal conductivity, density, and specific heat.

1.3 This test method is intended for measuring fabrics in a dry state at ambient conditions.

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

1.5 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *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.*

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[1] This test method is under the jurisdiction of ASTM Committee D13 on Textiles and is the direct responsibility of Subcommittee D13.51 on Conditioning, Chemical and Thermal Properties.

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[2] Marin, E., "Teaching Thermal Physics by Touching," *Latin-American Journal of Physics Education*, Vol 2, No. 1, January 2008, pp. 15-17.

[3] Wongsriruska, S., Howes, P., Conreen, M., Miodownik, M., "The Use of Physical Property Data to Predict the Touch Perception of Materials," *Materials and Design*, Vol 42, 2012, pp. 238-244.

[4] The sole source of supply of the TCi instrument known to the committee at this time is C-Therm Technologies, Ltd., C/O RPC, 921 College Hill Rd., Fredericton, New Brunswick, Canada, E3B 6Z9. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

2. Referenced Documents

2.1 *ASTM Standards:*[5]
D123 Terminology Relating to Textiles
D1518 Test Method for Thermal Resistance of Batting Systems Using a Hot Plate
D1776 Practice for Conditioning and Testing Textiles
D4920 Terminology Relating to Conditioning, Chemical, and Thermal Properties
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
F1868 Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *modified transient plane source (MTPS), n*—an apparatus that has a one sided planar heat source and a guard, or guard ring, mounted perpendicular to the planar heat source, that is put in contact with one side of a test specimen, so that a short duration heat pulse can penetrate into the specimen.

3.1.1.1 *Discussion*—
The purpose of the guard (or guard ring) is to maintain a consistent unidirectional heat flow across the test specimen.

3.1.2 *penetration depth, n*—the functional depth to which the initial radiation applied at the surface travels into the specimen.

3.1.2.1 *Discussion*—
To ensure that the heat wave is contained within the test specimen, the thickness of the test specimen must be greater than the penetration depth.

3.1.3 *thermal effusivity, n*—a material property that describes its ability to exchange thermal energy with another material with which it is in contact.

$$e = \sqrt{\lambda \cdot c_p \cdot \rho} \tag{1}$$

where:

e = thermal effusivity, $W \cdot S^{1/2}/(m^2 \cdot K)$,
λ = thermal conductivity, $W/(m \cdot K)$,
c_p = specific heat capacity, $J/(kg \cdot K)$, and
ρ = mass density, kg/m^3.

3.1.3.1 *Discussion*—
The thermal effusivity of two materials that are in contact determines the temperature at their interface as a result of heat energy exchange.

3.2 For definitions of other textile terms used in this test method refer to Terminology D123.

3.3 For definitions of other terms related to conditioning, chemical and thermal properties used in this test method, refer to Terminology D4920.

4. Summary of Test Method

4.1 A constant momentary heat pulse is applied to the surface of a test specimen. The heat pulse elevates the temperature of the surface as the heat diffuses into the test specimen in one dimensional heat flow. Thermal effusivity is determined from the temperature increase at the surface of the material with elapsed time. The temperature increase at the surface is inversely proportional to the thermal effusivity of the sample material.

5. Significance and Use

5.1 This test method measures the rate of thermal transport between a heating element and a fabric specimen. Some of the comfort

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[5] 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.

properties of a garment relate to initial thermal sensations (that is, cold or warm feeling upon initial contact), where lower thermal effusivity values indicate sensations of warmth and higher values indicate sensations of coolness. The thermal effusivity of different fabrics and their initial perceived surface temperature are important to assist product developers with fabric selection.

5.2 The sensor and the test specimen being measured shall be at the same temperature for measurements at standard conditions. This test method may be applied to any fabric with a thermal effusivity in the range of 35 to 1700 $Ws^{1/2}/m^2 \cdot K$.

5.3 Air flow shall be kept at a minimum to ensure temperature fluctuations do not occur during the measurement.

6. Apparatus

6.1 *Modified Transient Plane Source Apparatus*—See Fig. 1. The essential instrumentation required to provide the minimum transient plane source capability for this test method includes:

6.1.1 *Heater,* to provide a heat pulse to one surface of the test specimen sufficient to cause the surface temperature of the specimen to increase 1 to 3°C.

6.1.2 *Temperature sensor,* to provide an indication of the surface temperature of the test specimen readable to within ±0.01°C.

6.1.3 *Temperature programmer,* capable of providing a power pulse of 1 to 3 s to the heater resulting in an increase in the specimen surface temperature of 1 to 3°C.

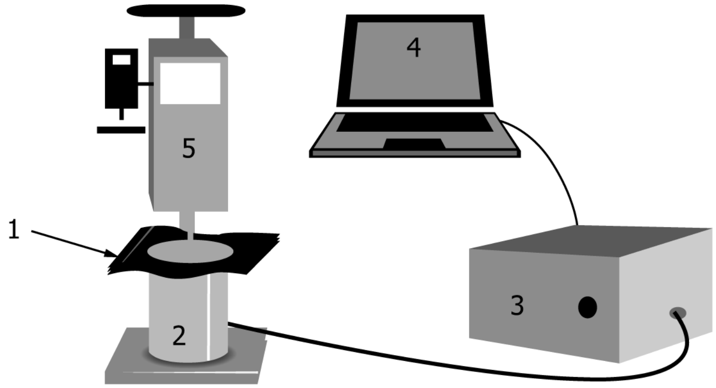
6.1.4 *Heated guard ring,* or other device to ensure a unidirectional heat flow in the test specimen perpendicular to the heated surface.

6.1.5 *Data acquisition device,* to provide a means of acquiring, storing, and displaying measured or calculated signals, or both, with a digital acquisition rate of 20 data points per second or greater. The minimum output signals required are temperature or temperature rise and time.

6.1.6 Auxiliary instrumentation considered necessary or useful for conducting this test method include:

6.1.6.1 *Data analysis capability,* to perform the necessary calculations to derive the property of thermal effusivity from the temperature and time experimental variables.

6.2 *Load device,* to apply a fixed controlled force of 10 to 50 kPa to the specimen to ensure that the test specimen is in intimate contact with the heater and temperature sensor.



(1) Fabric Specimen
(2) Heater and Sensor
(3) Controller
(4) Data Acquisition System
(5) Constant Pressure Applicator

FIG. 1 Basic Layout of an Effusivity Measurement Apparatus

7. Preparation of Test Specimens

7.1 *Specimen Preparation*—Cut specimens so that the sensor area is covered completely. Take a minimum of five specimens from each sample to be tested. Specimens shall be staggered in such a manner that no two specimens contain the same yarns. The specimens need to be thicker than 1.0 mm so that the heat wave does not penetrate beyond its maximum test penetration of 1.0 mm thickness during the sampling period. That thickness ensures that even if the fabric is on the higher end of the thermal effusivity range, the penetration depth of the heat flux during the measurement time is maintained within the fabric.

8. Conditioning

8.1 Maintain the room condition as directed in Practice D1776.

8.2 Bring the test specimens to moisture equilibrium for testing as directed in Practice D1776. It is necessary to equalize the temperatures of the sensor and the specimen by placing them in the same location.

NOTE 1—A repeat sensor temperature measurement before the test may verify the equalization and sensor stabilization.

9. Calibration

9.1 Prepare the instrument for operation and perform any instrument calibrations according to the operations manual.

9.2 Select a industry reference material of known thermal effusivity (e_r).

NOTE 2—The instrument operations manual may offer suggestions for suitable industry reference materials.

9.3 Determine the thermal effusivity of the industry reference material according to Section 10 and confirm measured values are within ±5 % of the expected value for the material.

10. Procedure

10.1 Place sufficient layers of the fabric test specimen over the heater surface so that the heater is completely covered and that a total specimen thickness of more than 1.0 mm is achieved. Rotate each fabric layer by about 30° from those above and below so that no layer is aligned with the adjacent one.

10.2 Select and apply a fixed load of between 10-50 kPa to the fabric layers on the side opposite to the heater to ensure intimate contact with the heater.

10.3 Initiate the experiment. Provide a constant momentary power pulse to the heater and guard ring so that a temperature rise of 1 to 3°C occurs at the surface of the test specimen within 1 to 3 s.

NOTE 3—The temperature increase at the surface is inversely proportional to the thermal effusivity of the sample material. A scouting run may be used to determine the optimal power and timing perimeters. Alternatively, instrument operations manual may recommend specific power levels.

10.4 Record the thermal effusivity (e_o).[6]

10.5 Allow the test specimen and apparatus to cool to ambient temperature.

NOTE 4—This normally takes less than 1 min.

10.6 Repeat the thermal effusivity measurement according to steps 10.3 – 10.5 on each specimen two additional times.

10.7 Repeat steps 10.1 – 10.6 for the additional four specimens.

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[6] "Thermal Conductivity 28/Thermal Expansion 16, with R. Dinwiddie, M. A. White, and D. L. McElroy, eds., DEStech Publishing, Lancaster PA, 2005, pp. 256-268.

11. Calculation

11.1 Average data from all five specimens to determine the average thermal effusivity values and standard deviation for the fabric samples.

12. Report

12.1 Report the following information:

12.1.1 Identification of the material tested,

12.1.2 Identification of the calibration materials and timing perimeters employed in the calibration (test time, calculated start time, cooling period, frequency, power level, and temperature),

12.1.3 Temperature and relative humidity of the test environment,

12.1.4 Sensor temperature,

12.1.5 The side of each specimen that was applied against the sensor,

12.1.6 The thermal effusivity of each specimen, the average thermal effusivity, and standard deviation of all specimens of one fabric type,

12.1.7 The test time applied to the measurement pulse,

12.1.8 Applied force used with the compression test accessory and sample thickness.

13. Precision and Bias

13.1 The precision of this test method is based on an ~~intralaboratory~~interlaboratory study (ILS) of ~~ASTM WK43374, New Standard~~ Test Method D7984~~for Measuremetn of Thermal Effusivity of Fabrics Using a Modified Transient Plane Source (MTPS) Instrument, conducted in 2014. A single laboratory participated in this study, testing five fabrics.~~ , conducted during 2018 and 2019. Seventeen data sets from seven laboratories were submitted to this study, which tested three fabrics at two different levels of compression. Every "test result" represents an individual determination, and is an average of five measurements in a given location. The laboratory reported three replicate test results for each ~~material. Except for the use of only one laboratory,~~ material at each compression level. Practice E691 was followed for the design and analysis of the data; the details are given in a Research Report.[7]

13.1.1 *Repeatability (r)*—The ~~difference between repetitive results obtained by the same operator in a given laboratory applying the same test method with the same apparatus under constant operating conditions on identical test material within short intervals of time~~pooled repeatability relative standard deviation was 1.5 %. At the 95 % confidence level, no significant difference exists between two test results on the same material in the same laboratory if the value between the two differs by less than a factor of 0.042x ~~would in the~~(4.2 %), where ~~*long*~~x ~~run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.~~is total test value.

13.1.1.1 Repeatability can be interpreted as maximum difference between two results, obtained under repeatability conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

~~13.1.1.2 Repeatability limits are listed in Table 1.~~

13.1.2 *Reproducibility (R)*—The ~~difference between two single and independent results obtained by different operators applying the same test method in different laboratories using different apparatus on identical test material would, in the long run, in the normal and correct operation of the test method,~~pooled reproducibility relative standard deviation was 5.4 %. At the 95 % confidence level, no significant difference exists between two test results on the same material between different laboratories if the value between the two differs by less than a factor 0.15x ~~exceed the~~(15 %), where ~~*following*~~x ~~values only in one case in 20.~~is the total test value.

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[7] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report ~~RR:D13-1142~~RR:D13-2000. Contact ASTM Customer Service at service@astm.org.