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.

Designation: F3538 − 22

Standard Test Method for Measuring Heat Transmission Through Flame-Resistant Materials for Clothing in Flame Exposure Using a Cylindrical Specimen Holder[1]

This standard is issued under the fixed designation F3538; 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 measures the thermal response of a material or combination of materials using a combined convective/radiant heat transmission apparatus consisting of an eccentric cylindrical test sensor. It can be used to estimate the non-steady state thermal transfer through flame-resistant materials used in clothing when subjected to a continuous, combined convective and radiant heat exposure. The average incident heat flux is 84 kW/m^2 (2 $cal/cm^2 \cdot s$), with durations up to 30 s.

1.1.1 This test method is not applicable to materials that melt, drip, or cause falling debris during the test.

NOTE 1—Because of the arrangement of the equipment, if materials melt, drip, or cause falling debris during the test, the test result is invalid.

1.2 Heat transmission through clothing is largely determined by its thickness, including any air gaps. The air gaps can vary considerably in different areas of the human body. This method provides a means of grading materials when tested under standard test conditions and an air gap exists between the fabric and the sensor. During the exposure, fabric temperatures can exceed 400 °C. At these temperatures some fabrics are not dimensionally stable and can shrink or stretch. The cylindrical geometry used in this test method allows such motion to occur, which will affect the time to achieve the end point of the test. These effects are not demonstrated in planar geometry test methods such as Test Method F2700.

1.3 This test method is used to measure and describe the response of materials, products, or assemblies to heat under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions.

1.4 The measurements obtained and observations noted only apply to the particular material(s) tested using the specified heat flux, flame distribution, and duration.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units or other units commonly used for thermal testing. If appropriate, round the non-SI units for convenience.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. Fire testing is inherently hazardous. Adequate safeguards for personnel and property shall be employed in conducting these tests. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D123 Terminology Relating to Textiles

E457 Test Method for Measuring Heat-Transfer Rate Using a Thermal Capacitance (Slug) Calorimeter

F1494 Terminology Relating to Protective Clothing

F2700 Test Method for Unsteady-State Heat Transfer Evaluation of Flame-Resistant Materials for Clothing with Continuous Heating

2.2 *AATCC Standard:*[3]

AATCC LP1 Laboratory Procedure for Home Laundering: Machine Washing

3. Terminology

3.1 *Definitions:*

[1] This test method 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.

Current edition approved July 1, 2022. Published July 2022. DOI: 10.1520/F3538-22.

[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 Association of Textile Chemists and Colorists (AATCC), P.O. Box 12215, Research Triangle Park, NC 27709-2215, http://www.aatcc.org.

3.1.1 *breakopen, n*—in testing thermal protective materials, a material response evidenced by the formation of a hole in the test specimen during the thermal exposure that may result in the exposure energy in direct contact with the heat sensor.

3.1.2 *charring, n*—the formation of a carbonaceous residue as the result of pyrolysis or incomplete combustion.

3.1.3 *cylinder heat transfer performance value (CHTP), n*—in testing of thermal protective materials with the use of a cylindrical specimen holder, the cumulative amount of thermal energy identified by the intersection of the measured time-dependent heat transfer response through the subject material to a time-dependent, empirical performance curve, expressed as a rating or value; J/cm^2 (cal/cm^2).

3.1.4 *embrittlement, n*—the formation of a brittle residue as a result of pyrolysis or incomplete combustion.

3.1.5 *heat flux, n*—the thermal intensity indicated by the amount of energy transmitted divided by area and time; kW/m^2 ($cal/cm^2 \cdot s$).

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

3.1.7 *melting, n*—a material response evidenced by softening of the polymer.

3.1.8 *response to heat exposure, n*—in testing the thermal resistance of thermal protective materials, the observable response of the material to the energy exposure as indicated by breakopen, melting, dripping, charring, embrittlement, shrinkage, sticking, and ignition.

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

3.1.10 *sticking, n*—a material response evidenced by softening and adherence of the material to the surface of itself or another material.

3.1.11 *unsteady-state heat transfer value, n*—in testing of thermal protective materials, a quantity expressed as the time-dependent difference between the incident and exiting thermal energy values normal to and across two defined parallel surfaces of an exposed thermal insulative material.

3.2 For the definitions of protective clothing terms used in this test method, refer to Terminology F1494, and for other textile terms used in this test method, refer to Terminology D123.

4. Summary of Test Method

4.1 A test specimen is wrapped around an instrumented test cylinder that is horizontally positioned and exposed to a combined convective and radiant heat source with an exposure heat flux of 84 ± 2 kW/m^2 (2 ± 0.05 $cal/cm^2 \cdot s$).

NOTE 2—Other exposure heat flux values are allowed, however, different exposure conditions have the potential to produce different results. The test facility must verify the stability of other exposure levels over the material's exposure time interval (used to determine the heat transfer performance value) and include this in the test results report.

4.1.1 The transfer of heat through the test specimen is measured using a copper slug calorimeter with a convex curvature. The change in temperature versus time is used, along with the known thermophysical properties of copper, to determine the respective thermal energy passed through the test specimen.

4.1.2 A cylinder heat transfer performance value (CHTP) of the test specimen is calculated based on measurements from the calorimeter.

4.1.3 Observations of the thermal response of the specimen resulting from the exposure are optionally noted.

5. Significance and Use

5.1 This test method is intended for the determination of the cylinder heat transfer performance value of a flame-resistant material or combination of materials when exposed to a continuous and constant heat source. This is used to compare materials used in flame-resistant clothing for workers when exposed to combined convective and radiant thermal hazards.

NOTE 3—Air movement at the face of the specimen and around the calorimeter can affect the measured heat transferred due to forced convective heat losses. Minimizing air movement around the specimen and test apparatus will aid in the repeatability of the results.

5.2 This test method maintains the specimen with and without air gaps in a static, horizontal position and does not involve movement unless the test specimen naturally changes due to the thermal exposure.

5.3 This test method specifies a standardized 84 ± 2 kW/m^2 (2 ± 0.05 $cal/cm^2 \cdot s$) exposure condition. Different exposure conditions have the potential to produce different results. Use of other exposure conditions that are representative of the expected hazard are allowed but shall be reported with the results, along with a determination of the exposure energy level stability.

5.4 This test method does not predict skin burn injury from the heat exposure.

5.5 This test method is similar to Test Method F2700 in that it uses the same energy heat source, water-cooled shutter, data acquisition, and measures the heat transfer through protective clothing materials using a copper calorimeter. This test method differs from Test Method F2700 in the usage of an eccentric instrumented cylinder mounted horizontally that allows for the thermal shrinkage of materials when tested.

6. Apparatus and Materials

6.1 *General Arrangement*—The measurement apparatus configuration consists of a combined convective and radiant energy heat source, a water-cooled shutter for exposure control, a specimen and sensor support structure, a specimen holder assembly, a copper calorimeter sensor assembly, and a data acquisition/analysis system. Automation of the apparatus for execution of the measurement procedure is allowed. The general arrangement of the test apparatus configuration is shown in Fig. 1.

6.2 *Gas Supply*—Propane (commercial grade or better) or methane (technical grade or better).

6.3 *Gas Flow Meter*—Any gas flow meter or rotameter with range to give a flow equivalent of at least 6 L (0.21 ft^3)/min air at standard conditions.

6.4 *Thermal Energy Sources:*

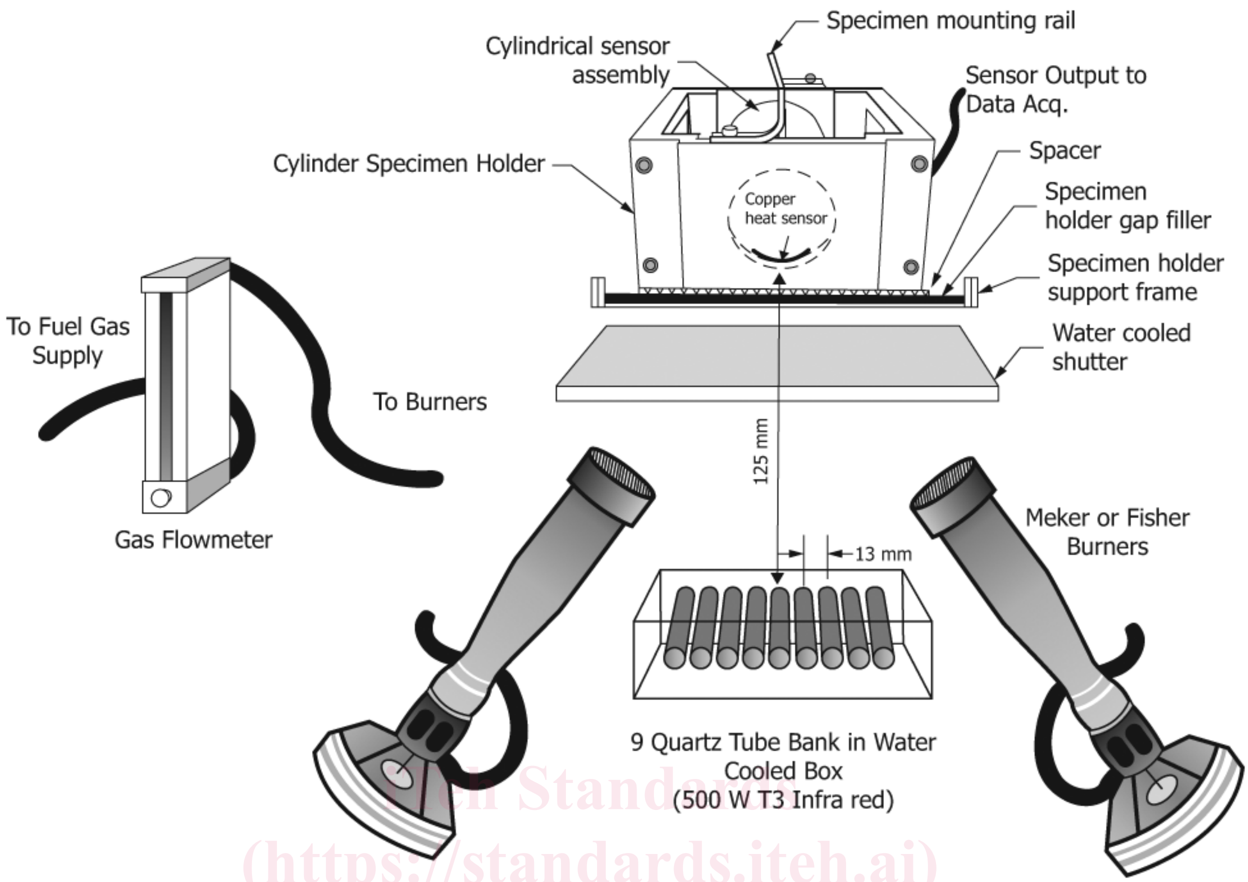

FIG. 1 Apparatus Used to Measure Heat Transfer Performance of Textile Materials

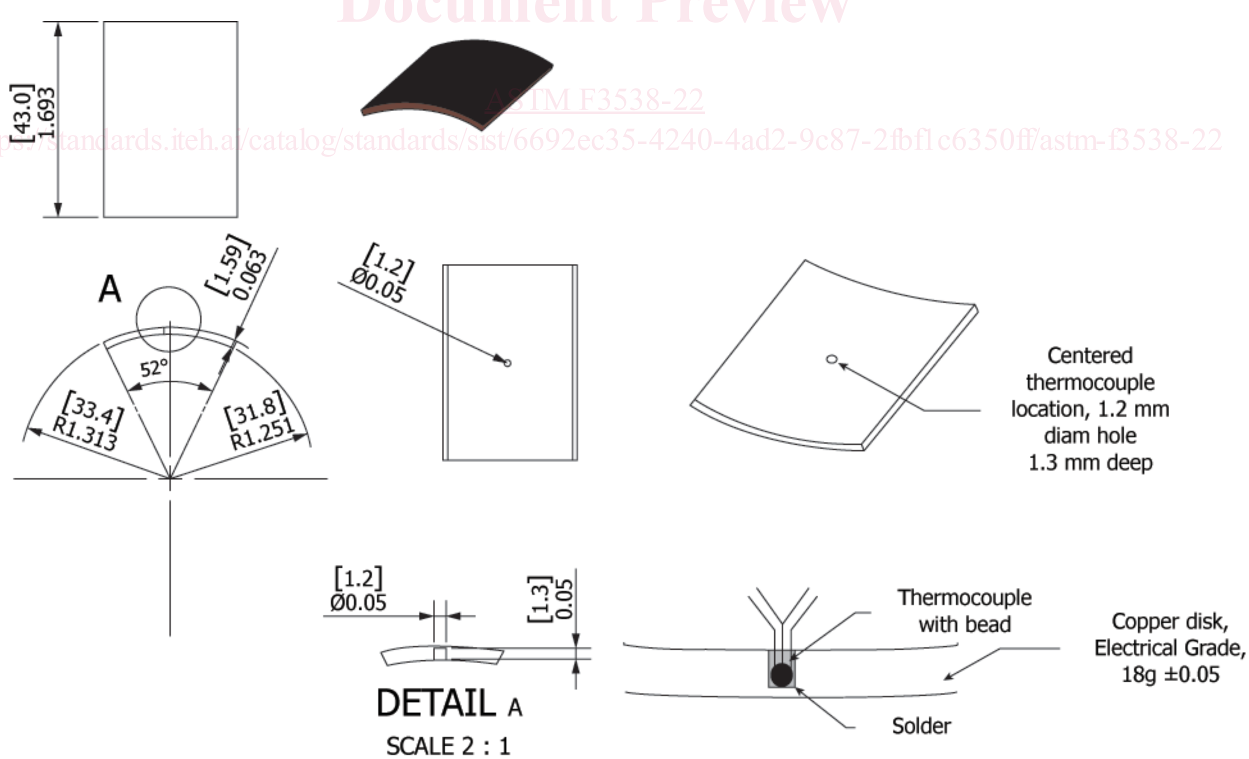

FIG. 2 Convex Thermal Copper Calorimeter Heat Sensor

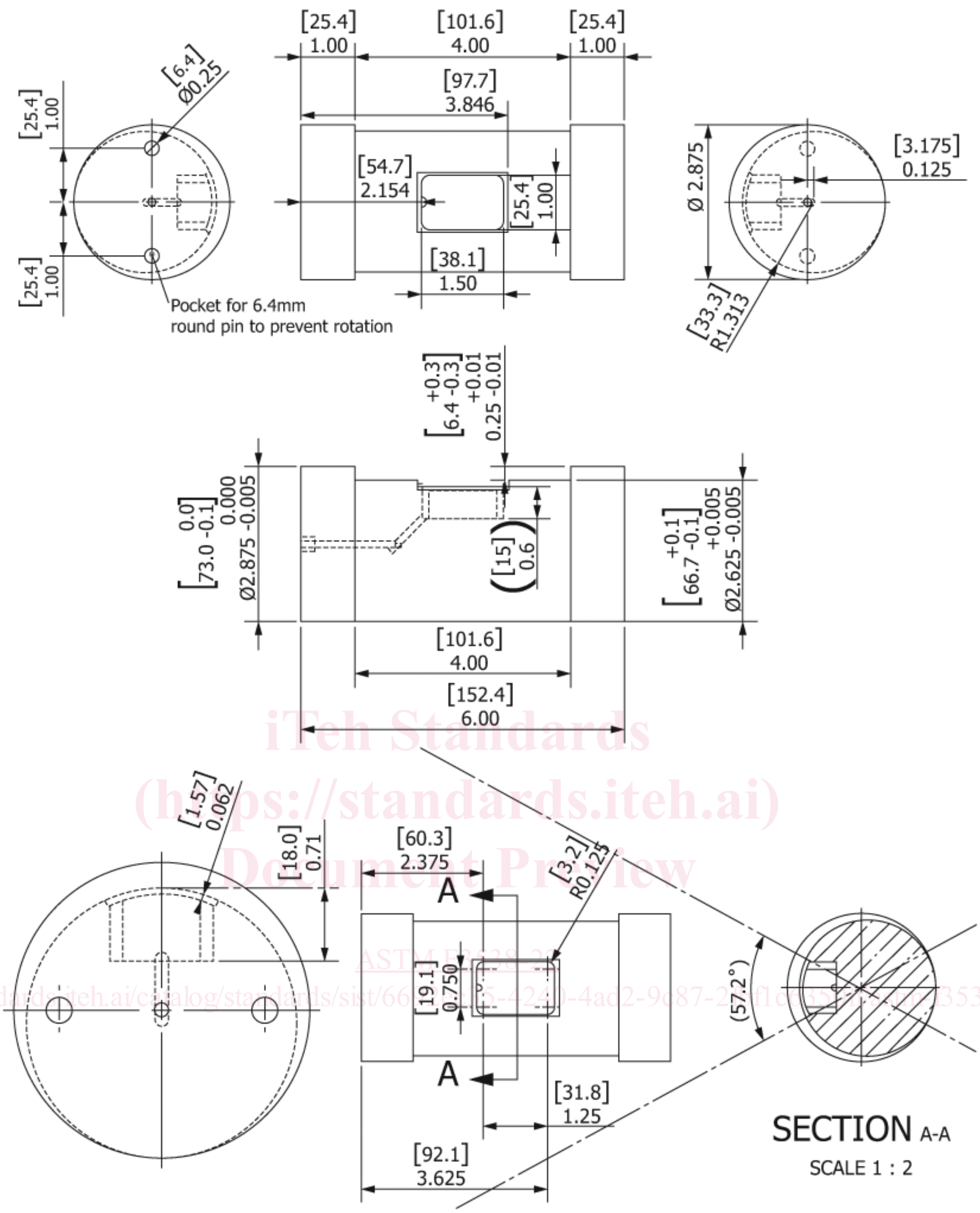

FIG. 3 Cylindrical Sensor Mounting Block

6.4.1 Two each, Meker or Fisher burners jetted for the selected fuel gas (propane or methane) with a 38 mm (1.5 in.) diameter top are arranged so that the bodies (top section) do not obstruct the quartz lamps and their flame profiles overlap. Dimension tolerances are ±5 %.

6.4.2 A minimum of nine 500W T3 translucent quartz infrared lamps, connected to a variable electrical power controller, arranged as a linear array with 13 ± 0.5 mm center-to-center spacing set 125 ± 10 mm from the specimen surface.[4]

6.4.2.1 Use of a water-cooled housing for the quartz infrared lamp bank is suggested. This helps to avoid heating adjacent mechanical components and to shield the operator from the radiant energy.

NOTE 4—The exposure heat source incorporates two Meker or Fisher burners and nine quartz infrared lamps.

6.5 *Cylindrical Test Assembly:*

NOTE 5—Tolerances are only provided for the mass of the thermal copper slug sensor and the cylindrical sensor mounting block; all other measurements are construction limits. Dimension units are mm (in.).

6.5.1 *Thermal Copper Slug Sensor*—A cylindrical-shaped disc, as shown in Fig. 2, shall be made of copper of at least

[4] A 500-Watt T3 120V AC quartz infrared heat lamp, product number 21651-1 from Philips Lighting Company, has been used successfully in this application.

99 % purity, having the dimensions shown and a mass of 18 ± 0.05 g before drilling the dimple for the thermocouple. A single ANSI Type J (Fe/Cu-Ni) thermocouple wire bead (0.254 mm wire diameter or finer, equivalent to 30 AWG) is installed as shown in Fig. 3 (see Test Method E457 for information regarding slug calorimeters). Only the length attached to the disc shall be bare.

6.5.2 The thermocouple wire bead shall be installed in the calorimeter as shown in Fig. 2.

6.5.2.1 The thermocouple wire bead shall be bonded to the copper disk with a suitable HMP solder with a melting temperature >280 °C. Only enough solder to fill the dimple shall be used so that the mass of the calorimeter will be kept within the stated limits.

NOTE 6—HMP solders consisting of 5 %Sb-95 %Pb (~307 °C melting point) and 5 %Sb-93.5 %Pb-1.5 %Ag (~300 °C melting point) have been found to be suitable. The 280 °C temperature minimum identified above corresponds to the point where melting of the solder bond would be experienced with a ~17 s exposure of an 84 kW/m^2 heat flux to a prepared copper calorimeter with a surface area of 12.57 cm^2 and a mass of 18.0 g. A careful soldering technique is required to avoid "cold" solder joints (where the solder has not formed a suitable bond of the thermocouple to the copper disk).

6.5.3 *Cylindrical Sensor Mounting Block*—The calorimeter is mounted in a cylindrical-shaped mounting block with the dimensions shown in Fig. 3. The thermal characteristics of the cylindrical sensor block shall be constructed from flame-resistant material with a thermal conductivity value of ≤0.15 W/m K, high temperature stability, and resistance to thermal shock which will not contribute fuel to the combustion process. A cavity machined in the center of the cylindrical-shaped mounting block to accommodate the curved copper sensor and an air gap as shown in Fig. 3. The cylindrical-shaped and insulated mounting block has an eccentric cylinder shape cut into it to produce a 6.35 mm air gap between the back of the test specimen and the curved copper calorimeter.

NOTE 7—Marinite I structural insulation has been found to be a suitable material for construction.

6.5.4 The face of the curved copper calorimeter shall be flush with the surface of the cylindrical-shaped and insulated mounting block. The sensor is held into the recess of the cylinder using four straight pins, trimmed to a nominal length of 5 mm, by placing them equidistant around the edge of the sensor so that the heads of the pins hold the sensor flush to the surface. The pinheads shall be trimmed so that they are flush with the surface of the cylinder (Fig. 4).

6.5.4.1 Paint the exposed surface of the copper slug calorimeter with a thin coating of a flat black, high-temperature spray paint with an absorptivity of 0.9 or greater. The painted sensor shall be dried and cured according to the manufacturer's instructions before use and present a uniformly applied coating (no visible thick spots or surface irregularities). In the absence of manufacturer's instructions, an external heat source, for example, an external heat lamp, shall be used to completely drive off any remaining organic carriers in a freshly painted surface before use.

NOTE 8—Absorptivity of painted calorimeters is discussed in the ASTM Research Report, "ASTM Research Program on Electric Arc Test Method Development to Evaluate Protective Clothing Fabric; ASTM F18.65.01 Testing Group Report on Arc Testing Analysis of the F1959 Standard Test Method— Phase 1."

6.5.5 *Cylindrical Sensor and Specimen Holder*—The cylindrical sensor is mounted in an aluminum frame as shown in Fig. 5. The aluminum frame has a thin aluminum rail running along its length for clamping the test specimen during the exposure.

NOTE 9—The dimensions of the aluminum frame which holds the cylindrical insulated mounting block are such that the device fits into the specimen holder support frame (Fig. 6) which has the same dimensions/specifications used in Test Method F2700 when used with the specimen holder gap filler (Fig. 7).

6.5.6 *Cylindrical Test Assembly Support Equipment (Support Frame, Gap Filler, and Spacer):*

6.5.6.1 *Support Frame*—A piece of steel 200 mm square, 3.0 mm thick, with a 100 mm square hole in its center (see Fig. 6). Note that the overall dimensions of this will be specific to the test apparatus. The intention is to provide a repeatable location for the sensor assembly placement.

6.5.6.2 *Gap Filler*—A piece of steel 200 mm square, 6.4 mm thick, with a hole of the dimensions shown in Fig. 7.

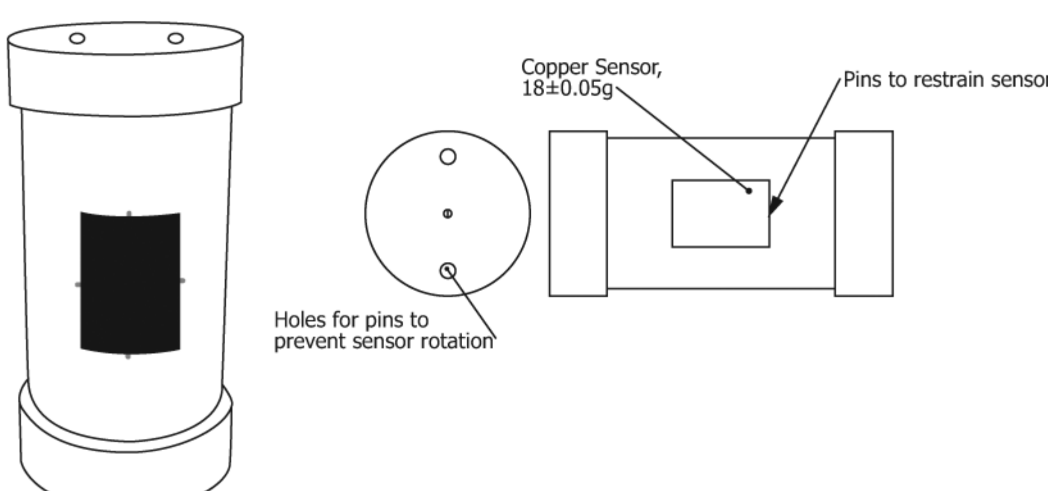

FIG. 4 Cylindrical Sensor (copper disk mounted into recess of cylindrical sensor mounting block)

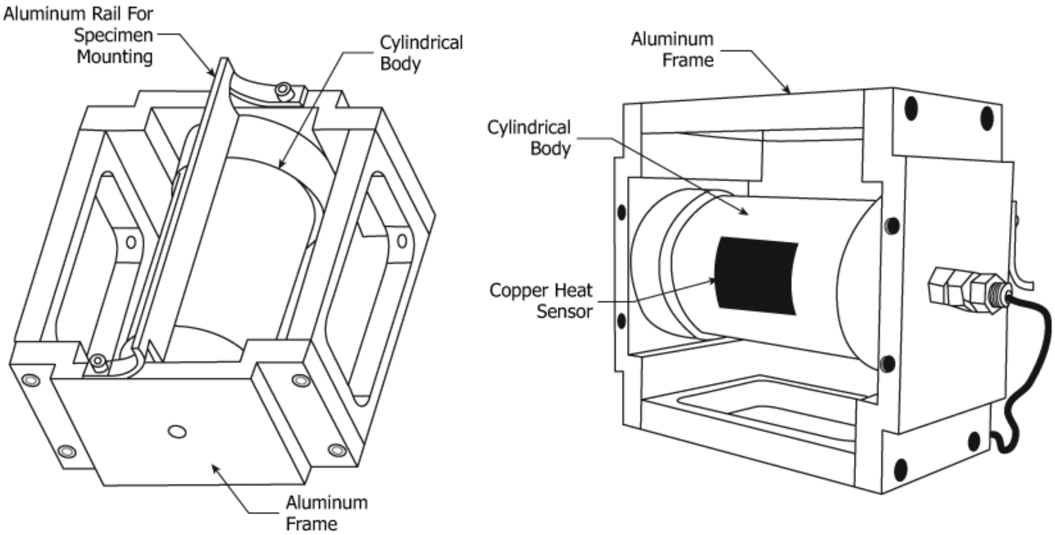

FIG. 5 Cylindrical Sensor and Specimen Holder

It is designed to sit inside the specimen holder support frame. The center cutout is such that the cylinder specimen holder will fit inside.

6.5.6.3 *Spacer*—A piece of steel 150 mm square, 6.35 mm thick, with a 125 mm square hole in its center (see Fig. 8). The plate is used to raise the cylindrical specimen holder 6.35 mm (0.25 in.) when testing the fabric in the spaced configuration. This is done so the incident heat flux seen at the lower surface of the test specimen is the same as the incident heat flux set in Section 9.

6.6 *Data Acquisition/Analysis System*—A data acquisition/analysis system is required that is capable of recording the calorimeter temperature response, calculating the resulting thermal energy and ratio value, and determining the test endpoint by comparing the time-dependent thermal energy transfer reading to an empirical performance curve.

6.6.1 The data acquisition component shall have a minimum sampling rate of four samples per second for temperatures to 250 °C, with a minimum resolution of 0.1 °C and an accuracy of ±0.75 °C. It must be capable of making cold junction corrections and converting the millivolt signals from the Type J thermocouple to temperature (see NIST Monograph 175 or ASTM MNL 12 Manual on the Use of Thermocouples in Temperature Measurement).

6.7 *Solvents,* alcohol or petroleum solvent, for cleaning the copper slug calorimeter.

6.8 *Paint,* flat black spray type, with an absorptivity value of >0.90. See Note 8 for details.

6.9 *Cylindrical Test Assembly,* see Figs. 9 and 10.

6.10 *Shutter*—A manual or computer-controlled shutter is used to block the energy from the burner (placed between the cylindrical test assembly and the burner). Water-cooling is recommended to minimize radiant heat transfer to other equipment components and to prevent thermal damage to the shutter itself.

7. Hazards

7.1 Perform the test in a hood to carry away combustion products, smoke, and fumes. Shield the apparatus or turn off the hood while running the test; turn the hood on to clear the fumes. Maintain an adequate separation between the burner and combustible materials.

7.2 The cylindrical test assembly is heated during testing. Use protective gloves when handling these hot objects.

7.3 Use care when the specimen ignites or releases combustible gases. Allow the sample to burn out or smother it if necessary.

7.4 Refer to Manufacturer's Safety Data Sheets for information on handling, use, storage, and disposal of materials used in this test method.

7.5 Refer to local codes for compliance on the installation and use of the selected fuel gas (propane or methane).

8. Sampling and Specimen Preparation

8.1 *Laboratory Sample*—Select a minimum of a 1.0 m^2 sample size from the material to be tested. Individual test specimens will be produced from this sample.

8.2 *Laundering of Laboratory Sample:*

8.2.1 For specimens submitted without explicit test laundering specifications, launder the laboratory sample for one wash and dry cycle prior to conditioning. Use laundry conditions of AATCC Laboratory Procedure 1 (1, V, A, i).

8.2.1.1 Stitching the edges of the laboratory sample is allowed to minimize unraveling of the sample material.

8.2.1.2 Restoring test specimens to a flat condition by pressing is allowed.

8.2.1.3 If an alternative laundry procedure is employed, report the procedure used.

8.2.2 For those materials that require cleaning other than laundering, follow the manufacturer's recommended practice

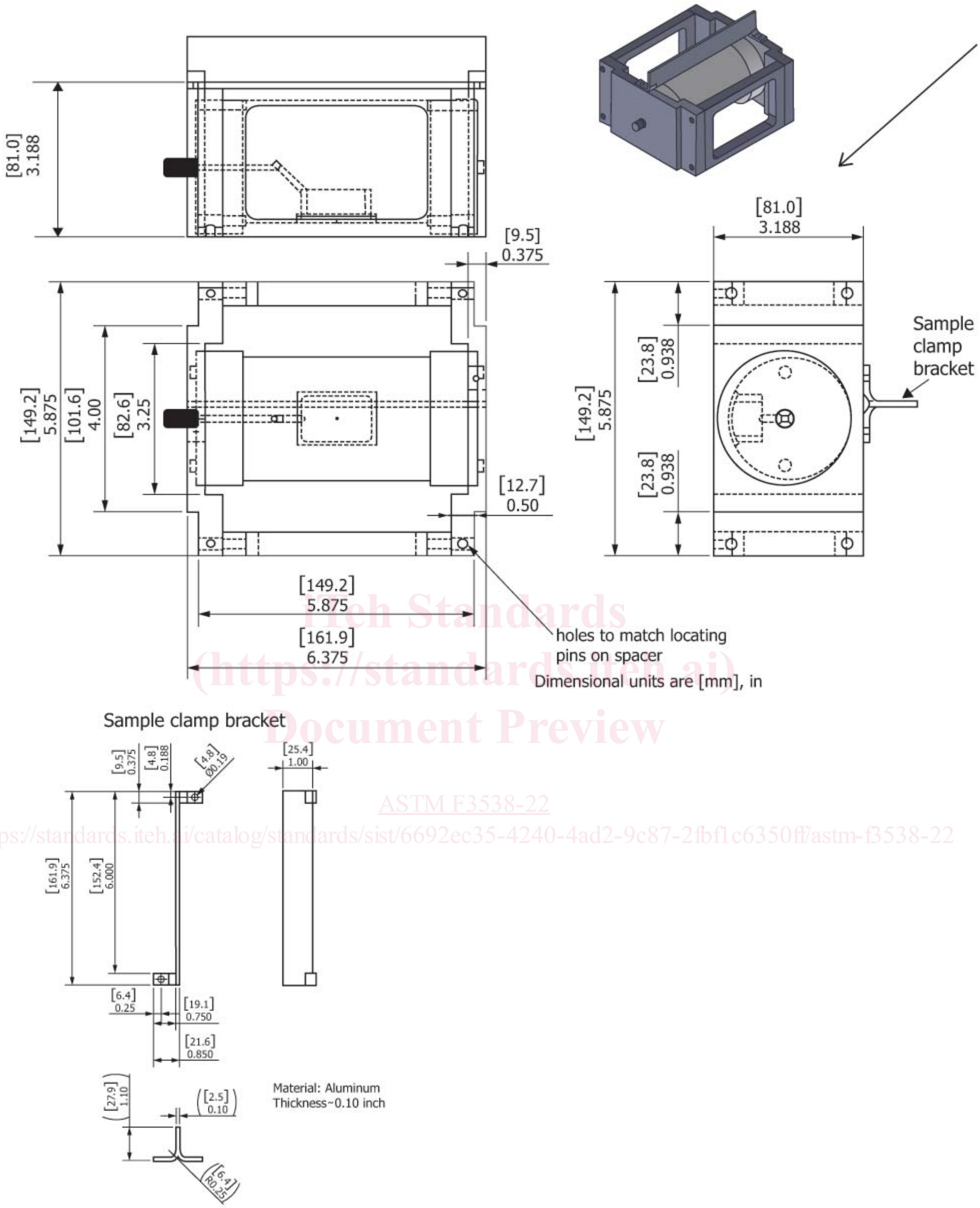

FIG. 5 Cylindrical Sensor and Specimen Holder *(continued)*

using one cleaning cycle followed by drying and note the procedure used in the test report.

8.2.3 Materials designated by the manufacturer not to be laundered or cleaned shall be tested as received.

8.3 *Test Specimens:*

8.3.1 *Spaced Configuration*—Cut and identify test specimens from each swatch in the laboratory sample. Make each test specimen 140 by 280 ± 5 mm (5.5 by 11 ± ⅛ in.). Five