Designation: E1474 – 14

An American National Standard

Standard Test Method for Determining the Heat Release Rate of Upholstered Furniture and Mattress Components or Composites Using a Bench Scale Oxygen Consumption Calorimeter[1]

This standard is issued under the fixed designation E1474; 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 test method provides a means for measuring the ignition time and heat release of the composite upholstered components of upholstered furniture and mattresses using an oxygen consumption calorimeter.

1. Scope

1.1 This fire-test-response test method can be used to determine the ignitability and heat release from the composites of contract, institutional, or high-risk occupancy upholstered furniture or mattresses using a bench scale oxygen consumption calorimeter.

1.2 This test method provides for measurement of the time to sustained flaming, heat release rate, peak and total heat release, and effective heat of combustion at a constant initial test heat flux of 35 kW/m^2. This test method is also suitable to obtain heat release data at different heating fluxes. The specimen is oriented horizontally, and a spark ignition source is used.

1.3 The times to sustained flaming, heat release, and effective heat of combustion are determined using the apparatus and procedures described in Test Method E1354.

1.4 The tests are performed on bench-scale specimens combining the furniture or mattress outer layer components. Frame elements are not included.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard is used to measure and describe the response of materials, products, or assemblies to heat and flame 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.*

1.7 *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.* For specific precautionary statements, see Section 6.

1.8 *Fire testing is inherently hazardous. Adequate safeguards for personnel and property shall be employed in conducting these tests.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D123 Terminology Relating to Textiles

D5865 Test Method for Gross Calorific Value of Coal and Coke

E176 Terminology of Fire Standards

E603 Guide for Room Fire Experiments

E906 Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using a Thermopile Method

E1354 Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter

2.2 *Other Documents:*

CA TB 133, Flammability Test Procedure for Seating Furniture for Use in Public Occupancies[3]

[1] This test method is under the jurisdiction of ASTM Committee E05 on Fire Standards and is the direct responsibility of Subcommittee E05.21 on Smoke and Combustion Products.

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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 State of California, Dept. of Home Furnishings and Thermal Insulation, North Highlands, CA 95660-5595.

ISO 5725 Part 2, Accuracy (Trueness and Precision) of Measurement Methods and Results—Basic Method for the Determination of Repeatability and Reproducibility of a Standard Measurement Method[4]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms relating to this test method refer to Terminology D123 and E176.

3.1.2 *effective heat of combustion, n*—the amount of heat generated per unit mass lost by a material, product, or assembly, when exposed to specific fire test conditions. (see *gross heat of combustion*.)

3.1.2.1 *Discussion*—The effective heat of combustion depends on the test method and is determined by dividing the measured heat release by the mass loss during a specified period of time under the specified test conditions. Typically, the specified fire test conditions are provided by the specifications of the fire test standard that cites effective heat of combustion as a quantity to be measured. For certain fire test conditions, involving very high heat and high oxygen concentrations under high pressure, the effective heat of combustion will approximate the gross heat of combustion. More often, the fire test conditions will represent or approximate certain real fire exposure conditions, and the effective heat of combustion is the appropriate measure. Typical units are kJ/g or MJ/kg.

3.1.3 *gross heat of combustion, n*—the maximum amount of heat per unit mass that theoretically can be released by the combustion of a material, product, or assembly; it can be determined experimentally only under conditions of high pressure and in pure oxygen (contrast *effective heat of combustion*).

3.1.4 *heat flux, n*—heat transfer to a surface per unit area, per unit time (see also *initial test heat flux*).

3.1.4.1 *Discussion*—The heat flux from an energy source, such as a radiant heater, can be measured at the initiation of a test (such as Test Method E1354 or Test Method E906) and then reported as the incident heat flux, with the understanding that the burning of the test specimen can generate additional heat flux to the specimen surface. The heat flux can also be measured at any time during a fire test, for example as described in Guide E603, on any surface, and with measurement devices responding to radiative and convective fluxes. Typical units are kW/m^2, $kJ/(s\ m^2)$, W/cm^2, or $BTU/(s\ ft^2)$.

3.1.5 *initial test heat flux, n*—the heat flux set on the test apparatus at the initiation of the test (see also *heat flux*).

3.1.5.1 *Discussion*—The initial test heat flux is the heat flux value commonly used when describing or setting test conditions.

3.1.6 *oxygen consumption principle, n*—the expression of the relationship between the mass of oxygen consumed during combustion and the heat released.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *heat release rate, n*—the heat evolved from the specimen, expressed per unit area of exposed specimen area per unit of time.

3.2.2 *ignitability, n*—the propensity for ignition, as measured by the time to sustained flaming at a specified heating flux.

3.2.3 *mattress, n*—a mattress is a ticking (outermost layer of fabric or related material) filled with a resilient material, used alone or in combination with other products, intended or promoted for sleeping upon.

3.2.4 *net heat of combustion, n*—the oxygen bomb (see Test Method D5865) value for the heat of combustion, corrected for the gaseous state of product water.

3.2.4.1 *Discussion*—The net heat of combustion differs from the gross heat of combustion in that the former assesses the heat per unit mass generated from a combustion process that ends with water in the gaseous state while the latter ends with water in the liquid state.

3.2.5 *orientation, n*—the plane on which the exposed face of the specimen is located during testing, which is horizontal facing up for this test.

3.2.6 *sustained flaming, n*—the existence of flame on or over the surface of the specimen for a period of 4 s or more.

3.2.7 *upholstered, adj*—covered with material (as fabric or padding) to provide a soft surface.

3.2.8 *upholstery material, n*—the padding, stuffing, or filling material used in a furniture item, which may be either loose or attached, enclosed by an upholstery cover material and support system, if present.

3.2.8.1 *Discussion*—This includes, but is not limited to, material such as foams, cotton batting, polyester fiberfill, bonded cellulose, or down.

4. Summary of Test Method

4.1 This test method is based on the observation that the net heat of combustion is generally directly related to the amount of oxygen required for combustion (**1**).[5] Approximately 13.1×10^3 kJ of heat is released per 1 kg of oxygen consumed. Specimens in the test are burned in ambient air conditions while being subjected to a prescribed initial test heat flux of 35 kW/m^2.

4.2 The heat release is determined by measurement of the oxygen consumption, as determined by the oxygen concentration and flow rate in the combustion product stream, as described in Test Method E1354.

4.3 The primary measurements are oxygen concentration and exhaust gas flow rate. Additional measurements include the mass loss rate of the specimen, the time to sustained flaming, and the effective heat of combustion. Ignitability is determined by measuring the time from initial exposure to the time of sustained flaming of the specimen.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[5] The boldface numbers in parentheses refer to the list of references at the end of this test method.

5. Significance and Use

5.1 This test method is used to determine the time to sustained flaming and heat release of materials and composites exposed to a prescribed initial test heat flux in the cone calorimeter apparatus.

5.2 Quantitative heat release measurements provide information that can be used for upholstery and mattress product designs and product development.

5.3 Heat release measurements provide useful information for product development by yielding a quantitative measure of specific changes in fire performance caused by component and composite modifications. Heat release data from this test method will not be predictive of product behavior if the product does not spread flame over its surface under the fire exposure conditions of interest.

5.4 *Test Limitations*—The test data are invalid if either of the following conditions occur: (*1*) explosive spalling; or (*2*) the specimen swells sufficiently prior to ignition to touch the spark plug, or the specimen swells up to the plane of the heater base during combustion.

6. Safety Precautions

6.1 The test procedures involve high temperatures and combustion processes. Therefore, the potential for hazards such as burns, ignition of extraneous objects or clothing, and inhalation of combustion products exists. The operator must use protective gloves for insertion and removal of the test specimens. Do not touch either the cone heater or the associated fixtures while hot, except with the use of protective gloves.

7. Test Specimen Preparation—Method A (2)

7.1 *Equipment and Supplies for Specimen Preparation:*

7.1.1 *Cutting Equipment*—Cut foams with a band saw; a foam-cutting blade shall be used. This blade has no teeth; instead, it has a wavy scallop to the edge. Ensure that the blade is well sharpened. Make certain that no silicones or other oils are applied to lubricate the blade; lubrication shall be solely with graphite or molybdenum compounds. The band saw blade must make a straight and true cut of the foam. Set the blade guide no higher than 12 mm above the stock to be cut.

7.1.2 *Forming Blocks*—The specimen preparation rests crucially upon the proper use of forming blocks. These blocks are made in dimensions of 98 by 98 by 50 mm. Each of these dimensions shall be controlled to ± 0.5 mm. Use, as the material for the forming blocks, a dense wood, such as maple, which is minimally subject to dimensional changes when the humidity is changed. Do not use pine. Use only fully kiln-dried timber for making the forming blocks. Ensure that all surfaces are cut straight and true and are smooth. The edges shall not be rounded, but the corners shall be slightly rounded. It is preferable to lacquer the blocks with an acrylic lacquer to ensure a hard, smooth, stable surface. Make up a minimum of 12 blocks to allow a reasonable number of specimens to be prepared at the same time.

7.1.3 *Adhesive*—Several adhesives have been found suitable for securing the fabrics. The adhesive shall be low in flammability and shall have suitable holding power to permit inserting the resilient padding, stay in place until the testing is performed (that is, through the required conditioning) and during the flammability test procedure. For the latter, the glued portions of the fabric shall neither flame excessively nor retard burning. Adhesives that are based on polychloroprene, acrylic, or water have been found suitable.

7.1.3.1 *Adhesive Selection*—Adhesives based on polychloroprene in methylene chloride solvent have been found suitable for all composites tested.[6] Adhesives based on acrylic in water solvent (white glue, readily available in hardware and craft stores)[7] have been proven adequate for many, but not all, fabrics and interliners tested by a United States testing laboratory. Other adhesives are also suitable, provided they meet the stated requirements.

7.1.3.2 *Adhesive Application*—The method of adhesive application depends on the particular adhesive selected. Water-soluble adhesives are applied directly from the bottle and therefore do not require a brush. Likewise, any spillage is readily cleanable with water. This type of adhesive does not set as quickly as the solvent-based adhesives, which permits shifting the fabric as necessary to create a neat, tight package. However, the glued specimen shall be left overnight to ensure a good seal. On the other hand, polychloroprene-based adhesives are applied with a brush made of hog bristles or other stiff, course material. The brush shall be flat and square cut, with a width of 7 to 8 mm. A solvent compatible with the adhesive shall be used for cleanup and storage of the brush. The solvent-based glues set up very quickly and do not permit any adjustment around the wood block.

7.1.3.3 *Adhesive Checking*—To test the efficiency of an adhesive, apply a small amount on two small pieces of the fabric or interliner to be used. Allow the adhesive to dry (at least overnight), and then attempt to tear the fabric pieces from one another. To be acceptable, the glued pieces shall not be able to be separated without tearing the fabric.

7.1.4 *Tape*—Masking tape or other tape with adhesive is used to assist in assembling the test composites. Any type of tape which will adequately adhere to all fabrics and be easy to remove after completion of assembly is suitable for this purpose. Some interliners or fabrics will be damaged by direct application of masking tape to their surface, since removal results in tearing or marring the surface. For items susceptible to such damage, prepare strips of paper slightly wider than the width of the masking tape and long enough to reach all the way around the forming block. Then secure the paper strips with tape.

7.1.5 *Aluminum Foil*—Use aluminum foil that is 0.03 to 0.04 mm thick.[8] No other foil thickness shall be used; it is especially important not to substitute a thicker foil.

7.2 *Basic Preparation of Specimens:*

7.2.1 The basic instructions here pertain to specimens which comprise only a single layer of fabric over a single layer of

[6] Parabond A-1535 obtained from Para-Chem Southern, Inc., Simpsonville, SC is an example of a suitable adhesive of this type.

[7] DAP Weldwood, Hobby'n Craft Glue is an example of a suitable adhesive of this type.

[8] Commercially available heavy duty foil has the appropriate thickness.

resilient padding. The same instructions apply to specimens where an interliner is laminated onto the back of the fabric; in the latter case, the fabric/interliner combination is simply treated as a fabric alone. For specimens which use multiple padding layers, separate interliner layers and other more specialized constructions. Supplemental instructions are given in 7.3.

7.2.2 *Cutting of Resilient Padding Blocks*—The thickness of the resilient padding block will normally be 50 mm when a single layer of resilient padding is the only padding material used in the composite. With a typical fabric thickness, this will result in a total specimen thickness of approximately 50.9 mm, which is acceptable. Each resilient padding block shall be cut square, with 90° corners and face dimensions of 102.5 ± 0.5 by 102.5 ± 0.5 mm. This size ensures that the resilient padding will be compressed during composite assembly, leading to tight, well-formed specimens.

7.2.2.1 Some resilient paddings have a tendency for high friction against the sawing table and the guide. To make a smooth cut by allowing the resilient padding to slide easier, put a piece of paper between the resilient padding and the table/guide. Push the assembly of resilient padding and paper forward and allow the blade to cut through both the resilient padding and the paper.

7.2.3 *Forming Resilient Padding Blocks*—The cone calorimeter test results will not be repeatable if the density of the resilient padding tested is not very closely controlled. For this purpose, each batch of resilient padding specimens prepared shall be checked for mass. It is assumed here that three replicate tests will be performed for each specimen type. Therefore, once three blocks of resilient padding have been cut, the mass shall be determined. No block shall have a mass of more than 105 % of the mean of the three masses, nor a mass of less than 95 %. If such a difference occurs, additional blocks shall be cut and the mass determined. The preparation of composites cannot start until three blocks of resilient padding which conform to the above 5 % deviation limit have been obtained. The blocks accepted shall be marked so as to be traceable. The mass of each block of resilient padding shall be noted along with the identification marks of the blocks. The mass of resilient padding shall be reported in the test report along with other information about this test run.

7.2.4 *Fabric Cutting:*

7.2.4.1 First, cut a square of 200 by 200 mm.[9]

7.2.4.2 For cone calorimeter results to be repeatable, fabric for the different replicates shall show uniformity. When fabric material is obtained directly from a bolt of cloth, do not cut specimens using closer than 10 to 12 cm to the selvedge (that is, the finished edge).[10]

7.2.4.3 To assist in verifying that uniform specimens have been cut, check each set of fabric specimens that has been cut to the 200 by 200 mm size for mass. Determine the mass once three replicate pieces have been cut. None of the pieces shall have a mass of more than 105 % of the mean of the three, nor a mass of less than 95 %. If such a difference occurs, check to see if any of the pieces have been cut oversized; trim them if this is found to be the case. If the cause of variation was not due to oversized pieces, then additional fabric pieces shall be cut and the mass determined.

7.2.4.4 If fabrics cannot be prepared to within the 5 % deviation limit, note the fabric masses and mass range of the specimen. Continue cutting the fabric for each specimen by cutting it to the shape indicated in Fig. 1. All given dimensions shall be controlled in accordance with the tolerances given in the figure (± 0.5 mm). Only essential dimensions are given in the figure. The 95 and 102 mm dimensions shall be checked both before and after cutting. When a fabric having thick yarns is cut, stop cutting outside the 102 mm dimension when a yarn is reached. Do not cut through the yarn if this will make the dimension smaller than 102 mm.

7.2.5 *Preparing the Fabric Shell:*

7.2.5.1 Assemble the finished shell upside-down upon a forming block. Place the fabric, top side down, on the table. Place the block on top, making sure that it is well centered. Bend up the two short sides. Tape each of these sides on to the top of the forming block in the center of the top edge. Bend up the long sides and also tape them to the top of the block. Make sure that the fabric does not slip sideways on the block by checking all four corners of the top face. The fabric shall be snug but not stretched.

7.2.5.2 For sensitive interliners, when paper strips are used, put two strips, forming a cross, under the fabric before placing the forming block on top of it.[11] When the fabric is bent up, allow the strips to follow. Secure the paper strip with masking tape to hold it on. Turn the block to stand on one of its short side faces. Using the suitable adhesive, glue down the 10 mm gluing area marked with stripes in Fig. 1 on each corner flap (the area that corresponds to the long side) onto its mating short-side surface. Apply adhesive both to the underneath surface of the flap and to the surface against which it will mate. Use of a 7 to 8 mm wide brush (for solvent based adhesives) will ensure that the glued area is approximately 10 mm wide. Press down immediately after applying the adhesive or after waiting to dry, as appropriate, according to the instructions of the adhesive manufacturer.

7.2.5.3 The grey area shown in Fig. 1 is used for gripping and stretching the fabric around the corners of the forming block. After applying adhesive to the first two corners, turn the block to rest on the side just glued and apply adhesive to the other two corners. If necessary, tape over the gripping handles and around the corners in order to secure the fabric in the shape of the forming block (see above), or wrap the block with paper strips prior to sealing with masking tape.

7.2.5.4 Allow the specimen to dry face down for 24 h (do not stack specimens during drying). Be certain to clean up the brush or other utensils used to apply the adhesive. Wipe the solvent and any excess adhesive off the brush with a piece of cloth before gluing the next specimen. After 24 h have elapsed,

[9] Do not cut fabrics on the bias. If the fabric weave is such that the yarns in the two directions do not lie at 90° to each other, do not cut the sample along yarns in both directions since a skew specimen would result.

[10] This is because sometimes there are weaving or coating variations that occur closer to the selvedge.

[11] Make the paper strips wider than the tape, but shorter, so the tape can adhere to the wood block or to itself.

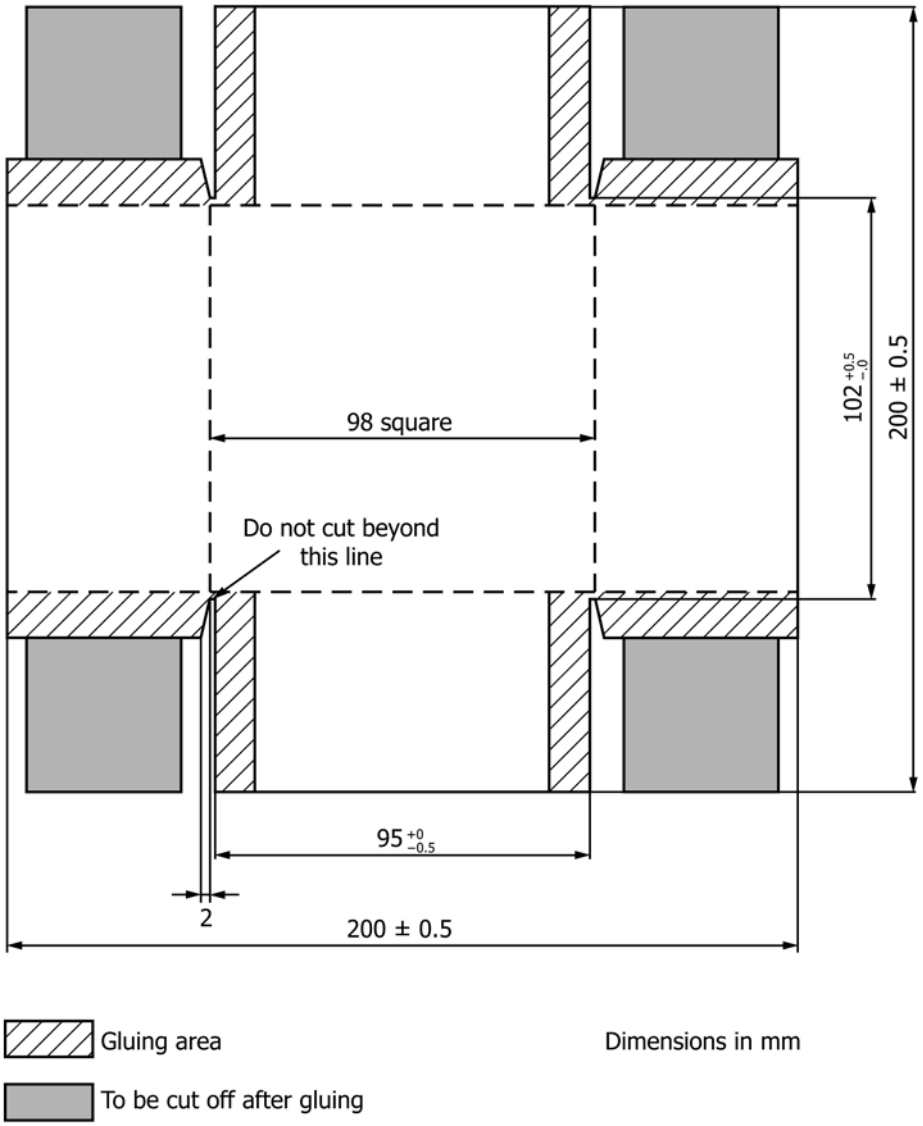

FIG. 1 Fabric Cutting Shape

remove all the pieces of masking tape and trim off the four flaps down to the indicated offset mark so that only the 10 mm glued-down portion is left. Trim any fabric protruding below the bottom edge of the forming block.

7.2.6 *Preparing the Aluminum Foil*—Cut an over-sized piece of aluminum foil. If the foil has a shiny and a dull side, place the shiny side face up. The actual specimen is slightly larger than the forming block, depending on the thicknesses of the fabric and interliner (if present). Shape the aluminum foil for the final specimen according to either 7.2.6.1 or 7.2.6.2.

7.2.6.1 Use a fabric-covered forming block encased with the fabric shell top side up. Place the block on the aluminum foil. Hold the block firmly in place and pull each side of the foil up to create the bottom folds. Form the corners by holding the foil firmly in contact with the corner of the specimen. Stretch the corner of the foil and make a 45° fold at each corner. Finally, pull the corners flat against the two sides of the specimen and pat all sides down flat against the specimen. Fig. 2 illustrates the folds to be made. Make sure that the bottom edges and the corners are crisp, straight, and smooth. Remove the forming block and its encasing fabric shell from the foil cup.

7.2.6.2 Set aside one forming block specifically for shaping the aluminum foil containers. Either prepare another block with dimensions 102 by 102 mm (rather than 98 by 98 mm), or glue or tape cardboard to the sides of a block to create one that is 102 by 102 mm. Then use this new block for shaping the aluminum foil as described in 7.2.6.1.

7.2.7 *Assembling the Shell of Resilient Padding and Fabric:*

7.2.7.1 Remove the forming block from the fabric shell. If bits of adhesive make the fabric stick to the block, use a chemist's spatula or a similar dull, knife-like device to loosen the corners. It is easiest to release the fabric by grabbing along the top edge of the fabric between the thumb and the index finger. Remove any adhesive which has remained stuck to the forming block. Make certain that the blocks of resilient padding are identified and tracked according to their masses, which have already been recorded.

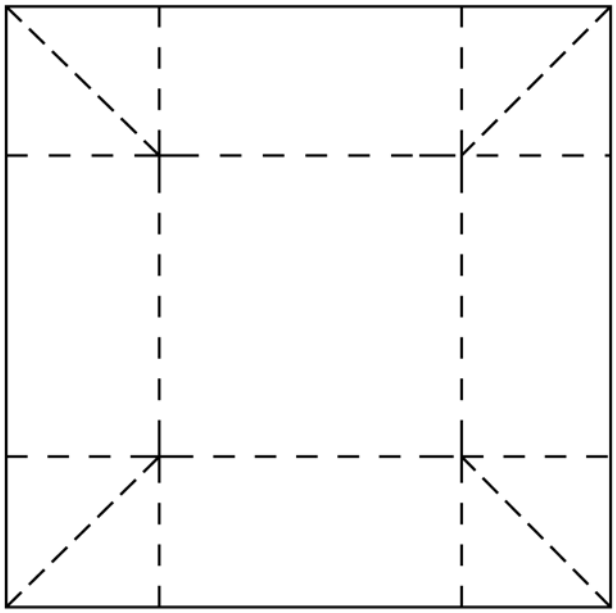

FIG. 2 Folding of Foil

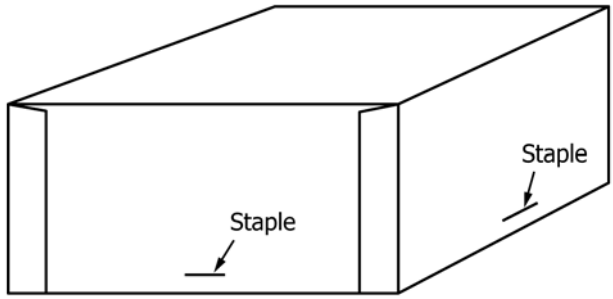

FIG. 3 Assembled Specimen

7.2.7.2 Compress the four corners of the selected resilient padding block slightly with the fingers and insert the block into the fabric shell. Make sure that the resilient padding is inserted straight. Check each of the resilient padding block corners to see that they line up exactly at the corners of the fabric shell. Check the top face to see that the block of resilient padding is inserted fully into the shell and that there are no gaps. Also check that the bottom of the resilient padding is neatly lined up with the bottom edge of the fabric. If the specimen construction involves additional padding layers or different padding layers, follow similar steps to ensure that a straight, taut assembly is made.

7.2.7.3 Carefully inspect the specimen. There shall be no buckles, warping, twisting, pulling, etc. The fabric shall be taut and there shall not be any air spaces between the fabric and the padding. If any such problems are discovered and cannot be corrected, discard the specimen. Staple each of the four sides as shown in Fig. 3. Inspect the top face of the specimen. None of the four tabs are to overhang at the top of the specimen. If there is excess material there, trim it with scissors. Be certain that no holes are made in the specimen while doing the trimming.

7.2.8 *Assembling the Specimen and the Foil*—Put the assembled specimen in the foil cup. Pat the aluminum foil sides down flush against the specimen. Cut the top of the foil to be flush with the top of the specimen. Open up the corners of the aluminum foil slightly and pull the foil top about 20 mm away from the specimen. This will allow good access of air in the conditioning chamber.

7.2.9 *Conditioning*—Place the specimen in the conditioning chamber for 24 h. Condition to moisture equilibrium (constant mass) at an ambient temperature of 23 ± 3°C and a relative humidity of 50 ± 5 %.

7.2.10 *Final Preparation*—Remove the specimen from the conditioning chamber. Check that the specimen is wrinkle-free, smooth, and visually completely uniform and symmetrical. Fix or reject the specimen if defects are found. Determine the specimen mass with and without the aluminum foil. Pat the aluminum foil sides again down flush against the specimen. Place the specimen on the sample holder. Gently push down on the top of the specimen, pushing against the ceramic fibre blanket. This ensures that the bottom conforms smoothly to the same bottom conditions as will be seen during the testing. The specimen is now ready to be tested.

7.3 *Preparation of Specimens with Multiple Layers and Specialized Constructions:*

7.3.1 The following instructions give additional details for preparation of those constructions that involve more than a single fabric layer and a single resilient padding layer. The instructions also provide for some materials which need specialized preparation techniques.

7.3.2 *Specimens That Use a Separate Interliner Layer:*

7.3.2.1 Specimens that use a separate interliner layer are prepared according to the instructions above, but with the following special provisions. For these composites, the forming block is covered twice, first with the interliner and then with the fabric, using the following steps. Some interliners are mechanically quite fragile. Avoid tearing them when the masking tape is stripped off. Test the tape to be used first to make sure that it can be smoothly pulled off of the interliner without damage.

7.3.2.2 Select an alternate tape or use paper strips if needed. Cut the interliner using the same method as described for cutting fabrics (7.2.4). Glue up the interliner around the forming block using the same instructions as for fabrics (7.2.5). Leave the specimen to dry for 24 h. After 24 h have elapsed, remove all the pieces of masking tape. If there is any interliner protruding below the bottom edge of the forming block, trim such excess off with scissors. The forming block is now covered with a layer of interliner.

7.3.2.3 Once this is done, follow the instructions above for cutting and preparing the fabric. To minimize thickness variations along the completed assembly, when placing the fabric on top of the interliner, turn its orientation by 90°. As a result of this procedure the two sides where the fabric flaps are glued will not line up with the corresponding flaps on the interliner. Thus, two of the sides of the finished specimen will contain doubled-up areas of fabric flaps and the two remaining sides will contain doubled-up areas of interliner flaps. After this procedure continue on to 7.2.6.

7.3.3 *Specimens That Use a Polyester Fibre Topper Layer on Top of the Foam:*

7.3.3.1 If a polyester fibre batting layer is present over the top of the foam, the padding assembly is prepared in accordance with 7.3.3.2 or 7.3.3.3.

7.3.3.2 If the uncompressed polyester fibre layer is 20 mm thick or less, it shall be compressed to one half of that thickness in the final assembly. The foam block thickness is then to be the difference between 50 mm and one half of the uncompressed thickness of the polyester fibre layer.

7.3.3.3 If the uncompressed polyester fibre layer is greater than 20 mm, the polyester fibre layer shall be cut back to give a 20 mm depth, and the preparation continued as above. The polyester topper layer shall be placed on top of the foam block. This composite block shall be used wherever the general instructions refer to actions to be taken on the block of resilient padding.

7.3.3.4 During final assembly of the padding inside the fabric, the polyester plus foam composite block shall be compressed so as to have a total depth of 50 mm when the assembly is finished.

7.3.4 *Specimens That Use More Than One Padding Layer (Except Polyester Fibre)*—Use any padding layers thinner than 8 mm in their natural thickness. The thickness of each remaining layer (those ≥ 8 mm in thickness) shall be proportioned so that its relative thickness in the remaining specimen depth (50 mm minus the thin layers) is in the same proportion as is found for those layers in the full-scale furniture article. Once the appropriate layers are prepared according to this instruction, they are used in exactly the same way as is the single foam block which forms the basis of the general instructions above.

7.3.5 *Specimens from Furniture Items of Unusually Thin Construction:*

7.3.5.1 For some furniture items, the total thickness of the entire padding layer is less than 50 mm. Examples include thinly padded chairs and innerspring mattresses. For such items, the padding layer is still tested in a 50 mm depth.

7.3.5.2 To do this requires that two or more layers of padding be stacked together to achieve the required 50 mm depth. When testing cone calorimeter samples that represent known full-scale constructions, the test report shall clearly identify what the maximum thickness of padding found in the full-scale article was when that thickness was less than 50 mm.

7.3.5.3 For specimens where the padding comprises layers of several different materials, yet with a total thickness of less than 50 mm, each layer will be laid-up in an increased thickness so that the total padding thickness is 50 mm and maintaining the ratios of individual layer thickness in the same proportion as occurs in the full-scale article. The layers in the test specimen are to be laid up in the same order as the layers of the furniture item.

7.3.6 *Specimens Upholstered in Leather:*

7.3.6.1 Upholstered furniture specimens using leather shrink significantly during testing and need restraint against excessive movement. This requires the use of four tie wires. Stainless steel or copper wires of approximately 1 mm diameter and 350 mm long are used for this.

7.3.6.2 The sample is prepared in the standard manner and placed in the sample holder. A tie wire is then looped around the sample and the holder such that it is parallel to, and 20 mm away from, one of the four edges of the sample holder as shown in Fig. 4. The wire is to run along the outside of the square locating frame that is welded to the underside of the sample holder. The ends of the wires are twisted together such that the wire is pulled firmly against the sample holder and the sample without distorting the latter. Excess wire is trimmed from the twisted section before testing. Fit the other remaining tie wires parallel to the other three sample holder edges.

7.3.7 *Specimens That Use Loose Filling Materials:*

7.3.7.1 Loose filling materials shall include feathers, down, shredded foam, and any other fillings which are poured into place rather than cut to size. Cone calorimeter samples for these shall be prepared by the manufacturer rather than by the testing laboratory. The manufacturer shall prepare a square pillow filled with the product. This will involve a fabric casing made from that fabric (not normally the outside upholstery fabric) that is used in the full-scale furniture article to hold together the loose filling material.

7.3.7.2 The outside dimensions of this casing is to be 98 by 98 by 48 mm. The fabric casing shall be prepared from two pieces. The top piece is to be cut slightly larger than 200 by 200 mm. The exact dimensions will depend on the needs of the sewing technique.[12] The casing top piece is now folded in a waterfall fold. (See Fig. 5.) The four corners are tucked inside. The blind opening left at each corner is then sewn shut. The second fabric piece (not shown in the figure) is used to form the bottom. Its size is slightly larger than 100 by 100 mm.

7.3.7.3 The bottom piece is to be sewn to the bottom edge of the top piece by sewing around all the four sides. Before the bottom is completely sewn shut, fill the inside of the casing with the same density of material as will be used in the intended test article. Make sure that the corners are filled evenly and that any bulging of the top is minimized. It is also possible to have multi-layer constructions, where the loose fill material does not comprise the entire depth of construction, with the remaining depth comprising foam, battings, or other non-loose materials. In such cases, the fabric casing shall still be constructed to the dimensions specified above. For such multi-layer constructions the casing shall be filled inside with proportionate depths of loose-fill and non-loose fill material, proportioned to the depths in the full-scale furniture article.

NOTE 1—For information concerning the effect of specimen preparation on the test responses, see Appendix X2.

7.4 An alternate method of specimen preparation is available. See Annex A1.

8. Test Procedure

8.1 *Preparation:*

8.1.1 Calibrate the test apparatus as directed in Test Method E1354. Position the cone heater for a horizontal specimen orientation, and set the radiant flux level to the required 35 kW/m^2 ± 1 kW.

8.1.2 Verify that the distance between the bottom of the cone heater baseplate and the top of the specimen is 25 mm.

[12] The thread to be used to sew the casings shall replicate the material used in the end product.

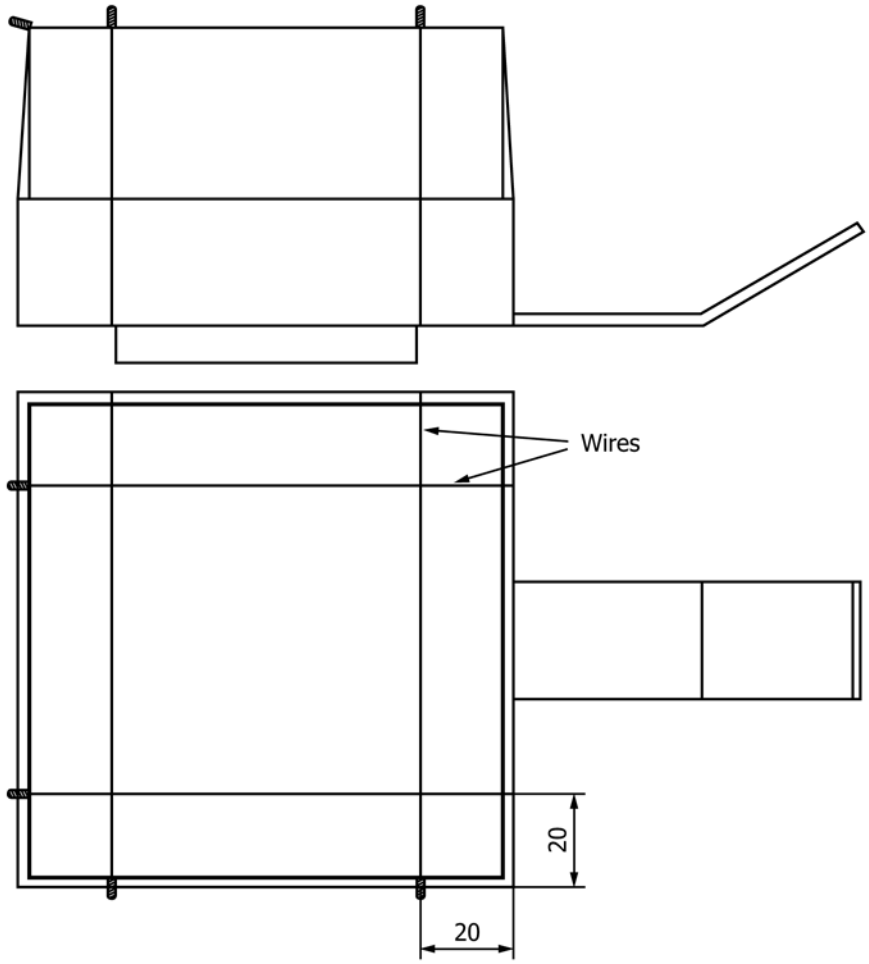

FIG. 4 Assembling of Specimen Upholstered with Leather

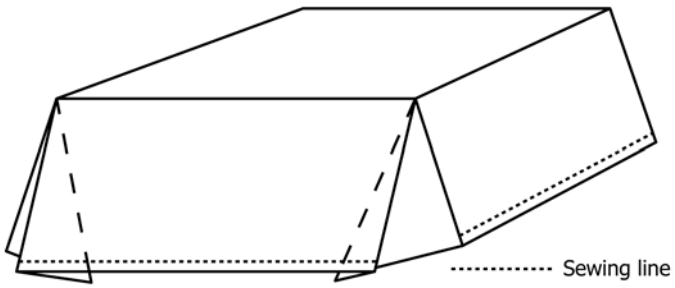

FIG. 5 Folding of Fabric for Loose Filling Materials

8.1.3 Position the spark igniter (sparker) as high as possible, without hitting the cone heater assembly. It is possible that some padding materials will swell up and contact the sparker during the test. If the specimen comes into contact with the sparker or the heater base plate, the mass loss and heat of combustion values will not be usable.

8.2 *Procedure:*

8.2.1 Prepare the data collection system for testing according to the operating procedures for the system. Place the specimen, in the appropriate holder, on the load cell. The holder must initially be at room temperature. The edge frame is not required.

8.2.2 Energize the sparker and move it into place as rapidly as possible after specimen insertion.

8.2.3 Record the time to flaming ignition. Move the sparker out of the flame. Note that the ignition time is the time for sustained flaming to start; therefore, if the timer is stopped at the end of the 4-s observation period, the time to be reported is that value minus 4 s.

8.2.4 Collect data until flaming or other signs of combustion cease or until 20 min have elapsed. Observe and record physical changes to the specimen, such as melting, swelling, and cracking.

8.2.5 Remove the specimen holder.

8.2.6 Replace with an empty specimen holder or insulated pad to prevent thermal damage to the load cell.

8.2.7 If the specimen did not ignite within 10 min, remove and discard.

8.2.8 Test a minimum of three specimens of each sample.

9. Report

9.1 Report the following information, as a summary, for all specimens of a particular material or product:

9.1.1 Specimen identification or number;

9.1.2 Manufacturer or submitter;

9.1.3 Date of test;

9.1.4 Composition or generic identification;

9.1.5 Details of preparation; and

9.1.6 Number of replicate specimens tested, which shall be a minimum of three.

9.2 Include the following information for each specimen:

9.2.1 Specimen thickness (mm);

9.2.2 Initial mass of the overall specimen, and individual masses of each component, namely fabric, and padding (and interliner, if applicable) (g);

9.2.3 Heat flux and exhaust system flow rate;

9.2.4 Time to sustained flaming(s);

9.2.5 Heat release rate curve;

9.2.6 Average heat release rate for the first 180 s after ignition (kW/m^2);

9.2.7 Peak heat release rate (kW/m^2);

9.2.8 Total heat released by the specimen (MJ);

9.2.9 Average effective heat of combustion for the entire test (MJ/kg);

9.2.10 Peak effective heat of combustion (MJ/kg);

9.2.11 Curve of effective heat of combustion (optional);

9.2.12 Mass remaining at test termination (g);

9.2.13 Specimen mass loss (g);

9.2.14 Additional observations, if any; and

9.2.15 Difficulties encountered in testing, if any.

9.3 Average the following final values for all specimens:

9.3.1 Time to sustained flaming (s);

9.3.2 Average heat release rate value (kW/m^2) over the first 180 s after ignition;

9.3.3 Average effective heat of combustion (MJ/kg) for the entire 20-min test, which is obtained by dividing the total heat released by the specimen mass loss;

9.3.4 Peak heat release rate (kW/m^2); and

9.3.5 Total heat released (MJ/m^2).

10. Precision and Bias

10.1 *Precision*—Two series of interlaboratory tests for this test method were run using constructions simulating upholstered furniture composites: the one for Method A of test specimen preparation (Section 7) was conducted using seven laboratories and five constructions **(3)**; the one for Method B of test specimen preparation (Annex A1) was conducted using five laboratories and three constructions. In the series for Method A, three replicates were tested for each construction, while for Method B six replicates of each construction were tested, all at an initial test heat flux of 35 kW/m^2. For Method A, within-laboratory data were obtained for each of the seven laboratories, and for Method B, within data were obtained from ten replicates within a single laboratory.

10.1.1 Tables 1-5 present the data for repeatability and reproducibility of the individual combinations used to examine precision of test specimen preparation Method A. The analysis was conducted following ISO 5725. Stragglers were those entries with a probability of occurring between 1 and 5 % based on their differences from the average, and they were identified and retained in the calculations. Outliers were those entries with a probability of occurring of less than 1 % based on their differences from the average, and they were removed from the calculations. The abbreviations used for Tables 1-5 are as follows: TTI: time to ignition(s); THR: total heat released (MJ/m^2); Av RHR 60: average heat release rate for the period of 60 s after ignition (kW/m^2); Av RHR 180: average heat release rate for the period of 3 min after ignition (kW/m^2); EHC: average effective heat of combustion (MJ/kg); SEA: average specific extinction area (m^2/kg); m: average value; r: repeatability; R: reproducibility.

10.1.2 Table 6 presents the overall repeatability and reproducibility of the investigation for precision using test specimen

TABLE 1 Repeatability and Reproducibility for Combination 1, Method A

Variable	# Labs	m	r	R	Notes[A]
TTI	7	16	2	4	1
THR	7	35	4	4	2, 3, 4
Av RHR 60	7	159	34	83	
Av RHR 180	7	123	27	63	5
EHC	7	18.2	2.0	6.2	6, 7
SEA	5	399	93	366	8

[A] Combination 1: Backcoated acrylic pile fabric (546 g/m^2) on non fire retarded high resilient polyurethane foam (21 kg/m^3). 1: Lab. 7 was removed as an outlier for repeatability. 2: Lab. 3 was removed as an outlier for repeatability. 3: Lab. 4 was removed as an outlier for repeatability. 4: Lab. 7 was identified as a straggler for reproducibility. 5: Lab. 4 was removed as an outlier for repeatability. 6: Lab. 3 was removed as an outlier for repeatability. 7: Lab. 4 was removed as an outlier for repeatability. 8: Lab. 1 was removed as an outlier for repeatability.

TABLE 2 Repeatability and Reproducibility for Combination 2, Method A

Variable	# Labs	m	r	R	Notes[A]
TTI	7	13	3	4	1
THR	7	40	5	11	2,3
Av RHR 60	7	116	16	47	
Av RHR 180	7	120	22	49	
EHC	7	16.9	1.3	3.6	
SEA	5	108	60	76	

[A] Combination 2: Fire retarded cotton fabric (422 g/m^2) on combustion modified high resilient foam (30 kg/m^3). 1: Lab. 7 was identified as a straggler for repeatability. 2: Lab. 2 was identified as a straggler for repeatability. 3: Lab. 6 was removed as an outlier for repeatability.

TABLE 3 Repeatability and Reproducibility for Combination 3, Method A

Variable	# Labs	m	r	R	Notes[A]
TTI	7	7	1	3	
THR	7	58	4	8	
Av RHR 60	7	320	59	82	
Av RHR 180	7	292	43	61	
EHC	7	30.5	2.4	5.0	
SEA	5	449	91	112	

[A] Combination 3: Polypropylene fabric (264 g/m^2) on non fire retarded high resilient polyurethane foam (21 kg/m^3).

TABLE 4 Repeatability and Reproducibility for Combination 4, Method A

Variable	# Labs	m	r	R	Notes[A]
TTI	7	14	3	7	
THR	7	57	5	11	
Av RHR 60	7	222	25	78	
Av RHR 180	7	266	33	56	
EHC	7	20.9	1.4	3.7	
SEA	5	241	27	56	

[A] Combination 4: Wool fabric (432 g/m^2) on combustion modified high resilient foam (30 kg/m^3).

TABLE 5 Repeatability and Reproducibility for Combination 5, Method A

Variable	# Labs	m	r	R	Notes[A]
TTI	7	15	2	11	
THR	7	31	5	24	1
Av RHR 60	7	137	19	136	
Av RHR 180	7	83	20	89	2
EHC	7	16.3	2.9	12.7	
SEA	5	341	93	333	

[A] Combination 5: Backcoated acrylic pile fabric (546 g/m^2) on non fire retarded high resilient polyurethane foam (21 kg/m^3) (as Combination 1), with an added Kevlar interliner (65 g/m^2). 1: Lab. 3 was removed as an outlier for repeatability. 2: Lab. 3 was removed as an outlier for repeatability.

TABLE 6 Overall Repeatability and Reproducibility, Method A[A]

Variable	a	b	A	B
TTI	1.22	0.076	0	0.44
THR	4.48	0	11.70	0
Av RHR 60	0	0.164	85.19	0
Av RHR 180	12.75	0.092	63.42	0
EHC	1.66	0.016	6.25	0
SEA	28.83	0.14	15.63	0.56

[A] See 10.1.2.

preparation Method A. The constants a, b, A, and B correspond to the following linear regression equations:

$$r = a + b\ m \text{ and } R = A + B\ m \quad (1)$$

10.1.3 Fig. 6 shows a comparison of the results of an investigation where one of the laboratories (Lab 1) tested three test specimens it had prepared (labelled own-prepared in the figure) and three test specimens the lead laboratory (Swedish National Testing and Research Laboratory) had prepared (labelled SP-prepared in the figure). Fig. 6 indicates that there are no systematic deviations, meaning specimen preparation instructions were followed correctly.

10.1.4 Within laboratory (repeatability) data of the individual combinations used to examine precision of test specimen preparation Method B are given in Table 7.

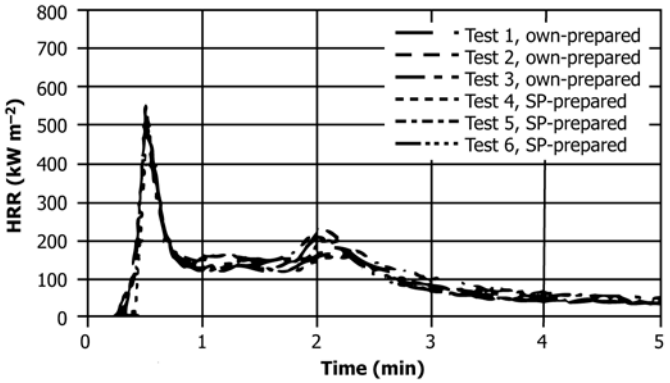

FIG. 6 Comparison of Results Obtained When Testing, Using Test Specimen Preparation Method A, Three Test Specimens Prepared at Two Different Laboratories: SP and Lab 1

10.1.5 Between laboratory (reproducibility) data of the individual combinations used to examine precision of test specimen preparation Method B are given in Table 8.

10.2 *Bias*—For solid specimens of unknown chemical composition, such as those used in building materials, furnishings, and common occupant fuel load, it has been documented that use of the relationship that approximately 13.1 X10^3 kJ of heat is released per 1 kg of oxygen consumed ($\Delta h_c/r_o$) results in an expected error band of ± 5 % compared to true value. For homogeneous materials with only a single pyrolysis mechanism, this uncertainty can be reduced by determining Δh_c from oxygen bomb measurements and r_o from ultimate elemental analysis. For most testing conditions, this is not practical, since some specimens are composites, are potentially non-homogeneous or have the potential to exhibit several degradation reactions. Therefore, for unknown samples, a ± 5 % accuracy limit is seen. For reference materials, however, careful determination of $\Delta h_c/r_o$ can decrease this source of uncertainty substantially.

11. Keywords

11.1 calorimeter; fire; fire test response; heat release; ignition; oxygen consumption; small scale; upholstered furniture

TABLE 7 Within-Laboratory (Repeatability) Precision Data

Material—Nylon Fabric on a Flame-Retardant Treated Polyurethane Foam				
Parameter	Units	Mean Value	SD[A]	RSD, %[B]
Time to sustained flaming	s	9	1	11
Average heat release rate at 180 s[C]	kW/m^2	258	6	2
Peak heat release rate	kW/m^2	364	27	7
Total heat release	MJ/m^2	89	1.5	2
Heat of combustion	MJ/kg	24	0.6	3
Material—Polyolefin Fabric on a Standard Polyurethane Foam				
Parameter	Units	Mean Value	SD[A]	RSD %[B]
Time to sustained flaming	s	8	0	0
Average heat release rate at 180 s[C]	kW/m^2	374	11	3
Peak heat release rate	kW/m^2	474	16	3
Total heat release	MJ/m^2	80	1	1
Heat of combustion	MJ/kg	25	1	4
Material—Cotton Velvet with Glass Fiber Liner on a Standard Polyurethane Foam				
Parameter	Units	Mean Value	SD[A]	RSD%[B]
Time to sustained flaming	s	8	0.5	6
Average heat release rate at 180 s[C]	kW/m^2	113	8	7
Peak heat release rate	kW/m^2	316	10	3
Total heat release	MJ/m^2	52	0.2	0
Heat of combustion	MJ/kg	16	0.8	5

[A] Standard deviation.

[B] Relative standard deviation: $\text{RSD} = \frac{\text{SD}}{\text{mean}} \times 100$.

[C] After ignition.

TABLE 8 Between-Laboratory (Reproducibility) Precision Data

Material—Nylon Fabric on a Flame-Retardant Treated Polyurethane Foam				
Parameter	Units	Mean Value	SD[A]	RSD, %[B]
Time to sustained flaming	s	12	2.5	21
Average heat release rate at 180 s[C]	kW/m^2	228	29	13
Peak heat release rate	kW/m^2	309	54	17
Total heat release	MJ/m^2	85	6	7
Heat of combustion	MJ/kg	24	1.6	7
Material—Polyolefin Fabric on a Standard Polyurethane Foam				
Parameter	Units	Mean Value	SD[A]	RSD %[B]
Time to sustained flaming	s	10	2.3	23
Average heat release rate at 180 s[C]	kW/m^2	389	19	5
Peak heat release rate	kW/m^2	442	64	14
Total heat release	MJ/m^2	77	2.8	4
Heat of combustion	MJ/kg	27	2.1	8
Material—Cotton Velvet with Fiber Glass Liner on a Standard Polyurethane Foam				
Parameter	Units	Mean Value	SD[A]	RSD %[B]
Time to sustained flaming	s	12	3	25
Average heat release rate at 180 s[C]	kW/m^2	92	29	32
Peak heat release rate	kW/m^2	262	52	20
Total heat release	MJ/m^2	48	7	15
Heat of combustion	MJ/kg	20	4	20

[A] Standard deviation.

[B] Relative standard deviation: $\text{RSD} = \frac{\text{SD}}{\text{mean}} \times 100$.

[C] After ignition.

ANNEX

(Mandatory Information)

A1. TEST SPECIMEN PREPARATION (METHOD B)

A1.1 In instances where the highest quality of specimen preparation is not needed, such as in screening tests, an alternate test specimen method is available. The construction of the test specimens is to reflect the actual construction used in the upholstered or mattress items. The test specimens are intended to represent the padding and upholstery fabric materials, but not frame materials, welt cord, decking construction articles, or dust covers. In all cases, the test specimen should comprise the upholstery or mattress fabric and any intermediate layers found between the upholstery fabric and the padding that are 8 mm or less in thickness. If there is only one padding material, its thickness should be such that the total specimen thickness, including fabric and any intermediate layers, is 50 mm. If the construction involves several material layers, the specimen should comprise all of the types of layers sampled in the following manner. Upholstery fabric or intermediate layers 8 mm thick or less should be used in full thickness. The depth taken up by the full thickness layers should be added up and subtracted from 50 mm. For the remaining depth, the remaining layers should be sectioned in thickness such that the ratio of their thicknesses in the test specimen is the same as that in the upholstered item.

A1.2 The upholstery or mattress fabric and intermediate layers (if any) should be cut to a size of approximately 200 by 200 mm with a square 50 by 50 mm removed at each corner. The length and width of the padding layers should be slightly less than 100 mm, so that the fabric and intermediate layers can be folded over each of the four sides and produce a specimen measuring 100 by 100 mm. The folded over sides should be edge stapled to the padding near the bottom of the specimen.

A1.3 Care should be taken to trim the fabric and intermediate layers so that they are even with the bottom of the test specimen. Otherwise, the specimen will not rest firmly and evenly on the specimen holder.

A1.4 The four sides and bottom of the finished test specimen shall be covered with aluminum foil (shiny side in) approximately 0.04 mm thick. A single sheet of aluminum foil, approximately 200 by 200 mm, should be used. The corners should be folded at a 45° angle flush against the sides.

A1.5 The specimens shall be conditioned to moisture equilibrium (constant mass) at an ambient temperature of 23 ± 3°C and a relative humidity of 50 ± 5 %.

APPENDIXES

(Nonmandatory Information)

X1. COMMENTARY

X1.1 *Introduction*—The purpose of this appendix is to provide a discussion of the prediction of the heat release rate for full-scale items of upholstered furniture. Predictive methods are discussed, and references for further reading are given.

X1.2 The fire behavior of full-scale upholstered furniture can be predicted by using a theory and appropriate experimental data. Such a procedure has been described (**4**); however, it is highly complex and not easy to use. For most purposes, estimation of the fire behavior of upholstered furniture can be obtained on the basis of simple predictive correlations. The full-scale fire hazard variable that is to be predicted is the peak heat release rate. The bench-scale measurement available is the 180-s average heat release rate per m^2 exposed specimen face. The predictive method to be used depends on the application intended. A predictive method for residential furniture was developed at the National Institute of Standards and Technology and published in a 1985 monograph (**5**). This document also discusses many of the engineering principles of upholstered furniture flammability and should be consulted for a general overview.

X1.2.1 Cone calorimeter tests of upholstered furniture have also been performed at an initial test heat flux of 25 kW/m^2 (**6,7**), which show that this flux could also be satisfactory for obtaining heat release data.

X1.3 A method for predicting the behavior of institutional and contract furniture and furniture for high-risk occupancies was developed more recently. The method is based on predicting the full-scale fire performance that is measured in the California Technical Bulletin 133 test. The predictive method was the result of an extensive investigation of CA TB 133 conducted jointly by NIST and the California Bureau of Home Furnishings (BHF). The CA TB 133 fire test is conducted in a room 3.6 by 3.0 by 2.4 m high lined with gypsum board. The furniture is located on a weighing platform in the rear corner farthest from the doorway. The ignition source may be a gas burner or five double sheets of loosely wadded newsprint placed at the back of the seat and confined by a wire-mesh cage. The temperatures, CO concentration, smoke opacity, and mass loss are measured during the test. For the purposes of this investigation, instrumentation was added to measure the heat

release rate by oxygen consumption.

X1.4 Ten sets of full-scale chairs were tested at NIST and at BHF. These were chosen to provide a broad range of fire performance data. The bench-scale heat release rates per unit area were measured according to the procedures of the present test method.

X1.5 For a chair to pass the full-scale CA TB 133 test, it must demonstrate a heat release rate of 80 kW or less. The test data developed during the study revealed that a 80-kW heat release rate in the full-scale corresponds to a bench-scale heat release rate measurement (180-s average value) of 107 kW/m^2. The general predictive relationship for q_{bs} < 180 kW/m^2 is demonstrated:

$$\dot{q}_{fs} = 0.75\, \dot{q}''_{bs} \quad \text{(X1.1)}$$

where:

fs = full-scale and
bs = bench-scale.

For chairs showing $\dot{q}''_{bs}$ > 180 kW/m^2, another relationship is obeyed. The latter is given in (**8**), but it is of limited importance to institutional furniture since the predicted full-scale values are well in excess of 80 kW. It must also be noted that the predictive relationship established by Eq X1.1 is applicable only to the type of ignition source used in the CA TB 133 test. Changing the ignition source would alter the relationship somewhat, although generally not to a major extent.

X2. TEST SPECIMEN PREPARATION

X2.1 An experiment was performed to determine the effect of the fabric and liner cutting and mounting procedure used for specimen preparation on selected responses of the cone calorimeter test. Two levels of each factor affecting the cone calorimeter responses were used. The levels were chosen to provide a wide range of effects. Non-FR polyurethane foam and FR melamine-filled polyurethane foam were used as the two foam levels. The levels of fabric were cotton and polypropylene. Cotton fabric is observed to char, and the polypropylene fabric is observed to melt. No-liner and a Kevlar liner provided the two levels in liners. It was expected that the greatest difference in the effect caused by fabric treatment would be determined by the amount of fabric on the test specimen. A200 by 200-mm piece of fabric folded over the foam, identified as the folded fabric treatment, would have the greatest amount of material, and a 100 by 100-mm piece of fabric stapled to the top of the specimen, identified as the top-only fabric treatment, would have the least. Although the liner can contribute a certain amount of heat itself, and the amount of liner is pertinent, the containment or suppression of products of pyrolysis was considered most critical. The folded and cut-liner treatments were chosen because the corners are closed with the folded treatment and the corners are open with the cut treatment. The folded liner treatment consisted of a 200 by 200-mm piece of liner folded over the foam block. The cut-liner treatment is a 200 by 200-mm piece of liner with 50-mm squares cut from the corners folded over the foam.

X2.2 In summary, the experiment using one-half of a 2^5 factorial design employed the following factors and levels:
Factor 1 = foam (conventional = −1, melamine = + 1)

TABLE X2.1 Experimental Design Matrix

	Condition Factors				
	Foam	Fabric	Liner	Fabric Configuration	Liner Configuration
1	– conventional	– polyprop	– none	– top	+ folded
2	+ melamine	– polyprop	– none	– top	– cut
3	– conventional	+ cotton	– none	– top	– cut
4	+ melamine	+ cotton	– none	– top	+ folded
5	– conventional	– polyprop	+ kevlar	– top	– cut
6	+ melamine	– polyprop	+ kevlar	– top	+ folded
7	– conventional	+ cotton	+ kevlar	– top	+ folded
8	+ melamine	+ cotton	+ kevlar	– top	– cut
9	– conventional	– polyprop	– none	+ folded	– cut
10	+ melamine	– polyprop	– none	+ folded	+ folded
11	– conventional	+ cotton	– none	+ folded	+ folded
12	+ melamine	+ cotton	– none	+ folded	– cut
13	– conventional	– polyprop	+ kevlar	+ folded	+ folded
14	+ melamine	– polyprop	+ kevlar	+ folded	– cut
15	– conventional	+ cotton	+ kevlar	+ folded	– cut
16	+ melamine	+ cotton	+ kevlar	+ folded	+ folded

Factor 2 = fabric (polypropylene = −1, cotton = + 1)
Factor 3 = liner (none = −1, Kevlar = + 1)
Factor 4 = fabric treatment (top = −1, folded = + 1)
Factor 5 = liner treatment (cut = −1, folded = + 1)

X2.3 The design matrix for the experiment is given in Table X2.1.

X2.4 The results of an analysis using the data from the experiment are listed in Table X2.2. If the coefficient is not listed, the factor or factor interaction has no effect on the response, as determined by multi-regression T and P tests at the 95 % confidence level. Identification of Responses 1 through 4 is given in the note to Table X2.2.

TABLE X2.2 Analysis of Experimental Results[A]

Least Squares Coefficients				
	Response 1	Response 2	Response 3	Response 4
Factor 1	−34.31	−1.81	0.20	−4.00
Factor 2	−25.94	−3.44	1.09	−9.38
Factor 3	−53.94		−0.26	−2.63
Factor 4	11.06	0.06	−0.30	15.88
Factor 5	2.69		−0.13	0.38
Interaction 1*2	3.44		−0.26	−0.63
Interaction 1*3	3.94			−4.13
Interaction 1*4	7.94	0.69	−0.23	2.63
Interaction 1*5	12.31		0.15	
Interaction 2*3	13.81			
Interaction 2*4	−11.94	−1.19	−0.09	−6.75
Interaction 2*5			−0.16	3.25
Interaction 3*4				4.00
Interaction 3*5	5.44		0.14	
Interaction 4*5				−0.75
Mean	168.8	22.6	12.45	56.00
R-sq.	0.9989	0.9506	0.9975	0.9998
RMS error	5.79	1.18	0.12	0.6455

[A] Response 1 = average HRR at 180 s after sustained flaming (kW/m^2),
Response 2 = average heat of combustion (MJ/kg),
Response 3 = time to sustained flaming (s), and
Response 4 = total heat release (MJ/m^2).

To evaluate the effect of the factors and factor interactions on a response, evaluate the algebraic function using the coefficients and the specified factor levels of the case being examined.

$$\text{Response} \approx + ((F_1)(B_1)) + ((F_2)(B_2)) + ((F_3)(B_3))\ldots\ \ldots$$
$$\ldots\ .\ .\ ((F_3)(F_5)(B_{35})) + ((F_4)(F_5L)(B_{45})) \pm \text{error}$$

where:

F_1 = Factor 1 levels (–1,1),
F_2 = Factor 2 levels (–1,1),
F_3 = Factor 3 levels (–1,1),
F_4 = Factor 4 levels (–1,1),
F_5 = Factor 5 levels (–1,1),
B_1 = Factor 1 coefficient,
B_2 = Factor 2 coefficient,
B_3 = Factor 3 coefficient,
B_4 = Factor 4 coefficient,
B_5 = Factor 5 coefficient,
B_{12} = Interaction 1*2 coefficient,
B_{13} = Interaction 1*3 coefficient,
. . . . .
. . . . .
B_{35} = Interaction 3*5 coefficient, and
B_{45} = Interaction 4*5 coefficient.

For example, to determine the effect on Response 2 of all the factors set to the—1 level, perform the following calculation:

$$\text{Response 2} \approx 22.56 + ((F_1)(B_1)) + ((F_2)(B_2)) + ((F_4)(B_4)) + ((F_1)(F_4)(B_{14})) + ((F_2)(F_4)(B_{24})) \pm \text{error}$$

$$\text{Response 2} \approx 22.56 + ((-1)(-1.81)) + ((-1)(-3.44)) + ((-1)(0.06)) + ((-1)(-1)(0.69)) + ((-1)(-1)(-1.19)) \pm 1.18$$

$$\text{Response 2} \approx 27.25\ \text{MJ/kg} \pm 1.18$$

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