Designation: C 1303 – 08$^{\varepsilon 1}$

# Standard Test Method for Predicting Long-Term Thermal Resistance of Closed-Cell Foam Insulation[1]

This standard is issued under the fixed designation C 1303; 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.

$\varepsilon^1$ NOTE—Table A1.3 was editorially corrected in February 2009.

## 1. Scope

1.1 This test method covers a procedure for predicting the long-term thermal resistance (LTTR) of unfaced or permeably faced rigid gas-filled closed-cell foam insulations by reducing the specimen thickness to accelerate aging under controlled laboratory conditions (**1-5**) .[2]

1.2 Rigid gas-filled closed-cell foam insulation includes all cellular plastic insulations manufactured with the intent to retain a blowing agent other than air.

1.3 This test method is limited to unfaced or permeably faced, homogeneous materials. This method is applied to a wide range of rigid closed-cell foam insulation types, including but not limited to: extruded polystyrene, polyurethane, polyisocyanurate, and phenolic. This test method does not apply to impermeably faced rigid closed-cell foams or to rigid closed-cell bun stock foams.

NOTE 1—See Note 7 for more details regarding the applicability of this test method to rigid closed-cell bun stock foams.

1.4 This test method utilizes referenced standard test procedures for measuring thermal resistance. Periodic measurements are performed on specimens to observe the effects of aging. Specimens of reduced thickness (that is, thin slices) are used to shorten the time required for these observations. The results of these measurements are used to predict the long-term thermal resistance of the material.

1.5 The test method is given in two parts. The Prescriptive Method in Part A provides long-term thermal resistance values on a consistent basis that can be used for a variety of purposes, including product evaluation, specifications, or product comparisons. The Research Method in part B provides a general relationship between thermal conductivity, age, and product thickness.

1.5.1 To use the Prescriptive Method, the date of manufacture must be known, which usually involves the cooperation of the manufacturer.

1.6 The values stated in SI units are to be regarded as the standard. The inch-pound values given in parentheses are for information only.

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.*

1.8 *Table of Contents*:



[1] This test method is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

Current edition approved Sept. 15, 2008. Published October 2008. Originally approved in 1995. Last previous edition approved in 2007 as C 1303 – 07.

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

## 2. Referenced Documents

2.1 *ASTM Standards:*[3]

C 168 Terminology Relating to Thermal Insulation

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus

C 518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus

C 578 Specification for Rigid, Cellular Polystyrene Thermal Insulation

C 591 Specification for Unfaced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation

C 1029 Specification for Spray-Applied Rigid Cellular Polyurethane Thermal Insulation

C 1045 Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions

C 1126 Specification for Faced or Unfaced Rigid Cellular Phenolic Thermal Insulation

C 1289 Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board

D 1622 Test Method for Apparent Density of Rigid Cellular Plastics

D 2856 Test Method for Open-Cell Content of Rigid Cellular Plastics by the Air Pycnometer[4]

D 6226 Test Method for Open Cell Content of Rigid Cellular Plastics

E 122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

2.2 *Other Standards:*

CAN/ULC S770 Standard Test Method for Determination of Long-Term Thermal Resistance of Closed-Cell Thermal Insulation Foams[5]

2.3 *ASTM Adjuncts:*

Test Method for Predicting Long-Term Thermal Resistance of Closed-Cell Foam Insulation[6]

## 3. Terminology

3.1 *Definitions*—For definitions of terms and symbols used in this test method, refer to Terminology C 168.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aging*, *v*—the change in thermophysical properties of rigid closed–cell plastic foam with time, primarily due to changes in the composition of the gas contained within the closed cells.

3.2.2 *core slice*, *n*—a thin-slice foam specimen that was taken at least 5 mm (0.2 in.) or 25 % of the product thickness, whichever is greater, away from the surface of the full-thickness product.

3.2.3 *effective diffusion thickness*, *n*—one-half of the geometric thickness minus the total thickness of damaged surface layer(s) (TDSL).

3.2.4 *facing*, *n*—a material adhered to the surface of foam insulation, including any foam product that has been suffused into the facing material, but not inclusive of any skin formed by the foam insulation itself.

3.2.5 *homogeneous material*, *n*—sufficiently uniform in structure and composition to meet the requirements of this test method (see A1.2).

3.2.6 *long-term*, *adj*—for the purposes of the Prescriptive Method, long term refers to five years.

3.2.7 *normalized service life*, *n*—product service life divided by the square of the full product thickness, units of time/length$^2$.

3.2.8 *scaled time*, *n*—time divided by the square of the specimen thickness.

3.2.9 *scaled service life*, *n*—time necessary for a thin specimen to reach the same thermal conductivity that a full thickness specimen would reach at the end of its service life, equals the product service life multiplied by the square of the ratio of the average slice thickness to the full product thickness, value has units of time.

3.2.10 *service life*, *n*—the anticipated period of time that the material is expected to maintain claimed thermophysical properties, may be dependent on the specific end-use application.

3.2.11 *surface slice*, *n*—a thin-slice foam specimen that was originally adjacent to the surface of the full-thickness product and that includes any facing that was adhered to the surface of the original full-thickness product.

3.2.12 *thickness of damaged surface layer (TDSL)*, *n*—the average thickness of surface cells, on one surface, that are either destroyed (ruptured or opened) during the preparation of test specimens or were originally open due to the manufacturing process.

3.3 *Symbols*:

$i$ = counter used in a summation

$k$ = thermal conductivity, W/(m·K)

$n$ = counter used in a summation

$N$ = number of cut planar surfaces

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

[5] Underwriters Laboratory of Canada, 333 Pfingsten Road, Northbrook, IL 60062-2096 USA,www.ulc.ca

[6] Available from ASTM International Headquarters. Order Adjunct No. ADJC1303.

$n_{SL}$ = counter in a time series that corresponds to the service life.

$R$ = thermal resistance, $(m^2 \cdot K)/W$

$TDSL$ = average thickness of damaged surface layer, m

$\Delta X_{eff}$ = effective diffusion thickness of thermal resistance specimen, m

## 4. Summary of Test Method

4.1 Rigid gas-filled closed-cell foam insulation is thin-sliced to reduce the gas diffusion path length which accelerates the aging process. The resulting temporal acceleration is proportional to the square of the ratio of the product use thickness to the slice thickness.

4.2 Careful and precise slice preparation is necessary and the process is described in detail in 6.4.

4.3 In Part A, the Prescriptive Method, specific test dates are calculated and the thermal resistance of the thin slices is measured on those dates.

4.3.1 Qualification tests are included to determine whether this method is applicable to a given material.

4.4 In Part B, the Research Method, thermal conductivity is measured for a series of time periods and extensive data analysis is possible.

## 5. Significance and Use

5.1 Rigid gas-filled closed-cell foam insulations include all cellular plastic insulations which rely on a blowing agent (or gas), other than air, for thermal resistance values. At the time of manufacture, the cells of the foam usually contain their highest percentage of blowing agent and the lowest percentage of atmospheric gases. As time passes, the relative concentrations of these gases change due primarily to diffusion. This results in a general reduction of the thermal resistance of the foam due to an increase in the thermal conductivity of the resultant cell gas mixture. These phenomena are typically referred to as foam aging.

5.1.1 For some rigid gas-filled closed-cell foam insulation products produced using blowing agent gases that diffuse very rapidly out of the full-thickness foam product, such as expanded polystyrene, there is no need to accelerate the aging process.

5.1.2 Physical gas diffusion phenomena occur in three dimensions. The one-dimensional form of the diffusion equations used in the development of this practice are valid only for planar geometries, that is, for specimens that have parallel faces and where the thickness is much smaller than the width and much smaller than the length.

NOTE 2—Please see Appendix X3 for a discussion of the theory of accelerated aging via thin slicing.

NOTE 3—Theoretical and experimental evaluations of the aging of insulation in radial forms, such as pipe insulation, have been made. (**6**) However, these practices have not evolved to the point of inclusion in the test standard.

5.2 The change in thermal resistance due to the phenomena described in 5.1 usually occurs over an extended period of time. Information regarding changes in the thermal resistance of these materials as a function of time is required in a shorter period of time so that decisions regarding formulations, production, and comparisons with other materials can be made.

5.3 Specifications C 578, C 591, C 1029, C 1126 and C 1289 on rigid closed-cell foams measure thermal resistance after conditioning at 23 ± 1°C (73 ± 2°F) for 180 ± 5 days from the time of manufacture or at 60 ± 1°C (140 ± 2°F) for 90 days. This conditioning can be used for comparative purposes, but is not sufficient to describe long-term thermal resistance. This requirement demonstrates the importance of the aging phenomena within this class of products.

5.4 The Prescriptive Method in Part A provides long-term thermal resistance values on a consistent basis for a variety of purposes, including product evaluation, specifications, or product comparisons. The consistent basis for these purposes is provided by a series of specific procedural constraints, which are not required in the Research Method described in Part B. The values produced by the Prescriptive Method correspond to the thermal resistance at an age of five years, which corresponds closely to the average thermal resistance over a 15-year service life (**7**, **8**).

5.4.1 It is recommended that any material standard that refers to C 1303 to provide a product rating for long-term thermal resistance specify the Part A Test Method of C 1303.

5.5 The Research Method in Part B provides a relationship between thermal conductivity, age, and product thickness. The calculation methods given in Part B can be used to predict the resistance at any specific point in time as well as the average resistance over a specific time period.

NOTE 4—The 5-year aged values produced in Part A can be derived from the Part B data only if all other Part A requirements are met.

5.6 This test method addresses three separate elements relating to the aging of rigid closed-cell plastic foams.

5.6.1 *Specimen Preparation*—Techniques for the preparation of thin flat specimens, including their extraction from the "as manufactured" product, and the measurement of specimen thickness are discussed.

5.6.2 *Measurement of the Thermal Resistance*—Thermal resistance measurements, taken at scheduled times, are an integral part of the test method.

5.6.3 *Interpretation of Data*—Procedures are included to properly apply the theory and techniques to achieve the desired goals.

## 6. Part A: The Prescriptive Method

6.1 *Applicability*:

6.1.1 *Qualification Requirements*—Before reporting the results from a C 1303 Part A aging test, the material must be qualified using the procedures given in Annex A1.

6.1.1.1 The qualification requirement tests must be performed whenever a significant change that would affect the thermal resistance properties is made to the product.

6.1.1.2 The qualification is valid for a period not to exceed two years.

NOTE 5—This test method is founded upon gas diffusion physical laws that apply to homogeneous materials with free surface exposure to the atmosphere as discussed more fully in Appendix X3 (**2-4 and 9-11**). Although rigid closed-cell foam insulation may not rigorously meet these homogeneity and exposure criteria, this test method has been shown to provide useful information for a wide range of products. Recognizing that none of the foam insulation products available today is perfectly homogeneous, the qualification requirements determine whether the product is

sufficiently homogeneous for this test method to produce meaningful results. The user should also be aware that the material characteristics of the thin specimens must approximate those of the material under investigation. The material characteristics that are of most importance are gas diffusion coefficients and initial cell gas content. One-dimensional diffusion must dominate in the full use thickness material; by design, one-dimensional diffusion dominates in the thin slice.

NOTE 6—If two thicknesses of a particular foam product are manufactured from identical components and have identical foam morphology, then thin slices from one specimen will accurately predict the long-term aging behavior of the other. However, due to possible differences in the foam morphology, the applicability of data derived from specimens taken from one product thickness to a different thickness of the same product is currently a subject of research. The "alternate product equivalence test" qualification in Annex A1 is provided in Part A to allow this type of data generalization.

NOTE 7—The age acceleration test method applies when one-dimensional diffusion dominates in the full-use thickness material. In bun-stock products, this condition does not exist during the time period between the initial foam production and the manufacturing process that cuts the buns into flat sheets. Because this time is variable, it is not possible to define a consistent initial time for the Prescriptive Method. Also, because the sheets may be cut from the bun stock in different orientations, the foam morphology may vary from one product sheet to another.

6.1.2 *Facing Permeability*:

6.1.2.1 Unfaced foam insulation meets the criteria of a free exposure to the atmosphere so the test method is applicable.

6.1.2.2 Faced products, with the exception of those foil-faced products that are Type 1 in Specification C 1289, that pass the homogeneity qualification test in Annex A1 meet the criteria of this test method.

6.2 *Apparatus*:

6.2.1 Thermal resistance test apparatus used for this test method shall conform to all of the requirements of Test Method C 518.

6.2.2 Specimen preparation equipment must produce slices that are consistent in dimension and surface morphology.

6.2.2.1 *Surface Damage*—Equipment for preparing thin specimens shall be selected based on the ability of the equipment to consistently limit the amount of surface damage (open cells) that occurs during the preparation process.

6.2.2.2 *Thickness Uniformity*—The equipment used to prepare specimens shall be capable of producing uniform thickness slices able to meet the requirements of 6.4.4.

6.2.2.3 The following two types of equipment have successfully been used to prepare thin slice specimens. Reference **(12)** summarizes these techniques and compares their effectiveness.

*(1)* High Speed Band-saw, with a fine-tooth 1 tooth/mm (14 teeth/in.) blade, 0.6 mm (0.025 in.) blade thickness, and blade speed of about 6 m/s (1185 ft/min).

*(2)* Combination Lathe/Motor-driven Meat Slicer.

6.2.2.4 Use of a hot-wire cutter is prohibited because it can produce a surface skin. For further discussion, please see 9.3 and Note 30.

6.3 *Sampling*:

6.3.1 *Schedule*—Specimens shall be collected between 7 and 20 days after production. The specimen collection schedule must be coordinated with the specimen preparation time requirement of 6.4.2.

6.3.2 *Replicate Product Samples*—The minimum number of product samples used to prepare test specimens shall be selected so that there is confidence that the average results from these product sheets are representative of the typical production quality. For additional guidance, refer to Practice E 122.

6.3.3 *Replicate Test Specimen Sets*—The minimum number of replicate specimens to be tested shall be selected so that there is confidence that the average results from these sliced specimens are representative of the material undergoing testing. At least three sets of thermal resistance specimens per material are recommended. For additional guidance, refer to Practice E 122.

NOTE 8—As discussed in Appendix X2, test results for three stack compositions are currently required by this test method. Pending the completion of the ruggedness test, the three stack sets serve as three replicates because they provide similar and related results. After the ruggedness test is complete and a single stack configuration is selected, it is likely that a minimum number of replicates will be specified.

6.4 *Specimen Preparation*:

6.4.1 *Goal*—The goal of this section is to produce thin slices, that when aged, are representative of the aged performance of the full-thickness product.

6.4.2 *Schedule*—The specimens shall be prepared between 14 and 21 days after the production date.

6.4.3 *Specimen Extraction*—Test specimens shall be extracted either from full size product sheets or from specially prepared spray-product constructions.

6.4.3.1 Extraction of test specimens from full size product sheets:

*(1)* Cut 300 by 300 mm ± 6 mm (12 by 12 in. ± 0.25 in.) full-thickness sections from two full-size product sheets. In no case shall these sections be taken within 15 cm (6 in.) of the product edge. The number of full-thickness sections needed will depend upon the equipment used to prepare the thin slices and the number of replicate sets tested, as discussed in 6.3.3.

*(2)* Slice the 300 by 300 mm ± 6 mm (12 by 12 in. ± 0.25 in.) full-thickness specimens prepared in 6.4.3.1*(1)* to produce stacks of thin slices. Surface slices shall include the product skin or facing.

6.4.3.2 The preparation and extraction of test specimens from spray-foam product is described in Annex A2.

6.4.4 *Slice Flatness*:

6.4.4.1 During the slicing process, the thickness of each individual slice shall be measured in eight locations distributed evenly over the surface of the slice as shown in Fig. 1.

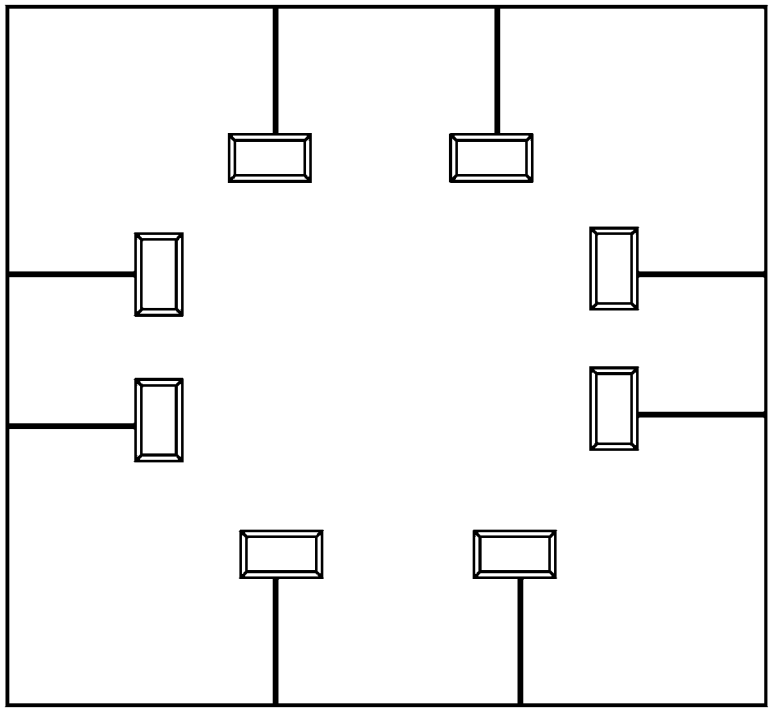
*(1)* These measurements shall be made using a digital caliper or a digital length meter. Care shall be taken so that the contact between the caliper jaws or the length meter's pressure foot does not indent the foam surface.

6.4.4.2 Each of these eight measurements must be within ±5 % of the average of the eight measurements.

6.4.4.3 The average of these eight measurements shall be used to represent the thickness of the slice for the purposes of 6.4.5.3.

6.4.4.4 It is possible that a apparatus and cutting technique adjustments will be necessary to meet the requirements of this section and those of 6.4.5.3. Practice is recommended.

6.4.5 *Slice Thickness*:



NOTE—Lines show position of caliper jaws.

**FIG. 1 Location of Eight Measuring Points for Slice Thickness on a 300 by 300 mm (12 by 12 in.) Slice**

6.4.5.1 Each core slice shall be a minimum of 9 mm thick.

6.4.5.2 The foam portion of each surface slice shall be a minimum of 9 mm (0.35 in.) thick. The total thickness of each surface slice shall be a minimum of 9 mm (0.35 in.) plus the thickness of any facing material. If the facing thickness is not known, the facing shall be removed from an edge portion of the product sheet and the thickness measured with a caliper or digital length meter to the nearest 0.1 mm (0.004 in.). If the facing thickness is less than 2 % of the total slice thickness, it shall be considered negligible in all succeeding calculations and the total slice thickness shall be used to represent the thickness of the foam portion of the surface slice.

6.4.5.3 Slice uniformity within each stack: The thickness of the foam portion of every slice (from 6.4.4.3) must be within ±5 % of the average of the foam portion of all the slices used within that stack.

6.4.5.4 The average of the foam portion of the slice thickness within the stack will be used later in 6.7.1 to determine appropriate testing periods. This is call the Average Slice Thickness in Eq. 1 in 6.7.1.

NOTE 9—The presence of a damaged layer of cells on every cut surface introduces errors into both the calculated testing period (causing it to be overestimated) and the thermal resistance (causing the measured value to be less than the true value). The 9 mm minimum thickness was selected based upon the magnitude of these errors (discussed in Appendix X1) and a desire to limit the controllable error sources associated with this test method to no more than the uncertainty of Test Method C 518. There have been numerous experiments that show results from accelerated aging with 10 mm slices are in good agreement with full-thickness aged values, as discussed more fully in Section 9.

NOTE 10—If foam product morphology is changed by the introduction of new materials or manufacturing processes, the manufacturer may wish to pursue the TDSL investigation described in the Part B test method to determine whether the slice thickness should be increased to keep the TDSL errors within the uncertainty of Test Method C 518.

NOTE 11—Errors in both the calculated testing period and the measured thermal resistance have the greatest effect for thermal resistance measurements made in the earlier portion of the aging curve. Therefore, when predicting aged values for thicker products, for example, 75 or 100 mm (3 or 4 in.) products, users may wish to elect slice thicknesses greater than the 9 mm minimum to extend the test time interval. This will improve the accuracy by: *(1)* reducing the effect of any small variation in the test time period and *(2)* reducing the magnitude of errors introduced into the calculated testing period due to the smaller relative fraction of TDSL (as discussed more fully in Appendix X1).

6.4.6 *Stack Composition*:

6.4.6.1 All thermal resistance measurements are made using stacks of slices in order to avoid errors (often referred to as the "thickness effect") introduced by radiation heat transfer phenomena at small specimen thicknesses (**13**).

6.4.6.2 Three stacks shall be prepared: four core slices, four surface slices, and a mixed stack of core and surface slices.

NOTE 12—For background and rationale regarding the use of these three stacks, please see X2.2.

6.4.6.3 Slice uniformity among the three stacks: The average slice thickness of each of the three stacks (that value calculated in 6.4.5.4 and used in 6.7.1 for each stack) must agree within ±1 mm (±0.04 in.).

6.4.6.4 For the stack of surface slices, the slices shall be organized so that every skin or facing faces upward, as shown in Fig. 2.

6.4.6.5 For the mixed stack, the core and surface slices shall be prepared at a uniform slice thickness that represents the

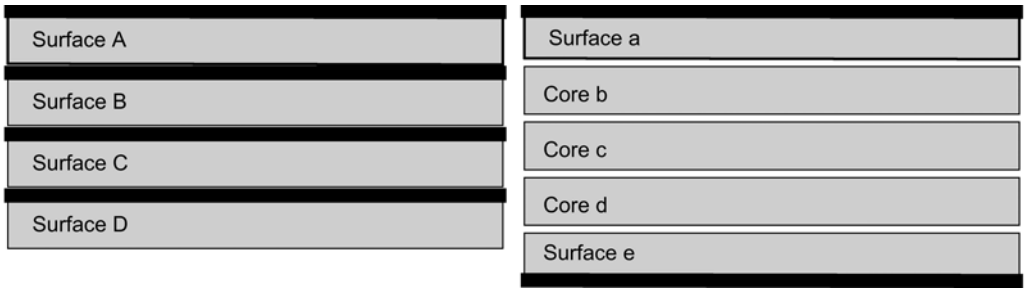



**FIG. 2 Surface Stack Arrangement (left) and Mixed Stack Arrangement (right)**

reassembled full cross-section of the product except for small amounts destroyed in the slice-cutting process and excluding any remainder less than 9 mm (0.35 in.) in thickness. The slicing shall be organized so that any such remainder comes from a non-surface section of the foam and both surfaces shall be included as the outward facing layers of the stack. The number of core sections in the mixed stack will vary according to the product thickness, as shown in Fig. 2.

6.4.6.6 Each stack shall be marked to assure that the specimens are placed in the same top to bottom order for every thermal measurement. Each stack shall be marked to assure that the stacks are oriented in the thermal measurement apparatus in the same direction for every measurement. Fig. 3 is one example of an effective marking scheme.

6.5 *Storage Conditioning*:

6.5.1 Specimens shall be stored during the extended time periods between thermal conductivity measurements in a conditioned space, at a temperature of 22°C (72°F) [±5°C (10°F)] and relative humidity between 40 and 70 %.

NOTE 13—The long-term storage conditioning requirements defined here are separate from the specimen conditioning requirements of Test Methods C 518 and C 177.

6.5.2 Specimens shall be stored so that each surface of each slice is exposed to free air circulation.

NOTE 14—One method used to assure such exposure is to stand the slices like books on a shelf with small spaces between each adjacent slice.

6.6 *Test Procedure*:

6.6.1 *Thermal Resistance Measurement Schedule*:

6.6.1.1 Calculate the testing period(s) corresponding to the desired product thickness(es), as described in 6.7. Add the testing period to the slicing date to determine the test date for each product thickness.

6.6.1.2 Measure the thermal resistance of the stack on the test dates determined in 6.6.1.1 within ±24 h. Meeting the calculated time period precisely is especially critical for any time period less than 40 days.

6.6.2 *Thermal Resistance Measurements*—All thermal conductivity and resistance measurements shall be made according to Test Method C 518 or C 177, used in conjunction with Practice C 1045. Of these test methods, the heat flow meter apparatus, Test Method C 518, is recommended.

6.6.2.1 The mean test temperature shall be 24 ± 2°C (75 ± 4°F) with a temperature difference of 22 ± 2°C (40 ± 4°F).

6.6.2.2 It is important to eliminate any air gaps between slices within the stack and between the stack and the controlled temperature plates. Therefore, if the apparatus offers the option of automatically positioning the plates and determining the specimen thickness, that option shall be used.

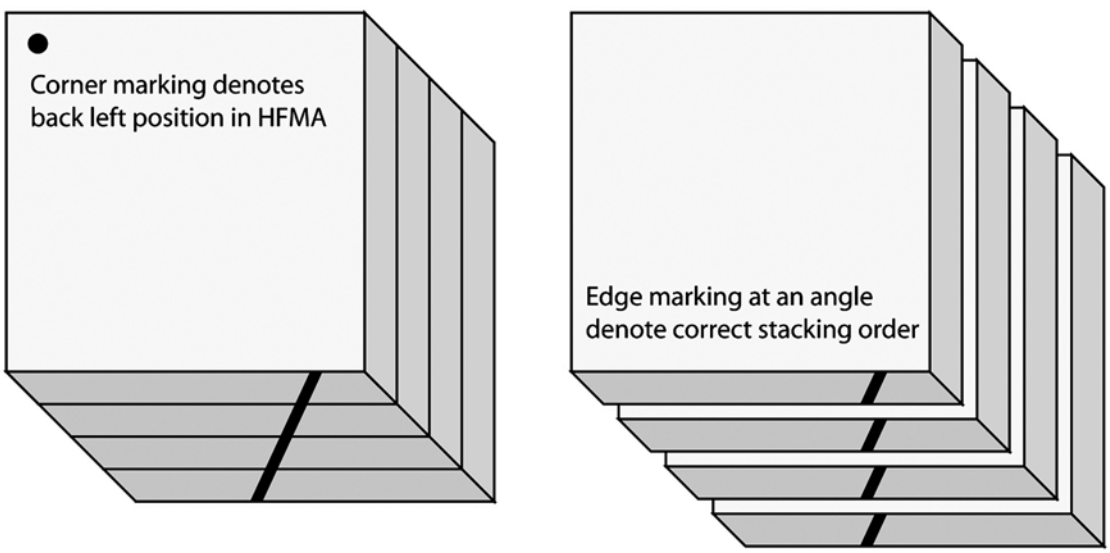



**FIG. 3 Examples of Useful Specimen Stack Marking Techniques**

6.6.2.3 If the apparatus does not include an automatic positioning feature, the user must ensure that there are no air gaps within the specimen stack or between the stack and the controlled temperature plates.

NOTE 15—The thermal conductivity reported by Test Method C 518 or C 177 apparatus is directly proportional to the distance between the controlled-temperature plates. If the apparatus reports the temperature difference and heat flux rather than the thermal conductivity, then the stack thickness used to calculate the thermal conductivity must equal the distance between the plates. This is not likely to be the sum of the individual slice thicknesses because of the pressure applied by the plate positioning apparatus within the device.

6.6.3 *Product Density*—For product identification and reporting purposes, the product apparent density shall be measured in accordance with Test Method D 1622.

6.6.3.1 The density of interest is that of the foam. Therefore, for faced products, the facing shall be removed before the product density is measured.

6.7 *Calculations*:

6.7.1 The equation used to determine each testing period (in days) is shown in Eq 1.

6.7.1.1 The Average Slice Thickness is that value calculated in 6.4.5.4. The constant 1826 represents the number of days in a 5-year period. Be sure to state the Average Slice Thickness and the Product Thickness in the same set of units.

6.7.2 Use Eq 1 to determine the test time for each product thickness of interest, subject to the limitations of Annex A1.

6.7.3 For the purpose of this calculation, the average slice thickness for surface slices shall not include the thickness of any facing material.

## 7. Part B: The Research Method

7.1 *Background*—In general, the prescriptive procedure described in Section 6 shall be followed. Modifications made to meet research needs must be carefully documented when reporting the results and must be based on a clear understanding of the gas diffusion physics that form the foundation of the accelerated aging theory. (See Appendix X3.)

7.1.1 Data taken using the Research Method shall not be used for product rating purposes unless all the requirements of the Prescriptive Method in Section 6 are satisfied.

7.1.2 The qualification tests of Annex A1 are not required, but are recommended.

NOTE 16—For research purposes, such as to benchmark numerical analysis methods, it may be desirable to perform thin slicing age acceleration of specimens known to be highly non-homogeneous.

NOTE 17—This method applies when one-dimensional diffusion dominates in the full-use thickness material. In bun-stock products, this condition does not exist during the time period between the initial foam production and the manufacturing process that cuts the buns into flat sheets. Also, because the sheets may be cut from the bun stock in different orientations, the foam morphology may vary from one sheet to another. Therefore, if this type of product is tested using the Research Method, extensive information regarding the specimen source and extraction must be provided.

7.2 *TDSL Apparatus*—Apparatus used to measure the effective diffusion thickness of the specimen shall be as specified in Test Method D 2856 or D 6226 or shall have demonstrated equivalent performance. See Ref **(14)** for a description of an acceptable alternative apparatus.

NOTE 18—Test Method D 2856 has been withdrawn. However, laboratories that have the apparatus described in that test method are allowed to use that apparatus following the withdrawn test method.

7.3 *Sampling Schedule*—It is acceptable to prepare the specimens from products where the production date is unknown, but every effort must be made to acquire the foam soon after its production.

7.3.1 Data analysis must address the question of initial age using the aging theory found in Appendix X3 and Refs **( 4, 8)**.

7.3.2 Other resources, including data from the manufacturer and the pertinent material standard, shall be consulted to determine whether the estimated initial age is reasonable.

7.4 *Specimen Preparation*:

7.4.1 *Stack Composition*—The choice of core, surface, or mixed stacks, or a combination thereof is acceptable in the Research Method. However, data for each stack shall be kept independent from data for any other stack.

NOTE 19—The effects of facers and density gradients on the accuracy and applicability of the accelerated aging test method are of great interest. Researchers may select alternative stacking compositions in order to investigate these phenomena.

7.4.2 It is acceptable to vary the extraction of specimens described in 6.4.3 if necessary to meet research goals. In no case shall these sections be taken within 15 cm (6 in.) of the product edge.

7.4.3 It is acceptable to reduce the slice thickness below the minimum specified for Part A in 6.4.5. See 7.6.5 and Appendix X1.

7.4.4 If the TDSL is measured, prepare the TDSL test specimens using the same slicing equipment as was used for the thermal test specimens. Prepare test specimens with dimensions that are required for the closed-cell volume measurement apparatus described in Test Method D 2856 or D 6226. Prepare these specimens from sample material taken adjacent to the thermal specimen sections.

7.5 *Storage Conditioning*—In order to investigate the effect of environmental conditions on product aging, it is acceptable to use environmental conditions other than those specified in 6.5. If other conditions are used, they shall be recorded on a monthly basis.

7.6 *Test Procedure*:

7.6.1 Start an initial thermal conductivity measurement as soon as possible but no more than 6 h after the slicing procedure begins. Record the time elapsed between this measurement and the slicing procedure to the nearest hour.

$$\text{Test Time} = \left[\frac{\text{Average Slice Thickness}}{\text{Product Thickness}}\right]^2 \times 1826 \quad (1)$$

7.6.2 A series of subsequent thermal conductivity measurements shall be adequate to provide data for the integration calculation procedure described in 7.7. The precise timing on these measurements is flexible, but it is important that the test schedule recognize that the foam aging progresses at a more rapid rate in the earliest portion of the aging period. Measurements need to continue until a steady state condition has been reached. Steady state conditions can be recognized when thermal conductivity measurements, taken over a period of at least 100 days, agree within ±2 %, and show no trend. See 7.7.2.

NOTE 20—A suggested test schedule for 10 mm (0.4 in.) thick slices from a 25 mm (1 in.) product would include measurements at 5 days, 10 days, 30 days, 60 days, 100 days, 150 days, 210 days, 365 days, and 480 days.

NOTE 21—If a more accurate representation of the earliest aging period is desired, slice thickness should be increased to extend the time period over which this phenomenon occurs.

7.6.3 It is acceptable to make thermal conductivity measurements at other mean test temperatures and temperature differences.

NOTE 22—Gas diffusion rates increase at elevated temperatures. Repeated thermal conductivity measurements made at elevated mean temperatures may therefore change the very aging behavior that is the subject of the study. The thin slice adjacent to the hottest surface during the thermal conductivity measurement is the most likely to be affected. It may be necessary to rotate the slice stacking order, or to use a smaller number of measurements on a larger number of specimen stacks, in order to limit the exposure of any particular specimen to the higher temperatures.

7.6.4 It is acceptable to make the apparent specimen density in accordance with Test Method D 1622 on the same test schedule as the thermal conductivity.

7.6.5 Use Test Method D 2856 or D 6226 to measure the TDSL and effective diffusion thickness if necessary.

NOTE 23—Test Method D 6226 has replaced Test Method D 2856 because the equipment specified in Test Method D 2856 is no longer commercially available. Both Test Methods D 2856 and D 6226 contain the same procedures, but some of the procedures included in the main body of Test Method D 2856 are located in a non-mandatory Appendix in Test Method D 6226. The accuracy of the measured TDSL from either method is strongly influenced by the proportion of closed cells in the body, because any open cells that are connected to the surface will be counted in the TDSL volume.

7.6.5.1 The slice thickness, slice preparation method, and foam morphology shall be considered in making this determination. If the foam morphology varies from foam products previously tested, or if the slice thickness is decreased such that the TDSL will potentially comprise more than 4 % of the slice thickness, the TDSL shall be measured.

NOTE 24—The specimen preparation techniques employed by this test method destroy the closed cell integrity of the surface cells. For thinner specimens, these damaged surface cells may account for an appreciable percentage of the total specimen thickness. See Appendix X1 for more information about the effect of the thickness of the destroyed surface layer on the test results.

NOTE 25—The accuracy of Test Method D 2856 or D 6226 may be insufficient when used to determine the effective diffusion thickness of some thin specimens. The uncertainty associated with this procedure shall be considered when selecting the geometric thickness of the thin test specimen.

NOTE 26—When using Test Method D 2856 or D 6226, it is recommended that an average of the half-atmosphere and two-atmosphere methods be used. The two-atmosphere method is likely to cause cell damage in low density materials; for these materials, the half-atmosphere method should be used exclusively.

NOTE 27—At a minimum, equivalency between Test Method D 2856 or D 6226 and the proposed alternative shall be demonstrated by direct comparison of the two procedures.

7.7 *Calculations*:

7.7.1 A functional relationship between thermal conductivity, time, and product thickness is developed using simple interpolation and trapezoidal integration techniques. Note that thermal conductivity is used throughout this section. The thermal resistance is calculated only after all other calculation steps are complete. All the necessary equations are given here and are also available in an Excel spreadsheet.[6]

7.7.2 Extrapolate data with the greatest caution. These products typically reach a steady-state value at some point in time. However, if the last two data points are unequal, any extrapolation using the linear data analysis methods given here will falsely show a product eventually reaching infinite or zero thermal conductivity.

7.7.3 Organize the data in two columns, the first showing the test date and the second the measured thermal conductivity. Convert the test dates to elapsed test time periods in days, measured from the day of slicing. Create a column of normalized test times corresponding to each elapsed test time period according to Eq 2.

7.7.3.1 The Average Slice Thickness comes from 6.4.5.4 and does not include the facing thickness for surface slices. See 7.7.6 for adjustments related to slice thickness and TDSL.

7.7.4 The average effective thermal conductivity of a given product over a projected service life can be determined by performing an integration of thermal conductivity versus time, and then dividing by the service life. The time scale used in this equation is real, not normalized, time. The concept is shown in Eq 3.

7.7.5 Several time scales are used in this section. The Scaled Service Life has units of time, usually days, and is comparable to the "elapsed time period" scale in the thin-slice test data. The integration is accomplished in this time scale. The Normalized Service Life has units of time per length$^2$, usually days/cm$^2$, and is comparable to the normalized test time scale. The interpolation is accomplished in this normalized time scale. The normalized time scale is also used to determine the thermal conductivity of a given thickness product at any specific point in time.

7.7.5.1 The service life integral can be approximated using a numerical trapezoidal integration based upon thin-slice test data taken over a much shorter time period. This shorter time period corresponds to the Scaled Service Life. (Other integration techniques were tested and found to offer results very similar to this simple method (**15**).) See Eq 4.

7.7.5.2 The final time in this series, or time($n_{SL}$), is by definition the Scaled Service Life, which is determined using Eq 5.

7.7.5.3 It is possible that the thin slice data will not include a data point corresponding to the scaled service life (where $n = n_{SL}$ in Eq 4). In that case, it is necessary to interpolate to obtain

the thermal conductivity corresponding to that point, as shown in Fig. 4. This value becomes the last thermal conductivity value in the series in Eq 4.

*(1)* Because the diffusive aging process is an exponential function, this interpolation is more accurate if it is based on the normalized time defined in 7.7.3. Determine the Normalized Service Life corresponding to the full-thickness product and projected service life according to Eq 6. Be sure to use the same set of units that were used in 7.7.3, for example, days per $cm^2$.

*(2)* Comparing the Normalized Service Life from 7.7.5.3*(1)* to the Normalized Test Time column of values from 7.7.3, select the two test data points that bracket the Normalized Service Life, as shown in Table 1.

**TABLE 1 Time Scale Interpolation**

| | |
|---|---|
| Normalized Test Time (i) | $k$(i) |
| Normalized Service Life | $k(n_{SL})$ |
| Normalized Test Time (i+1) | $k$(i+1) |
| [Normalized Test Time(i)< Normalized Service Life< Normalized Test Time(i+1)] | |

*(3)* Interpolate the values shown in 7.7.5.3*(2)* to obtain the instantaneous thermal conductivity corresponding to the service life according to Eq 7.

7.7.6 Measured thermal conductivity values include the effect of the TDSL, as discussed in Appendix X1. When the researcher considers that the TDSL represents a significant fraction (typically greater than 4 %) of the average slice thickness, then adjustments (given in the remainder of this section) to the above equations to account for the TDSL shall be made.

7.7.6.1 Determine the effective diffusion thickness of the thermal resistance specimen, $\Delta X_{eff}$, where $N$ is the number of cut planar surfaces. Usually $N$=2 for a core specimen and $N$=1 for a surface slice. The TDSL was measured in 7.6.5. The Geometric Thickness corresponds to the average slice thickness from 6.4.5.4. See Eq 8.

7.7.6.2 Use two times the effective diffusion thickness as the average slice thickness for the purposes of 7.7.3 and 7.7.5.3.

7.7.6.3 Depending upon the proportion of the average slice thickness represented by the TDSL, in some circumstances it will also be necessary to correct the thermal conductivity measurements. See Appendix X1.

$$\text{Normalized Test Time(i)} = \frac{\text{Test Time(i)}}{(\text{Average Slice Thickness})^2} \tag{2}$$

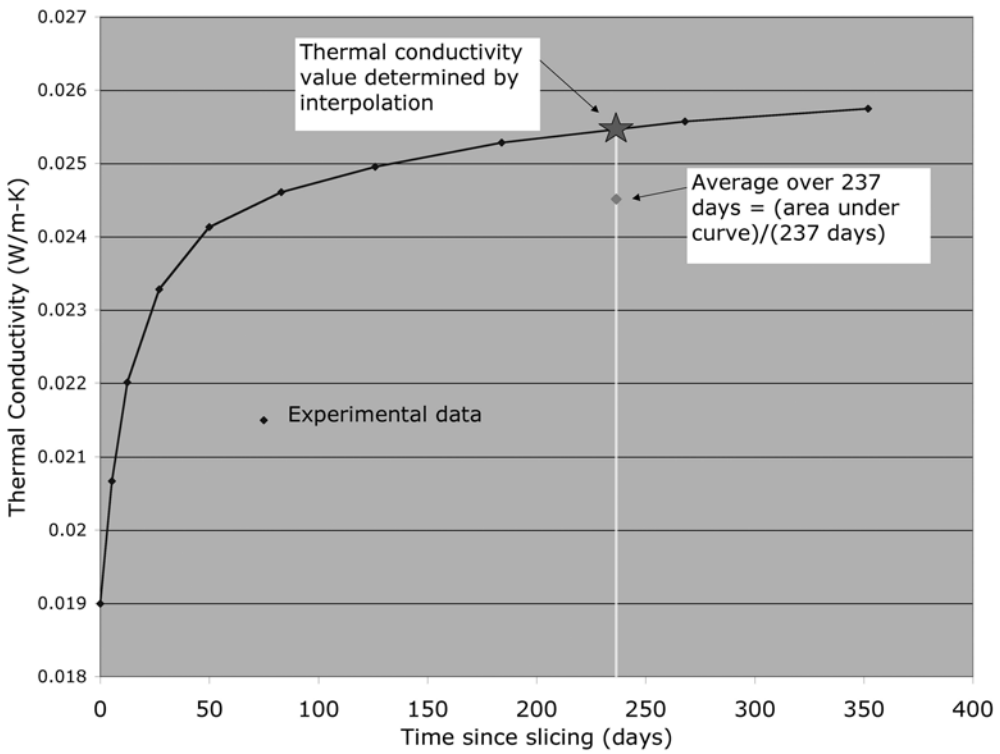



**FIG. 4 Illustration of the Integration and Interpolation Methods Used in the Research Method**

$$k_{\text{avg, service life}} = \frac{\int_{\text{Service Life}} k \times d(\text{time})}{\text{Service Life}} \tag{3}$$

$$k_{\text{avg, predicted}} = \frac{\sum_{n=2}^{n=N_{SL}} \frac{(k_{n-1} + k_n)}{2} \times (\text{time}_n - \text{time}_{n-1})}{\text{Scaled Service Life}} \tag{4}$$

$$\text{Scaled Service Life} = \text{Service Life} \times \left[\frac{\text{Average Slice Thickness}}{\text{Full Product Thickness}}\right]^2 = \text{time}(n_{SL}) \tag{5}$$

$$\text{Normalized Service Life} = \frac{\text{Projected Service Life}}{(\text{Full Product Thickness})^2} \tag{6}$$

$$k(NSL) = k(i) + \left[\left\{\frac{\begin{pmatrix}\text{Normalized}\\ \text{Service}\\ \text{Life}\end{pmatrix} - \begin{pmatrix}\text{Normalized}\\ \text{Test}\\ \text{Time}(i)\end{pmatrix}}{\begin{pmatrix}\text{Normalized}\\ \text{Test}\\ \text{Time}(i+1)\end{pmatrix} - \begin{pmatrix}\text{Normalized}\\ \text{Test}\\ \text{Time}(i)\end{pmatrix}}\right\} \times \{k(i+1) - k(i)\}\right] \tag{7}$$

$$\Delta X_{eff} = \frac{1}{2} \times [(\text{Geometric Thickness}) - (N \times TDSL)] \tag{8}$$

## 8. Report

8.1 *Reporting for Part A, the Prescriptive Method*:

8.1.1 Report the following, including references to applicable test methods.

8.1.2 The name, address, and any other identification of the test laboratory and the date of the report. State that Part A: The Prescriptive Method was used.

8.1.3 The name and any other identification of the material tested.

8.1.3.1 Report the ASTM material specification designation, type, class, and grade (as applicable).

8.1.3.2 Report the density of the test specimen.

8.1.4 The manufacturer of the material, the date obtained and the date of manufacture.

8.1.5 The method of slice specimen preparation and the date(s) of specimen preparation.

8.1.6 The environmental conditions at which the specimens were aged.

8.1.7 Mean test temperature and temperature difference for the thermal resistance measurements. State the test method used for thermal resistance measurements, Test Method C 177 or C 518.

8.1.8 The results of qualification tests in Annex A1.

8.1.9 For each of the three stacks, show (see Table 2):

8.1.9.1 The average slice thickness for each stack.

**TABLE 2 Reporting Requirements for All Three Test Stacks**

| Stack type | Core | Surface | Mixed |
|---|---|---|---|
| Product thickness #1 | | | |
| Average slice thickness | | | |
| Test Period | | | |
| Calculated test date | | | |
| Actual test date | | | |
| 5-Year predicted R-value | | | |
| Repeat last five rows for each product thickness. | | | |

8.1.9.2 The test periods calculated in 6.7 for each product thickness, the calculated test dates, and the actual test dates.

8.1.9.3 The thermal resistance corresponding to the resistance at 5 years for each product thickness as measured in 6.6.2.

NOTE 28—The application of these results for product rating purposes is beyond the scope of this test method. See the pertinent material specification for guidance.

8.1.10 The precision and bias for the Part A test method are not yet available, but are under development.

NOTE 29—Precision and bias for previous editions of C 1303 are described in Section 9.

8.2 *Reporting for Part B, the Research Method*:

8.2.1 The composition of the test stacks used for the test measurements. This shall include a description of any facer material present on the original product, and whether or not the facer was included in the test specimens.

8.2.2 The average slice thickness for each stack.

8.2.3 A table showing the test dates and the measured thermal conductivity for each test, along with the mean test temperature and temperature difference.

8.2.4 Other analysis results pertinent to the objectives of the research project. It is possible that this will include graphical representations of functional relationships between product thickness, product service life, thermal conductivity, and average effective thermal conductivity.

8.2.5 The precision and bias for this test method, and the expected effect of any differences between the research tests and those used to define the method's precision and bias.

8.2.6 State explicitly whether the Qualification tests of Annex A1 were performed, and if so, give the results of the homogeneity qualification in A1.2.

8.2.7 Other values listed in 8.1.

## 9. Precision and Bias

9.1 The precision of this test method is significantly influenced by the specimen preparation techniques and the dimension measurement procedures, as well as the precision of the thermal test method used. Precision data on these combined procedures are not yet available for all material types. All precision and bias data reported before 2005 was collected under the conditions specified in the version of C 1303 published in 2000.

9.2 A round robin was conducted between 1993 and 1994, and employed unfaced, rigid closed-cell polyisocyanurate (PIR) foam specimens from 7.6 to 33-mm (0.3 to 1.3-in.) thick.**(8)** The PIR boardstock was blown with hydrochlorofluorocarbon 141b and $CO_2$. Thirteen laboratories were involved in this study. The ratios of predicted lifetime thermal resistance to initial thermal resistance for the seven data sets on board Set 1 had a coefficient of variation of 1.1 % for 10-year lifetimes and 1.3 % for 20-year lifetimes for a thickness of 38 mm (1.5 in.) The results for Set 2 are not pertinent here because there was a significant and variable delay between the slicing and the initial thermal conductivity measurement.

9.3 A round robin was conducted 1995, and employed a selected extruded polystyrene (XPS) foam insulation.**(12)** The specimens varied from 7.9 to 41 mm (0.31 to 1.6 in.) in thickness. Three laboratories participated in this study. The XPS foam insulation used in the round robin was produced in January 1995 using HCFC-142b as the blowing agent. The board stock was nominally 50 mm (2 in.) thick. Each laboratory prepared their own slices using different slice preparation methods including hot-wire, planer, slicer, and band saw. This comparison of slicing/scaling thermal resistance data for extruded polystyrene foamboard insulation resulted in a variability of no more than ±2.5 % in average thermal resistance computed for 38-mm (1.5-in.) thick specimens and ±2 % for 51-mm (2.0-in.) thick specimens. The 20-year time-averaged thermal resistance values for specimens prepared using the slicer and the band saw agreed within 0.7 %. The 20-year time-averaged thermal resistance values for specimens prepared using the hot wire were about 3 to 5 % higher than those of the band-saw and slicer specimens.

NOTE 30—Hot wires could produce surface skins that can affect the aging process as shown by the data available from Ref **(12)** when the hot wire is compared to the other preparation methods. This technique shall not be used as a specimen preparation technique.

9.4 A comparison of the thermal conductivity of full-thickness foam insulation specimens, aged from one to five years, to the thermal conductivity estimated for the same insulation samples from thin-slicing procedures was reported **(15)**. All of the XPS stacks of thin slices used in this comparison were composed of mixed surface and core slices. For the PIR specimens reported, the stacks of thin slices contained only core slices. The XPS full thickness specimens were aged under laboratory conditions, the PIR full thickness specimens were aged in a field installation. In this comparison, the thermal resistance predictions for one year all matched the full-thickness data within 1 %. For the five-year comparison, the thermal resistance predictions matched the full thickness data within 2 %. The standard deviation among the full-thickness specimens ranged from 1.9 to 2.6 %.

9.5 In 2006, a ruggedness test was initiated to examine the influences of several test variables, most importantly stack composition, slice thickness, and product homogeneity, on the accuracy of the aged foam thermal resistance prediction. As described in Appendix X2, it is likely that the ruggedness test will be complete in 2011.

9.6 A round robin was started in 2002 to determine the bias of the thin slicing procedure described in the Annex of Specification C 1289 on polyisocyanurate foam insulation. Two manufacturers supplied products and the study involved 10 participating laboratories. Separate stacks of core and surfaces slices with a thickness of 10 mm (0.4 in) were used in the study. The slices were prepared from 50.8 mm (2.0 in.) product. Three full thickness products at 25.4 mm (1.0 in.), 50.8 mm (2.0 in.) and 76.2 mm (3.0 in.) were also included in the study and their thermal resistance was measured every year. Although the test will not be complete until 2007, intermediate bias results were available after three years, comparing the predictions made from thin slices to the thermal resistance of the three full thickness products aged in laboratory conditions. In addition to what is required by the Specification C 1289 Annex, additional measurements were made that allowed the

**TABLE 3 Intermediate Bias Test Results from Interlaboratory Round Robin Study after Three Years ((predicted – measured)/measured)**

| Product Thickness (mm) | Bias[A] from Core Slices (%) | | Bias[A] from Surface Slices (%) | |
|---|---|---|---|---|
| Manufacturer | A | B | A | B |
| 25.4 | 1.3 | –6.4 | 0.4 | –6.2 |
| 50.8 | 0.2 | –1.8 | –1.0 | –1.3 |
| 76.2 | 5.0 | –2.4 | 2.6 | –2.7 |

[A] Bias were determined using LTTR values as calculated in Test Method C 1303 – 00.

application of C 1303 – 00. The bias results for this application of C 1303 – 00 are shown in Table 3.

## 10. Keywords

10.1 aging; long-term thermal resistance; LTTR; rigid closed-cell plastic foams; scaling factors; thermal insulation; thermal resistance; time-averaged thermal resistance

# ANNEXES

**(Mandatory Information)**

## A1. QUALIFICATION

A1.1 *Specimen Preparation*—The specimen collection and preparation shall be done as described in 6.3 and 6.4.

A1.2 *Homogeneity Qualification*—Use the aging equivalence test procedure shown in A1.3 to compare the aging characteristics of a stack of core thin slice (set 1) specimens to that of a stack of surface thin slice specimens (set 2). If the aging equivalence calculated is greater than 90 % and less than 110 %, the insulation specimen satisfies the homogeneity qualification for this practice. Otherwise, it is not acceptable to use the accelerated aging test.

A1.2.1 Prepare a stack of four core slices using the procedures described in 6.4.

A1.2.2 Prepare a stack of four surface slices using the procedures described in 6.4.

A1.3 *Aging Equivalence Test Procedure*—This procedure is used to compare the aging characteristics of two stacks of specimen thin slices. Equivalence is based on comparing the ratios of thermal conductivity measured at two points in time. The difference between these ratios is divided by the average of these two ratios.

A1.3.1 The time scale used in this procedure is the normalized time, that is, the clock time divided by the square of the average slice thickness in each stack.

A1.3.2 Initiate a thermal resistance measurement of each set of specimens 24 h/cm$^2$ (± 1 h) after the thin slices were prepared, measuring the elapsed time from the moment the initial cut was made in the full thickness product. Use Eq A1.1 to determine the test time and date.

A1.3.3 Initiate a thermal resistance measurement of each set of specimens 30 days/cm$^2$ (±1 day) after the thin slices were prepared, measuring the elapsed time from the moment the initial cut was made in the full thickness product. Use Eq A1.2 to determine the test date.

A1.3.4 Calculate the specimen aging equivalence from these two sets of measurements according to Eq A1.3.

A1.4 *Alternate Product Thickness Qualification*—Test results for specimens taken from a particular product thickness shall be considered representative of other products within 1.3 cm (±0.5 in.) of that thickness.

A1.4.1 Alternate product thickness qualification for the Prescriptive Method: For some products, the aging of a single product thickness will adequately represent the aging of another product thickness that is different by more than 1.3 cm (0.5 in.). If the product equivalence is demonstrated by meeting the requirements of A1.4.1.1 and A1.4.1.2, results for one product thickness shall be considered representative of both products.

A1.4.1.1 *Aging Equivalence*—Perform test procedure A1.3, using comparative specimens, prepared as described in 6.4, from the two product thicknesses under consideration. Four core slices from one product thickness (set 1) shall be compared to four core slices from the other product thickness (set 2). Four surface slices from one product thickness (set 1) shall be compared to four surface slices from the other product thickness (set 2). Test results with an aging equivalence value between 92 and 108 % for both core and surface comparisons satisfy this qualification.

NOTE A1.1—These criteria are the subject of an on-going ruggedness study and may be revised based upon the results of that study.

$$\text{DateTime}_{\text{Test}} = \text{DateTime}_{\text{Slice}} + \left(24\,\frac{h}{cm^2}\right) \times \left[\text{Average Slice Thickness}^2\right] \pm 1 \text{ hour} \quad \text{(A1.1)}$$

$$\text{Date}_{\text{Test}} = \text{Date}_{\text{Slice}} + \left(30\,\frac{days}{cm^2}\right) \times \left[\text{Average Slice Thickness}^2\right] \pm 1 \text{ day} \quad \text{(A1.2)}$$

$$\text{Age Equivalence} = 100\%\left\{1-\frac{2\left[\left(\frac{k_{24h/cm^2}}{k_{30d/cm^2}}\right)_{\text{set 1}}-\left(\frac{k_{24h/cm^2}}{k_{30d/cm^2}}\right)_{\text{set 2}}\right]}{\left[\left(\frac{k_{24h/cm^2}}{k_{30d/cm^2}}\right)_{\text{set 1}}+\left(\frac{k_{24h/cm^2}}{k_{30d/cm^2}}\right)_{\text{set 2}}\right]}\right\} \quad \text{(A1.3)}$$

A1.4.1.2 *Thermal Conductivity Equivalence*—Using the same test data as was used for A1.4.1.1, compare the thermal conductivity of the two specimens at 30 days/cm$^2$ after slicing according to Eq A1.4. Test results with a thermal conductivity equivalence between 92 and 108 % for both core and surface comparisons satisfy this qualification.

NOTE A1.2—These criteria are the subject of an on-going ruggedness study and may be revised based upon the results of that study. (See Eq A1.4.)

A1.5 *Example Calculations*

A1.5.1 *Example Case Description*:

For this example, a hypothetical 5 cm (2 in.) permeably-faced foam product was manufactured on May 16, collected on May 24, and submitted to the laboratory for a C 1303 accelerated aging test on May 27. Slices, approximately 1 cm (0.4 in.) thick were cut from the product on June 1, at 12:30 PM. The average thickness of the four core slices was 0.97 cm (0.38 in.). The average thickness of the facer was 0.06 cm (0.024 in.). The average thickness of the four surface slices, not including the thickness of the facer, was 0.96 cm (0.38 in.). Because this was a new product, it was necessary to perform the homogeneity qualification test described in A1.2. Also, it was desired to predict the performance of a thicker, 10 cm (4 in.) product based on the aging of slices from the 5 cm (2 in.) product. In order to meet the alternate thickness qualification, specimens of the thicker product were also delivered to the laboratory on a schedule to meet the time requirements of 6.3.1 and 6.4.2.

A1.5.2 *Example case calculation of time interval calculations for homogeneity aging equivalence test (Eq. A1.1).*

For the homogeneity qualification test, it is necessary to perform the Aging Equivalence Test Procedure described in A1.3 with set 1 representing the core slices and set 2 representing the surface slices. This test measures the thermal conductivity of core and surface slice stacks at specified time intervals to determine whether the core and surface slices are aging at a similar rate. The calculation of the time intervals approximates 1 day and 30 days after slicing. The test intervals are carefully adjusted to ensure appropriate comparisons even if there are differences in slice thickness between the surface and core stacks.

A1.5.3 *Example of Homogeneity Qualification for A1.2*

Based on the dates and times calculated in Table A1.1, tests were made using Test Method C 518 apparatus, generating the data summarized in Table A1.2. The measured thermal conductivity data is then used to evaluate the product homogeneity, using Eq A1.3 as demonstrated in Eq. A1.5. The result for this example, 106%, is greater than 90% and less than 110%, so this product would pass the homogeneity qualification requirement.

$$\text{k Equivalence} = 100\%\left\{1-\frac{2\left[\left(k_{30d/cm^2}\right)_{\text{set 1}}-\left(k_{30d/cm^2}\right)_{\text{set 2}}\right]}{\left[\left(k_{30d/cm^2}\right)_{\text{set 1}}+\left(k_{30d/cm^2}\right)_{\text{set 2}}\right]}\right\} \quad \text{(A1.4)}$$

$$\text{Age Equivalence} = 100\%\left\{1-\frac{2\left[\left(\frac{0.0247}{0.0271}\right)_{\text{core}}-\left(\frac{0.0267}{0.0276}\right)_{\text{surface}}\right]}{\left[\left(\frac{0.0247}{0.0271}\right)_{\text{core}}+\left(\frac{0.0267}{0.0276}\right)_{\text{surface}}\right]}\right\}=106\% \quad \text{(A1.5)}$$

A1.5.4 *Example case, Alternate product thickness qualification*

Also, because it was desired to use the thin slices from the 5 cm (2 in.) product to produce a rated value for a 10 cm (4 in.) product made from the same components, it was necessary to perform the alternate product thickness qualification described in A1.4. For this test, both the thermal conductivity at about 30 days and the aging behavior must be comparable and meet the specified criteria. To meet this test, the data shown above for the 5 cm (2 in.) product from Table A1.2 was used along with the data summarized in Table A1.3 for slices from a 10 cm (4 in.) product.

**TABLE A1.1 Example Test Schedule Calculations for the Homogeneity Aging Equivalence Tests**

| Slice Origin | Slice thickness * | Date-time the first cut is made in full thickness product to extract thin slices | Date time for start of 24h/cm² measurement (Eq. A1.1) | Date for start of 30d/cm² measurement (Eq. A1.2) |
|---|---|---|---|---|
| Core | 0.97cm | June 1, 12:30 PM | =June 1, 12:30 PM + (24 h/cm²× (0.97 cm)²)<br>=June 1, 12:30 PM + 22.6 h<br>=June 1, 12:30 PM + 22 h and 36 min.<br>=June 2, 11:06 AM<br>The test must be initiated at that time, ± 1 h, and so should start on June 2, between 10:06 AM and 12:06 PM | = June 1 + 30 d/cm²× (0.97 cm)²)<br>= June 1 + 28 days<br>= June 29<br>The test must be initiated on that day, ± 1 day, and so should be made on June 28, 29, or 30 |
| Surface | 0.96 cm | June 1, 12:30 PM | =June 1, 12:30 PM + (24 h/cm²× (0.96 cm)²)<br>=June 1, 12:30 PM + 22.1 h<br>=June 1, 12:30 PM + 22 h and 6 min.<br>=June 2, 10:36 AM<br>The test must be initiated at that time, ± 1 h, and so should start on June 2, between 9:36 and 11:36 AM | = June 1 + 30 d/cm²× (0.96)²)<br>= June 1 + 28 days<br>= June 29<br>The test must be initiated on that day, ± 1 day, and so should be made on June 28, 29, or 30 |

**TABLE A1.2 Aging Equivalent Data from a 50 cm (2in.) Product**

| Test date, time | Slice type | Stack thermal conductivity, W/m-K (Btu-in./h-ft²-°F) | Corresponding label in Equation A1.3 |
|---|---|---|---|
| June 2, 11:30 AM | Core | 0.0247 (0.171) | $k_{24h/cm^2}$ |
| June 2,10:00 AM | Surface | 0.0267 (0.185) | $k_{24h/cm^2}$ |
| June 29 | Core | 0.0271 (0.188) | $k_{30d/cm^2}$ |
| June 29 | Surface | 0.0276 (0.191) | $k_{30d/cm^2}$ |

**TABLE A1.3 Aging Equivalence data from a 10 cm (4in) Product**

| Corresponding label in Equation A1.3 | Slice type | Stack thermal conductivity, W/m-K (Btu-in./h-ft2-°F) |
|---|---|---|
| $k_{24h/cm^2}$ | Core | 0.0255 (0.177) |
| | Surface | 0.0292†(0.202) |
| $k_{30d/cm^2}$† | Core | 0.0281 (0.195) |
| | Surface | 0.0301 (0.209) |

† Editorially corrected in February 2009.

A1.5.4.1 For the alternate product qualification, the aging equivalence (Eq. A1.3), must be evaluated separately for the surface slices and for the core slices with one product thickness identified as 'set 1' and the other product thickness identified as 'set 2'. Two equations (Eq A1.6 and Eq A1.7) demonstrate this application of Eq. A1.3.

A1.5.4.2 The 30-day data are used in Eq. A1.4 to test for thermal conductivity equivalence, again with separate comparisons for surface and core slice stacks. (See Eq A1.8 and Eq A1.9.)

A1.5.4.3 The result for this example product thickness comparison passes the aging equivalence criteria because both the surface stack and core stack values, 100.3 and 99.6% respectively, satisfy the requirements. However, it does not pass the thermal conductivity equivalence criteria because the surface stack comparison has a value of 109%, which is greater than the allowed 108%. Therefore, for the purposes of the prescriptive method, the test specimens extracted from the 5 cm (2 in.) product shall not be used to predict the 5-year aged thermal conductivity for the 10 cm (4 in.) product.

$$\text{Age Equivalence}_{\text{Surface}} = 100\%\left\{1-\frac{2\left[\left(\frac{0.0267}{0.0276}\right)_{50\text{ mm product}}-\left(\frac{0.0292}{0.0301}\right)_{100\text{ mm product}}\right]}{\left[\left(\frac{0.0267}{0.0276}\right)_{50\text{ mm product}}+\left(\frac{0.0292}{0.0301}\right)_{100\text{ mm product}}\right]}\right\}=100.3\% \tag{A1.6}$$

$$\text{Age Equivalence}_{\text{Core}} = 100\%\left\{1-\frac{2\left[\left(\frac{0.0247}{0.0271}\right)_{50\text{ mm product}}-\left(\frac{0.0255}{0.0281}\right)_{100\text{ mm product}}\right]}{\left[\left(\frac{0.0247}{0.0271}\right)_{50\text{ mm product}}+\left(\frac{0.0255}{0.0281}\right)_{100\text{ n}}\right]}\right\}=99.6\% \tag{A1.7}$$

$$k\ \text{Equivalence}_{\text{Surface}} = 100\%\left\{1 - \frac{2\left[(0.0276)_{50\ \text{mm product}} - (0.0301)_{100\ \text{mm product}}\right]}{\left[(0.0276)_{50\ \text{mm product}} + (0.0301)_{100\ \text{mm product}}\right]}\right\} = 109\% \quad \text{(A1.8)}$$

$$k\ \text{Equivalence}_{\text{Core}} = 100\%\left\{1 - \frac{2\left[(0.0271)_{50\ \text{mm product}} - (0.0281)_{100\ \text{mm product}}\right]}{\left[(0.0271)_{50\ \text{mm product}} + (0.0281)_{100\ \text{mm product}}\right]}\right\} = 104\% \quad \text{(A1.9)}$$

## A2. PREPARATION OF TEST SPECIMENS FOR SPRAY-FOAM PRODUCTS

A2.1 Polyurethane foam insulation test panels shall be made by spray application consistent with the manufacturer's recommendations including: temperature of liquid components, air temperature, temperature of substrate, type and operation of spray equipment. The number of test panels needed will depend upon the equipment used to prepare the thin slices and the number of replicate sets tested, as discussed in 6.3.3.

A2.2 The air and substrate temperatures shall be 24 ± 3°C (75 ± 5°F). The relative humidity must not exceed 80 %.

A2.3 Sample will be sprayed on 60 by 60 cm (2 by 2 ft) sheet of ¾ in. plywood covered with 4 to 6-mil polyethylene film.

A2.4 Sample to be sprayed nominally in an initial 1.3 cm (½ in.) pass and three 2 cm (¾ in.) passes. It is recommended that the minimum total height of the foam be 6.4 cm (2.5 in.) above the substrate with a minimum of three passes and a maximum of four, see Fig. A2.1.

A2.5 The remaining portion of Annex A2 takes place 7 to 20 days after the spray foam test panel production, as per 6.3.1.

A2.6 Remove the foam portion of the test panels from the plywood and remove the polyethylene film. The side of the foam facing the removed film shall be defined as the "surface" for the purpose of preparing "surface slices" for the homogeneity test in Annex A1.

NOTE A2.1—Only one surface slice can be harvested from each test panel.

A2.7 Cut one 30 by 30 cm (12 by 12 in.) full-thickness section from the geometric center of each test panel (cutting away 15 cm (6 in.) from each of the four sides).

A2.8 For each full-thickness section, cut away the "free-rise" surface along a plane parallel to the surface that had been adjacent to the polyethylene film, leaving a foam specimen thickness no less than 5 cm (2 in.), see Fig. A2.2.

A2.9 Cut the 30 by 30 by 5 cm (12 by 12 by 2 in.) specimen(s) prepared in A2.8 to produce thin slices. The slices shall be prepared with no regard for the internal knit skins. These internal skins are to be treated as an intrinsic part of the core foam.

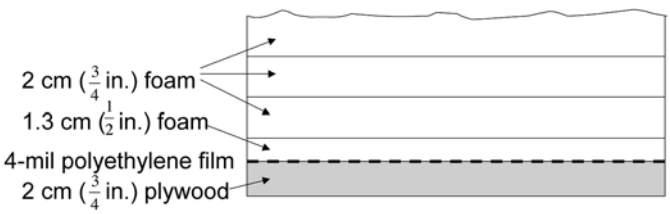



**FIG. A2.1 Spray Foam Test Panel Preparation**

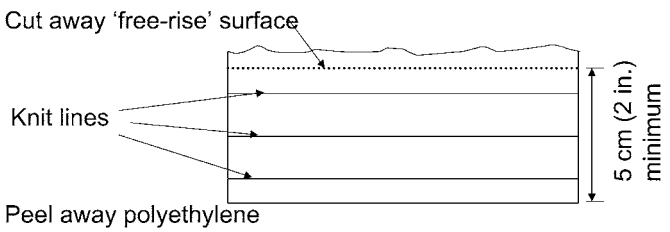



**FIG. A2.2 Spray Foam Specimen Preparation**

# APPENDIXES

**(Nonmandatory Information)**

## X1. EFFECT OF TDSL

X1.1 *Background*—When closed-cell foam insulation is cut to produce thin slices for accelerated aging purposes, a layer of cell walls is broken. The interior of the broken cells is immediately open to the atmosphere, so that the gas in that volume is almost immediately equal in composition to the surrounding air. This is the same state the rest of the foam will experience after a very long period of time during which atmospheric gases diffuse into the cells and blowing agent gases diffuse out of the cells. Throughout that long aging time, the layer of open cells at the surface will have a constant thermal conductivity. But the rest of the foam will undergo a much slower cell gas composition transformation, and a correspondingly slower change in thermal conductivity. Also, because these surface cells are already at atmospheric conditions, the effective diffusion distance for the rest of the foam is less than the full thickness of the slice.

X1.2 *Error in the Measured Thermal Resistivity*:

X1.2.1 In an ideal slice, with no broken surface cells, the measured thermal conductivity would perfectly represent the homogeneous foam from which it was cut. But in any real slice, the measured thermal conductivity will include the effect of heat transfer through the broken surface cells. That measured value can be represented as a series thermal resistance as shown in this equation.

$$R_{measured}(t) = \frac{(x_1 R_{final} + x_2 R_{cc}(t) + x_3 R_{final})}{(x_1 + x_2 + x_3)} \quad \text{(X1.1)}$$

where:

$R_{measured}(t)$ = thermal resistivity measured at time $t$,
$x_1$ = thickness of the top destroyed surface layer,
$R_{final}$ = final thermal resistivity of fully aged foam,
$R_{cc}(t)$ = thermal resistivity of undamaged closed-cell foam at time $t$,
$x_2$ = thickness of the undisturbed cells, and
$x_3$ = thickness of the bottom destroyed surface layer.

X1.2.2 If the slice is aged until it reaches a steady state, $R_{final}$ can be measured and the preceding data points can be adjusted using the equation given in X1.2.1. If we use s to denote the fraction of the geometric thickness that is the total thickness of the destroyed surface layer(s), or the total TDSL, then the equation given in X1.2 can be rewritten to give the desired resistivity of the undamaged portion of the slice as:

$$R_{cc}(t) = \frac{(R_{measured}(t) - sR_{final})}{(1 - s)} \quad \text{(X1.2)}$$

where:

$s = (x_1 + x_3) / (x_1 + x_2 + x_3)$

X1.2.3 The error in the resistivity is then directly proportional to the total TDSL and inversely proportional to the ratio of the closed-cell thermal resistivity and the final thermal resistivity, as shown here and in Fig. X1.1, Fig. X1.2, and Fig. X1.3.

$$\text{Error} = \frac{[R_{measured}(t) - R_{cc}(t)]}{R_{cc}(t)} = s\frac{(1 - C)}{C} \quad \text{(X1.3)}$$

where:

$C = R_{cc}(t) / R_{final}$

X1.3 *Error in the Scaled Time*:

X1.3.1 The scaled time is calculated using the square of the measured slice thickness (see 6.7 and 7.7). However, this relationship is based on Fick's Law, and the correct length scale should be the diffusion thickness, which differs from the slice thickness by the total thickness of the destroyed surface layer(s).

$$\text{Scaled time}_{used} = \frac{d^2}{(\text{product thickness})^2} \times (1826 \text{ days}) \quad \text{(X1.4)}$$

where:

$d = (x_1 + x_2 + x_3)$

$$\text{Scaled time}_{correct} = \frac{(d - sd)^2}{(\text{product thickness})^2} \times (1826 \text{ days}) \quad \text{(X1.5)}$$

X1.3.2 The error in the scaled time, shown in Fig. X1.1, is then approximately equal to twice the total TDSL, or:

$$\text{Error} = \frac{(\text{Scaled time}_{used} - \text{Scaled time}_{correct})}{\text{Scaled time}_{correct}} = \frac{(2s - s^2)}{(1 - 2s + s^2)} \quad \text{(X1.6)}$$

X1.4 The combined effect of these two corrections is shown in Fig. X1.1 and Fig. X1.2. The scaled time example points shown on this figure correspond to the thermal resistance of a 75 mm (3 in.) thick product at an age of 5 years. Note that as the fraction of TDSL increases, the measured R-value decreases and the calculated test period increases.

X1.5 Note that the errors in the measured thermal resistance due to TDSL go to zero as the foam ages, or as $R_{cc}$ goes to $R_{final}$. Also, at that point the error in the test time becomes unimportant because the thermal resistivity is no longer changing.

X1.6 TDSL values measured by three laboratories during an interlaboratory comparison are shown in Fig. X1.3, as are the relationship between slice thickness, TDSL, and %TDSL.

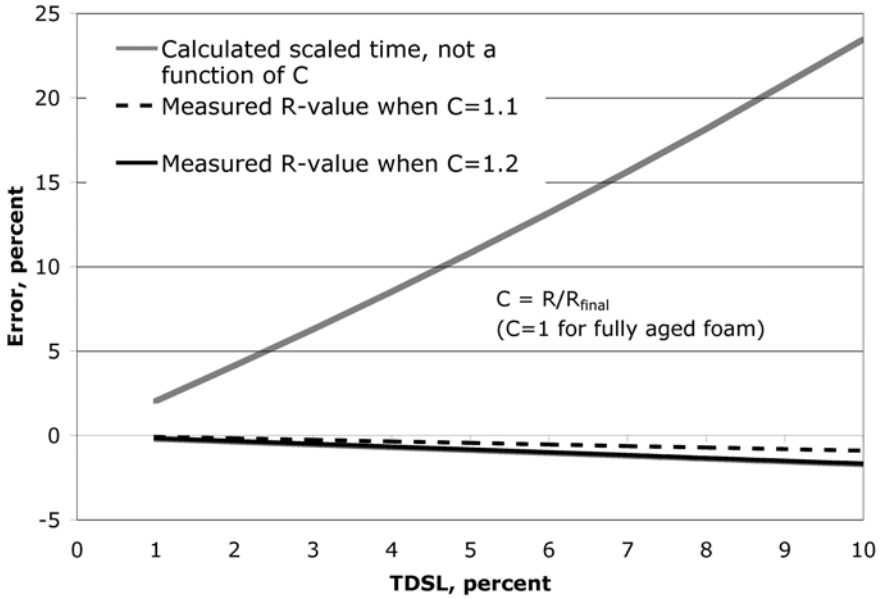
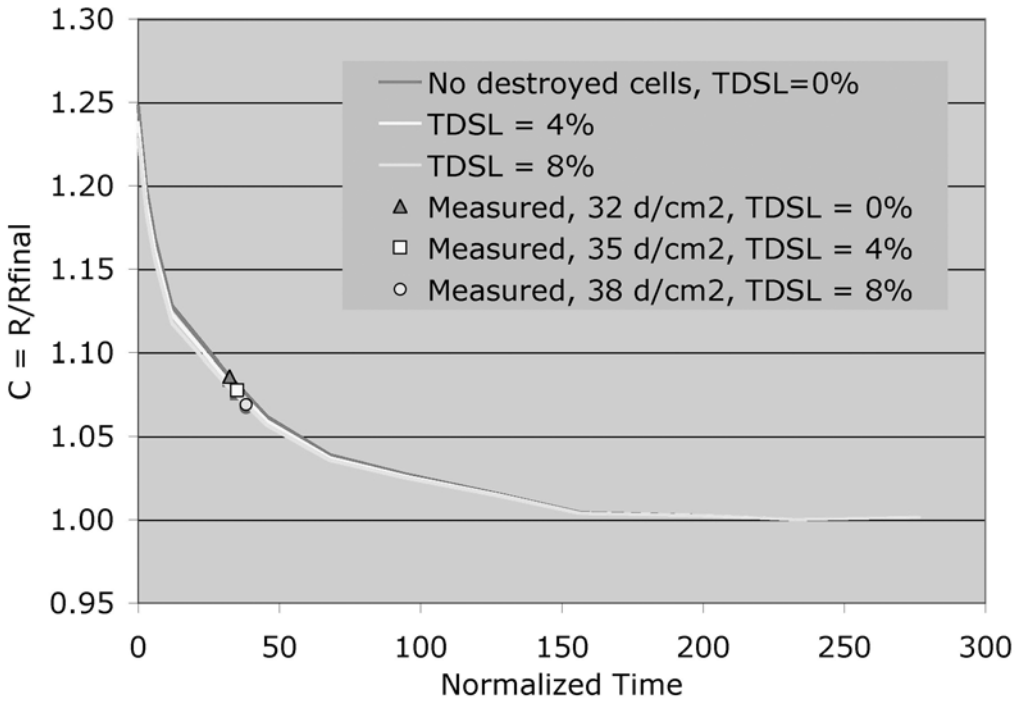
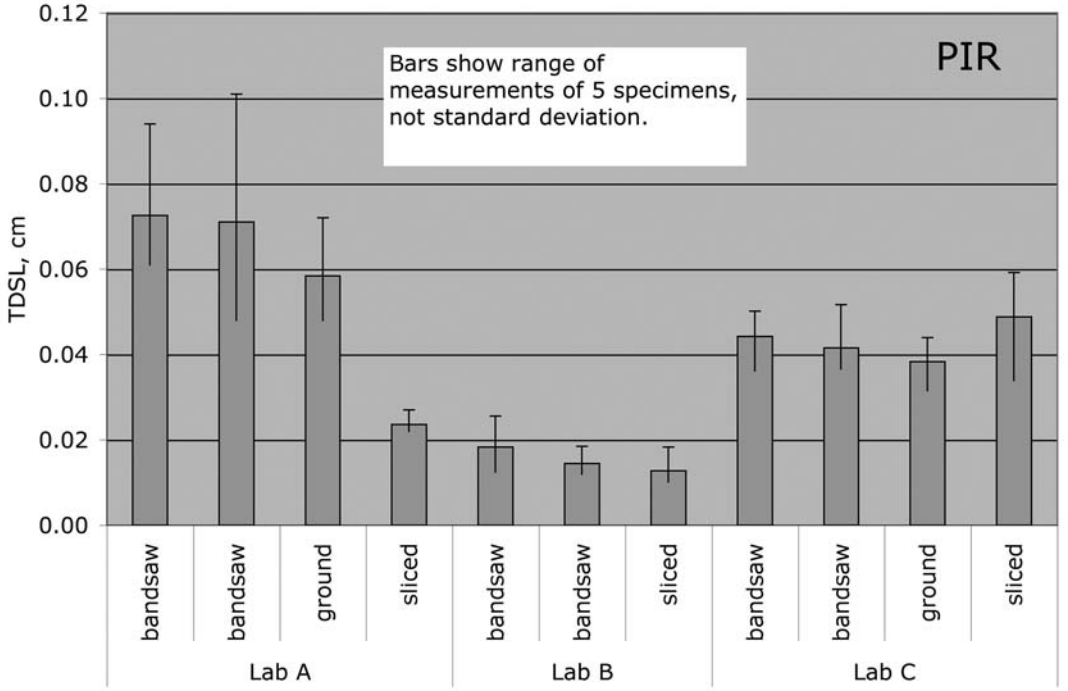



**FIG. X1.1 Errors in the Measured R-value and Calculated Test Time as a Function of TDSL**




NOTE—A comparison of accelerated aging test results for the same product, with the same diffusion thickness (thickness of closed cells in the thin slice), but varying TDSL, which also varies the geometric slice thickness.

**FIG. X1.2 Comparison of Accelerated Aging Test Results for the Same Product**



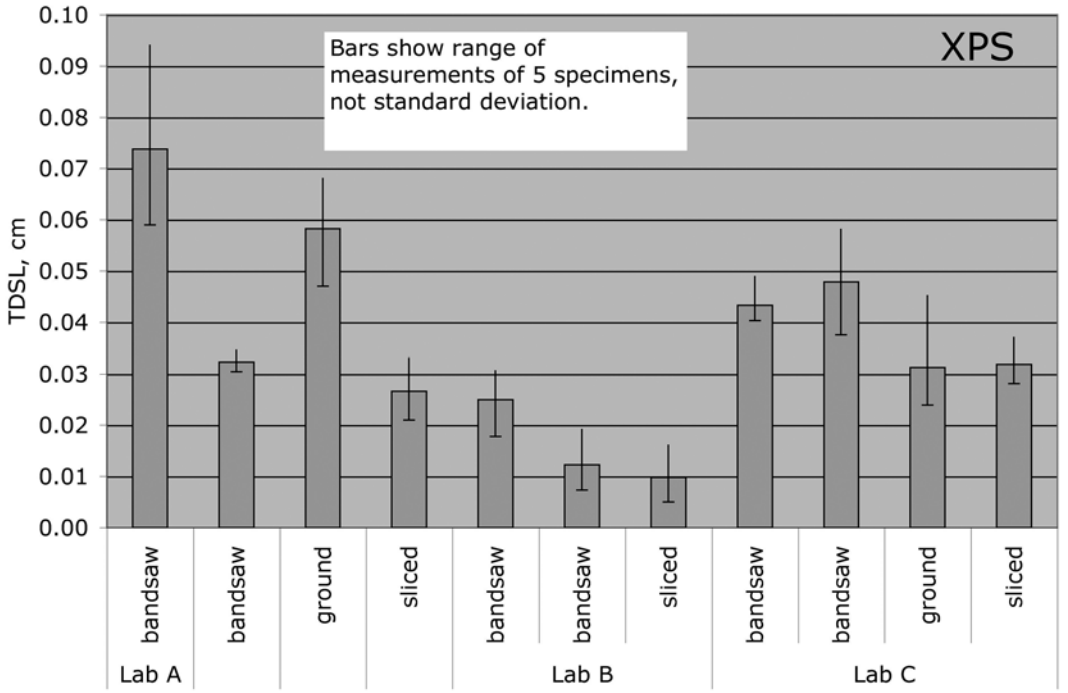




**FIG. X1.3 TDSL Values for PIR and XPS**

## X2. HISTORY OF THE STANDARD

X2.1 As shown by the references cited in this test method, foam insulation aging research goes back to the 1970s, if not before. Cooperative research supported by the Polyisocyanurate Insulation Manufacturing Association and the Department of Energy during the late 1980s and the 1990s advanced both the specimen preparation techniques and the data analysis methodology. In parallel, there were a number of user groups asking for long-term thermal performance values, and there was some controversy regarding the validity of thermal resistance values measured on relatively new foam. In this environment, an ASTM task group was formed in 1990 to develop a test methodology. The original version of this C 1303 test method was published in 1995, after a lengthy effort to reach consensus on the methodology and the usefulness of the results. A revision was approved in 2000 to make minor corrections and adjustments.

X2.2 Spurred by the appearance and use of the more prescriptive Canadian standard CAN/ULC S770, and by the reluctance of the Federal Trade Commission to require the use of the more flexible C 1303 – 00, efforts began in 2003 to produce a prescriptive version of C 1303. During the development of the prescriptive standard, it was discovered that some practitioners were using stacks of core slices, some were using stacks of surface slices, and some were using a mixed stack of slices that represented a cross-section of the product. Therefore, the use of core and/or surface slices in the accelerated aging stack of thin slice specimens came under investigation. A ruggedness test was planned to determine which stack composition produced results that were most representative of the aged full thickness product. Pending the completion (expected in 2011) of that ruggedness test, the reporting requirements include the results for three alternative stack compositions.

## X3. THEORY OF FOAM AGING

X3.1 *The Aging Process*:

X3.1.1 The overall thermal resistance of the foam is affected by the gas mixture within the foam. The thermal resistance of most blowing agents is greater than that of air, so the thermal resistance of the foam insulation is greater when there is more blowing agent and less air.

X3.1.2 During the service life of a rigid closed-cell plastic foam, air components diffuse into the cells, and the blowing agent diffuses out of the cells or partially dissolves into the polymer matrix. Each process occurs at a rate that depends on the type of polymer, the foam structure, the temperature, the gas type, and its pressure (**4**). In general, the inward diffusion of air components is much faster than the outward diffusion of the captive blowing agent. Because of this phenomenon, the aging rate is not constant and proceeds at a faster rate during the earliest portion of the service life. Once the diffusion of air components nears completion, the thermal resistance of the material changes more slowly. The thermal resistance continues to change, however, due to continuing diffusion of the blowing agent from the cells. Eventually, the gas concentrations within the foam will be equal to the gas concentrations in the environment. At that point, the thermal resistance of the material no longer changes with time.

X3.1.3 A number of researchers studying aging have depicted thermal resistance for rigid closed-cell plastic foams as a function of time and thickness using the following functional form (**7**, **9-10**, **16-19**).

$$\text{thermal resistance} = F\left(e^{\left\{\frac{time}{(thickness)^2}\right\}}\right) \quad \text{(X3.1)}$$

X3.1.3.1 This formulation is based upon Fick's Law for one-dimensional diffusion. An example of a foam-aging curve was shown in Fig. 4.

X3.2 *Use of Thin Specimens*:

X3.2.1 The heat flux passing through a rigid closed-cell plastic foam can be approximately expressed as the sum of the heat flux due to radiation, due to the gas mixture, and due to the solid polymer (**20**). It is assumed that the sum of the heat flux due to radiation and the heat flux due to the solid polymer do not change significantly with time even though the gas content within the cells changes.

X3.2.2 The aging process can therefore be considered in terms of the change in molecular concentration (partial pressure) of the cell gas components as a function of time. The governing parameters controlling the changes in the partial pressures of the gas components are their effective diffusion coefficients, the thickness, and time (**1**). To accelerate the aging process, either the diffusion coefficients can be increased or the thickness reduced.

X3.2.3 Diffusion coefficients can be increased by raising the temperature, but this method is not recommended for the following reasons (**21**). A specific increase in temperature does not equally change the diffusion coefficients of all the gases involved in the aging process. Another possible limitation is that elevating the temperature could damage the cellular structure of the foam (**22**).

X3.2.4 Reducing specimen thickness can increase the aging rates and does not expose the material to potentially damaging or unrealistic conditioning at elevated temperatures. For a material satisfying the requirements of constant diffusion coefficients and initial partial pressures, the same value of the ratio time/length$^2$ will yield the same partial pressure, and therefore the same heat flux due to the gas mixture. Therefore, the thermal resistance of a specimen of $thickness_1$ at $time_1$ can be determined after conditioning a specimen of $thickness_2$ over a $time_2$. $Time_2$ can be calculated by:

$$time_2 = time_1\left(\frac{thickness_2}{thickness_1}\right)^2 \quad \text{(X3.2)}$$

X3.2.5 The thermal conductivity of the thin slices is measured in stacks in order to avoid errors (often referred to as the "thickness effect") introduced by radiation heat transfer phenomena at small specimen thicknesses (**13**).

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