Designation: C 1303 – 00

Standard Test Method for Estimating the Long-Term Change in the Thermal Resistance of Unfaced Rigid Closed-Cell Plastic Foams by Slicing and Scaling Under Controlled Laboratory Conditions[1,2]

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.

1. Scope

1.1 This test method covers a procedure for estimating the long-term change in thermal resistance of unfaced rigid closed-cell plastic foams by reducing the material thickness to accelerate aging under controlled laboratory conditions (**1-3**).[3]

1.2 This test method is limited to unfaced, homogeneous materials (see 3.2.4). It may be applied to a wide range of rigid closed cell plastic foam types, including but not limited to, polystyrenes, polyurethanes, polyisocyanurates, and phenolics produced in board form, foamed-in-place, or spray-applied applications. No specific procedures are detailed in this test method to address the effects of permeable or impermeable facings or skins, manufactured thickness, orientation, manufacturing process, density, quality, the influence of structures or containments, or the end-use environmental conditions on internal cell gas composition. The user of this test method shall consider if these parameters limit the use of this test method for a specific application.

1.3 This test method utilizes standard test procedures for measuring thermal resistance. Periodic measurements are performed on specimens to observe the effects of aging. Specimens of reduced thickness are used to shorten the time required for these observations. The results of these measurements are coupled with a scaling factor to estimate the thermal resistance of the material under evaluation for other thicknesses as a function of time.

1.4 This test method specifies methods of specimen preparation, procedures for determining the specimen effective diffusion thickness (see 3.2.3), and precautions for determining the thermal resistance of thin specimens.

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 test method should be used to measure and describe the relative change in thermal resistance of rigid closed-cell plastic foams under controlled laboratory conditions. It should not be used to describe or appraise the performance of these materials or products under actual use conditions. With continuing development, results from this test method may be used as an element in an assessment which takes into account all of the factors that are pertinent to an estimation of the thermal performance of these materials. Critical elements of this assessment are presently not available. See 1.2.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 168 Terminology Relating to Thermal Insulating Materials[4]

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus[4]

C 236 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box[4]

C 518 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus[4]

C 578 Specification for Rigid, Cellular Polystyrene Thermal Insulation[4]

C 591 Specification for Unfaced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation[4]

C 976 Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box[4]

C 1029 Specification for Spray-Applied Rigid Cellular

[1] This test method is under the jurisdiction of ASTM Committee C-16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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[2] ISO/TC163/SC2/WG7 is also developing a standard to address the aging of unfaced rigid closed-cell plastic foams. This document is entitled," Determination of the Long-Term Thermal Resistance of Closed-Cell Cellular Plastic Thermal Insulation."

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

[4] *Annual Book of ASTM Standards*, Vol 04.06.

Polyurethane Thermal Insulation[4]
C 1045 Practice for Calculating Thermal Transmission Properties from Steady-State Heat Flux Measurements[4]
C 1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus[4]
C 1126 Specification for Faced or Unfaced Rigid Cellular Phenolic Thermal Insulation[4]
C 1289 Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board[4]
D 2856 Test Method for Open-Cell Content of Rigid Cellular Plastics by the Air Pycnometer[5]
E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[6]

3. Terminology

3.1 *Definitions*—For definitions of terms and symbols used in this test method, refer to Terminology C 168C 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 *effective diffusion coefficient*, *n*—a material property that relates the rate of gas transport to the gas partial pressure gradients across the material of a given thickness at a given temperature. The term "effective" is used to describe mass transport by several mechanisms.

3.2.3 *effective diffusion thickness*, *n*—the geometric thickness minus two times the thickness of damaged surface layer (TDSL). See *thickness of damaged surface layer (TDSL)*.

3.2.4 *homogeneous material*, *n*—a material with a variation of less than 10 % in the slope of the primary stage thermal resistivity versus τ^* results, for specimens within a specific sample. See 7.1.1 and 7.1.2. As more data becomes available, this description will be refined.

3.2.5 *normalized thermal resistance*—thermal resistance divided by the intial thermal resistance.

3.2.6 *primary stage*—that portion of the aging process where changes in thermophysical properties are primarily influenced by the diffusion of air components into the rigid closed-cell plastic foam.

3.2.7 *scaled time*—time divided by the square of the specimen thickness.

3.2.8 *scaling factor*, *n*—the square of the material thickness divided by the square of the test specimen thickness (see 5.2.4). This ratio represents the acceleration rate that is being applied to the aging process of a rigid closed-cell plastic foam because of thickness differences. See Ref **(1)** for a detailed derivation of scaling factor.

3.2.9 *secondary stage*, *n*—that portion of the aging process where changes in thermophysical properties are primarily influenced by the diffusion of blowing agent(s) from the rigid closed–cell plastic foam.

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

3.2.11 *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.

3.2.12 *time-averaged thermal resistance*, *n*—the thermal resistance of a material of given thickness averaged over a specified time period.

3.2.13 *transition point* , *n*—the estimated age of a rigid closed-cell plastic foam when the aging process switches from the primary to secondary stage (see Fig. 1).

[5] *Annual Book of ASTM Standards*, Vol 08.02.
[6] *Annual Book of ASTM Standards*, Vol 14.02.

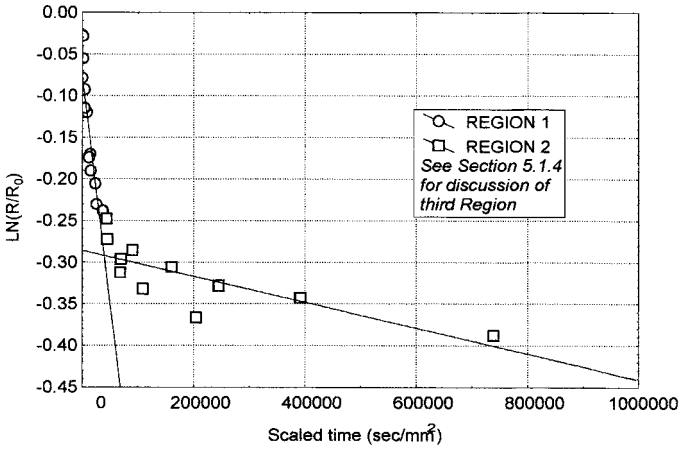

FIG. 1 The Log of the Normalized Thermal Resistance (see 9.2.2.2) v.s. the Scaled Time for Three Thickness of a Rigid Closed-Cell Plastic Foam. Data is from Ref (17).

3.3 *Symbols:*

A = surface area of Test Method D 2856D 2856 specimen, m^2
D = diffusion coefficient, m^2/s
R = thermal resistance, $(m^2 \cdot K)/W$
R^* = normalized thermal resistance=R_t/R_0
R_0 = initial thermal resistance
R_a = estimated time-averaged thermal resistance, $(m^2 \cdot K)/W$
R_t = thermal resistance on t^{th} day, $(m^2 \cdot K)/W$
t = time, days
t_m = service life, days
$TDSL$ = average thickness of damaged surface layer, m
τ^* = scaled time, sec/mm^2
V_b = bulk geometric specimen volume of Test Method D 2856D 2856 specimen, m^3
V_c = closed–cell volume of the specimen of Test Method D 2856D 2856 specimen, m^3
ΔX_{geo} = geometric thickness of thermal resistance specimen, m
ΔX_{eff} = effective diffusion thickness of thermal resistance specimen, m
ΔX = specimen thickness,m
q = heat flux, W/m^2
q_g = heat flux due to the cell gas mixture,W/m^2
q_r = heat flux due to thermal radiation,W/m^2
q_s = heat flux due to the solid polymer,W/m^2
σ = standard deviation

4. Significance and Use

4.1 Rigid closed–cell plastic foam insulations are produced by foaming various polymers. As manufactured, the cells of the foam usually contain their highest percentage of blowing agent and the lowest percentage of air components. As time passes, the relative concentrations of these gases change due primarily to diffusion, resulting in a reduction of the thermal resistance of the foam due to an increase in the thermal conductivity of the resultant cell gas mixture.

NOTE 1—The discussions in Sections 4 and 5 assume that the blowing agent(s) is a gas whose apparent thermal conductivity and effective diffusion coefficient are both lower than those of the air components. If the blowing agent diffuses faster than the air components, definitions of the stages of aging would require modification and any discussions regarding diffusion rates would need to be changed. However, the test procedures are applicable in either case.

4.2 The change in thermal resistance due to the phenomena described in 4.1 usually occurs over an extended period of time at room temperature. Information regarding changes in the thermal resistance of these materials as a function of time is required so that decisions regarding formulations, production, and comparisons with other materials can be made. Ideally, aging curves and estimated time-averaged thermal resistance data for the expected service life should be available after as short a period as possible.

4.3 Specifications C 578, C 591, C 1029, C 1126C 578 and C 1289 C 591C 1029C 1126C 1289, on rigid closed-cell plastic foams, indicate that this decrease in thermal resistance occurs over an extended period of time at room temperature. However, these standards currently require that freshly manufactured foams be measured for 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. These standards do not currently specify long-term or time-averaged thermal resistance criteria.

4.4 The procedure described in this test method requires that the material characteristics of the thin specimens approximate those of the material under investigation. In particular, the specimens of reduced thickness must have the same effective diffusion coefficient and initial cell gas content as those of the full thickness material, and that one-dimensional diffusion dominates, limiting the application of this test method to unfaced homogeneous materials as defined in 3.2.4.

4.4.1 When the thin specimen does not effectively represent the average behavior of the material, the results obtained by this test method may have a limited value.

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

4.5.1 *Specimen Preparation*—Techniques for the preparation of thin flat specimens and the measurement of specimen thickness are discussed, along with their limitations.

4.5.2 *Measurement of the Thermal Resistance*—In principle, any of the referenced test methods for the determination of thermal resistance are suitable. These include Test Methods C 177, C 236, C 518, C 976, and C 1114C 177C 236C 518C 976C 1114, used in conjunction with Practice C 1045C 1045. Of these test methods, the heat flow meter apparatus, Test Method C 518C 518, is preferred.

4.5.3 *Interpretation of Data*—Procedures are detailed for utilizing periodic short-term thermal resistance data to estimate long-term changes in the thermal resistance of the material. Examples are provided in Annex A1.

4.6 The procedure outlined in this test method can be used to produce a characteristic aging curve (relationship between the thermophysical properties with time). This relationship has been used by researchers to calculate effective diffusion coefficients (**2**, **3**).

5. Background and Theory

5.1 *The Aging Process*:

5.1.1 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 (**1**).

5.1.2 In general, as the inward diffusion of air components is much faster than the outward diffusion of the captive blowing agent, the aging process comprises two stages. During the primary stage, the cell gas composition changes at a significant rate because of the rapid diffusion of air components into the cell and the outward diffusion of all diffuse blowing agents, if present; so too does the thermal resistance of the material.

5.1.2.1 If carbon dioxide or other rapidly diffusing gases are used as blowing agents or are generated during foam manufacture, their outward diffusion rate will usually exceed the entry rate of air components during the primary stage.

5.1.3 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. This stage is defined as the secondary stage.

5.1.4 Upon completion of the secondary stage of aging, the thermal resistance of the material no longer changes with time.

5.1.5 A number of researchers studying aging have depicted their thermal performance data (thermal conductivity, thermal resistance, thermal resistivity) for rigid closed-cell plastic foams as a function of time using the following functional forms (**4-11**).

$$R^* = F\{\log (D \times t/(\Delta X)^2)\} \text{ or} \quad (1)$$

$$\log (R^*) = F\{D \times t/(\Delta X)^2\}$$

This formulation is the basis for the scaled time variable, τ^*. This variable does not include the diffusion coefficient, D, but because the diffusion coefficient for each gas is a constant at constant temperature, the functional form of the relationship is unaffected. Figs. 2 and 3, and Fig. 1 are examples of aging curves for a rigid closed-cell plastic foam (**17**). The inflection between the two stages of the aging process is defined as the transition point. A second transition may occur, if all of the blowing agent is replaced within the cells by air. After all the cells are filled with air, the thermal performance should remain constant.

5.2 *Use of Thin Specimens*:

5.2.1 The heat flux, q, passing through a rigid closed-cell plastic foam can be approximately expressed as the sum of the heat flux due to radiation (q_r), due to the gas mixture (q_g), and due to the solid polymer (q_s) (**12**).

$$q = q_r + q_g + q_s \quad (2)$$

5.2.2 It is assumed that the sum of the values of q_r and q_s does not change significantly with time even though the gas content within the cells changes. Then, Eq 2 implies that the aging process can be studied by exclusively investigating the change in the heat flux due to the gas, and q_g can be determined

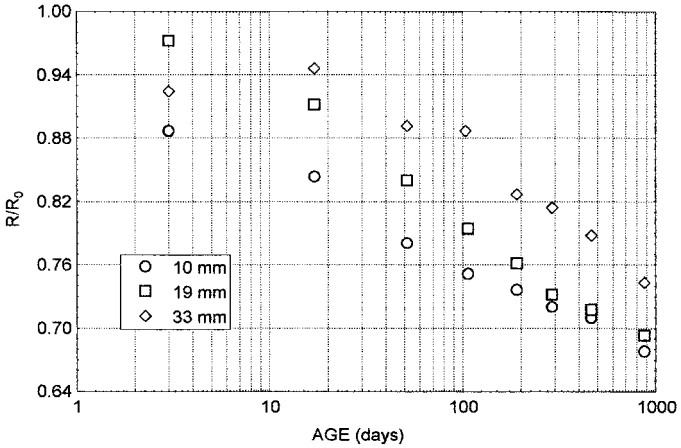

FIG. 2 The Normalized Thermal Resistance (see 9.2.2.2) of Two Thicknesses of a Rigid Closed Cell Plastic Foam as a Function of Real Time. Data is from Ref (12).

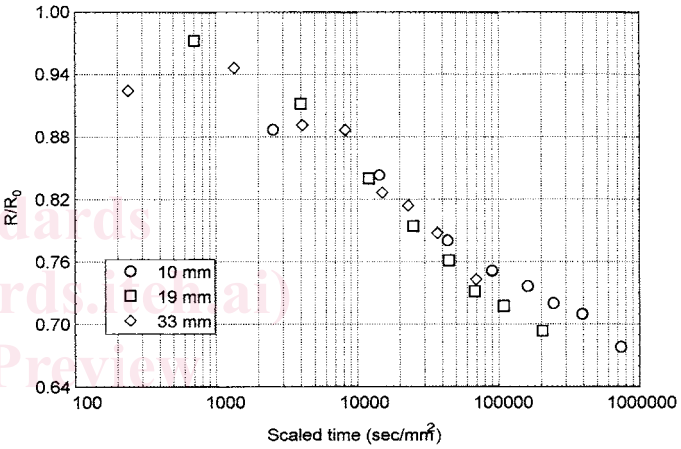

FIG. 3 The Normalized Thermal Resistance (see 9.2.2.2) of Two Thicknesses of a Rigid Closed Cell Plastic Foam After Application of the Scaling Factor. Data is from Ref (12).

by studying 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 D, the thickness ΔX, and time t (**1**). In order to accelerate the aging process, either the diffusion coefficients can be increased or the thickness reduced.

5.2.3 Diffusion coefficients can be increased by raising the temperature, but this method is not recommended for the following reasons (**13**). The amount of acceleration achievable by this test method is limited because the diffusion coefficients are typically not a strong function of temperature. A second limitation is that 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 (**14**).

5.2.4 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 D and initial p,