Title: Evaluation and Selection of Candidate Thermal Insulation Materials for NIST SRM 1450d, Fibrous-Glass Board

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ABSTRACT

The evaluation of candidate thermal insulation materials for National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) 1450d Fibrous-Glass Board is presented. The paper focuses on a preliminary study to assess the technical qualifications of the candidate molded fibrous-glass materials for an SRM material. The assessment considers the homogenitey of the material with regards to material properties that have a direct impact on thermal conductivity, namely, bulk density and thickness. In this study, a sample of ten specimens of each candidate material was obtained from two manufacturers. The key parameters of interest in assessing the material uniformity were the variability of specimen density and within- and between-specimen thickness. The capability of the manufacturer to provide specimens with material properties consistently within self defined tolerance limits was also key in the selection of the SRM candidate material. The paper presents thermal conductivity measurements at 297 K determined by a heat-flow-meter apparatus (ASTM Test Method C 518). Results are compared with similar measurements on previous lots of the SRM 1450 Series. The paper outlines the approach for development of SRM 1450d including, the SRM philosophy, historical background, and assessment approach.

INTRODUCTION

The development of Standard Reference Materials (SRMs) in the United States has traditionally been one of the primary functions of the National Institute of Standards and Technology (NIST). SRMs are physical artifacts, mixtures, or compounds that are manufactured according to strict specifications, some of whose chemical or physical properties NIST scientists quantify and certify, employing measurement methods whose uncertainty is characterized fully. Thermal insulation SRMs provide certified values of thermal conductivity (λ) and thermal resistance (R) for a range of parameters, such as density and temperature. SRMs are intended primarily as a method for providing measurement assurance to user communities by establishing traceability to a stated reference; for example, assistance in the calibration of heat-flow-meter apparatus and operation of guarded-hot-plate apparatus (ASTM Test Methods C 518 and C 177, respectively). The systematic use of common SRMs, including proper tracking with control charts, provides a means for accurate interlaboratory comparison of thermal conductivity data.

BACKGROUND

NIST has provided high-density fibrous glass insulation board as a reference material since 1958. Thermal resistance measurements of the first four lots (designated by the year of acquisition as 1958, 1959, 1961, and 1970) have been described [1]. In 1977, ASTM Committee C16 on Thermal Insulation published a position paper [2] advocating the development of an SRM approach for proficiency in a proposed thermal accreditation program. In response, NIST established SRMs 1450 and 1450a using materials from the above internal lots, which were depleted rapidly due to limited stockpiles. Two additional lots (1980 and 1981) were acquired and characterized as SRM 1450b by NIST laboratory facilities in Gaithersburg, Maryland and Boulder, Colorado [3]. In 1997, SRM 1450c [4] was established after the depletion of 1450b. Table I summarizes the chronology and physical properties of the SRM 1450 Series.

TABLE I. SRM 1450 SERIES, FIBROUS GLASS BOARD

SRM	Issue Date	Nominal Thickness (mm)	Bulk Density ($kg·m^{-3}$)	Temperature Range (K)
1450	26 May 1978	25.4	100 to 180	255 to 330
1450a	12 Feb 1979	25.4	60 to 140	255 to 330
1450b (I)*	21 May 1982	25.4	110 to 150	260 to 330
1450b (II)*	20 May 1985	25.4	110 to 150	100 to 330
1450c	5 March 1997	25.4	150 to 165	280 to 340

*The certification of SRM 1450b (I) was initially performed at NIST Gaithersburg and the certification of SRM 1450b (II) was subsequently performed at both NIST Gaithersburg and NIST Boulder using alternative methods to achieve a broader temperature range [3].

In the planning stage for SRM 1450d, NIST collaborated directly with industry and with members of ASTM International Committee C16 on Thermal Insulation to define important parameters for the SRM. Industry input confirmed the need for renewal of SRM 1450d and identified key customer specifications of 25.4 mm for specimen thickness (consistent with previous SRMs in Table I) and a nominal specimen bulk density of 128 $kg·m^{-3}$. In this investigation, two potential candidate materials, identified as CM1 and CM2, were obtained from two commercial manufacturers of molded fibrous-glass board. A sample lot of 10 boards, nominally 610 mm square, 25.4 mm thick and 128 $kg·m^{-3}$, was obtained from each manufacturer. As requested by NIST, each sample lot was selected by the manufacturer from a single production run. The selection of the candidate material was based primarily on the uniformity of specimen thickness, the demonstration of the manufacturers' capability to provide materials within tolerance, and, to a lesser extent, the range of bulk density among the boards within a lot.

MATERIAL PROPERTIES

Thickness (*L*)

The specimen thickness (*L*) for each board was determined using a height gage having a resolution of 0.01 mm. Measurements at nine equal-area locations were obtained and averaged. This procedure was repeated in its entirety to form a replicate measurement value for each specimen. Figure 1 plots the average thickness in rank order for the 20 boards; replicates are depicted by open symbols. Error bars for each data point are equal to the standard deviation of the 9 thickness observations. The target thickness of 25.4 mm and the tolerance interval of ± 0.8 mm defined by the manufacturers are shown as dashed lines. It should be noted that both manufacturers provided identical target values and tolerance intervals.

Figure 1 shows that, although the overall average thickness value for CM2 (25.6 mm) is closer to the target of 25.4 mm than that of CM1 (24.99 mm), the thickness variability within each board for CM1 consistently is less. The standard deviations for CM2 boards 2 and 6 are particularly large (Figure 1). The “pooled” standard deviations for the 10 boards are 0.19 mm and 0.30 mm for CM1 and CM2, respectively.

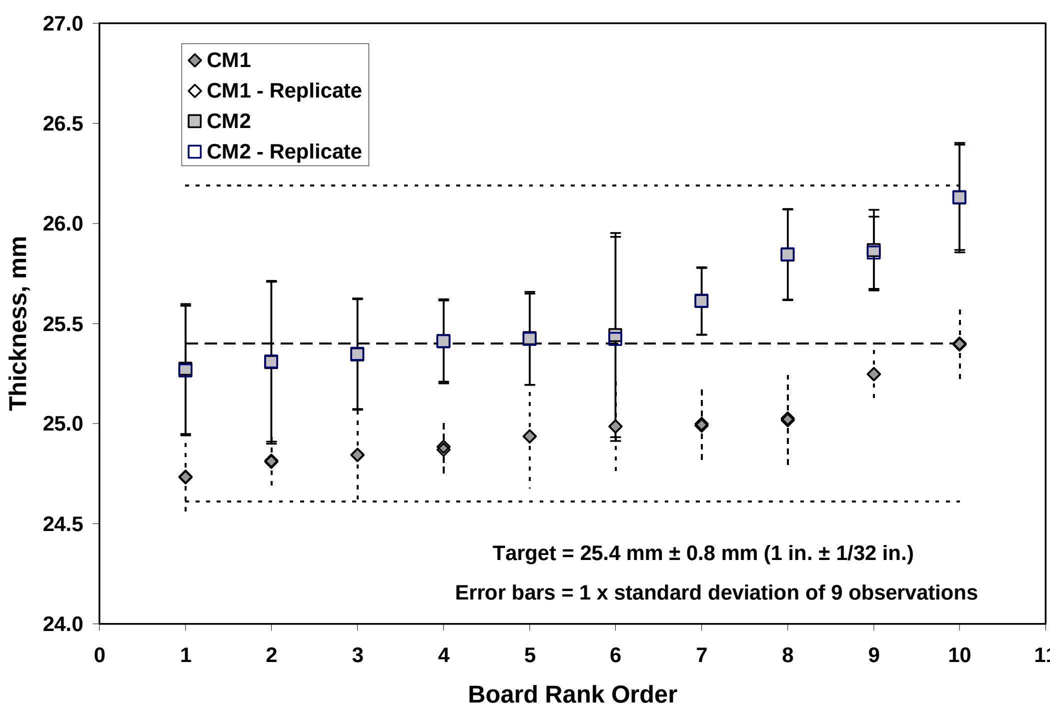

Figure 1. Average specimen thickness (*L*) as a function of board (rank ordered)

Bulk Density (ρ)

The specimen bulk density (ρ) was determined gravimetrically from mass (*m*) and dimensional measurements ($\overline{L}_1$, $\overline{L}_2$, and $\overline{L}_3$)of each specimen as shown mathematically in Equation 1.

$$\rho = \frac{m}{\overline{L}_1 \overline{L}_2 \overline{L}_3} \tag{1}$$

where $\overline{L}_1$, $\overline{L}_2$, and $\overline{L}_3$ are the average length, width, and thickness, respectively, of the specimen board.

Two replicate density measurements were made for each specimen. Figure 2 plots the specimen bulk density in rank order for the 20 boards; replicates are depicted by open symbols. The target bulk density of 128 kg·m^{-3} and the tolerance interval of ± 10 % defined by the manufacturers are shown as dashed lines. It should be noted that both manufactures provided identical target values and tolerance intervals.

Figure 2 shows that the bulk densities of 8 of the 10 boards for CM2 were less than the minimum tolerance bound of 115 kg·m^{-3}. All of the CM1 boards were within the manufacturer tolerance interval of 115 kg·m^{-3} to 141 kg·m^{-3}. The average bulk density and range for CM1 were 136.1 kg·m^{-3} and 7.3 kg·m^{-3}, respectively. The average bulk density and range for CM2 were 113.0 kg·m^{-3} and 10.2 kg·m^{-3}, respectively.

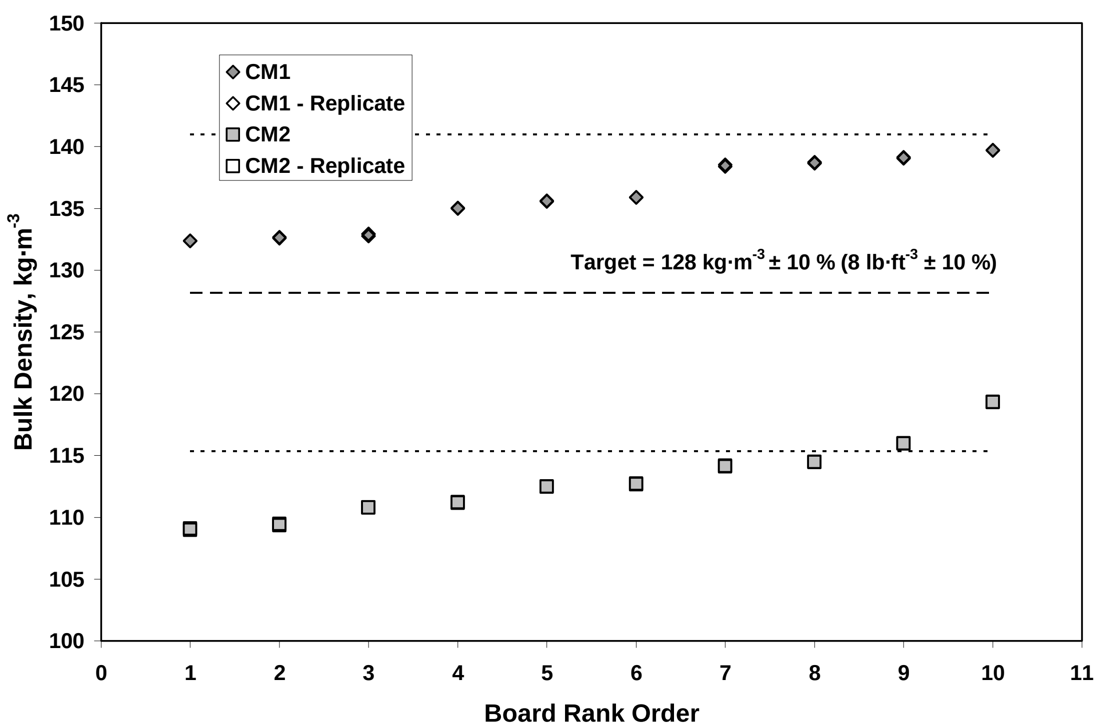

Figure 2. Specimen bulk density (ρ) as function of board (rank ordered)

THERMAL CONDUCTIVITY

To check the thermal performance of CM1, the specimen thermal conductivities of the boards were determined at a nominal mean temperature of 24 °C using a commercial heat-flow-meter apparatus conforming to ASTM Test Method C 518. The apparatus was calibrated using a similar specimen of fibrous-glass board having a thickness of 25.4 mm. Replicate measurements were made on each specimen of CM1. Results of the measurements are compared to previous SRM 1450 lots presented in Figure 3.

DISCUSSION

Thermal conductivity data at 23.89 °C ± 0.2 °C for the internal lots 1958, 1959, 1961, and 1970 have been compiled from NIST Standard Reference Database 81 [5] and are plotted in Figure 3. These internal lots, as discussed above, were initially offered to the public as transfer specimens and were, later, batch certified as SRMs 1450 and 1450a. The statistical analyses for these SRM data are discussed further in Reference [1]. The thermal conductivity data for CM1, shown as a solid diamond symbol or open for replicate, are in very good agreement with the data from the previous lots. At a bulk density of 136 kg·m^{-3}, the nominal thermal conductivity is 0.0332 W·m^{-1}·K^{-1}.

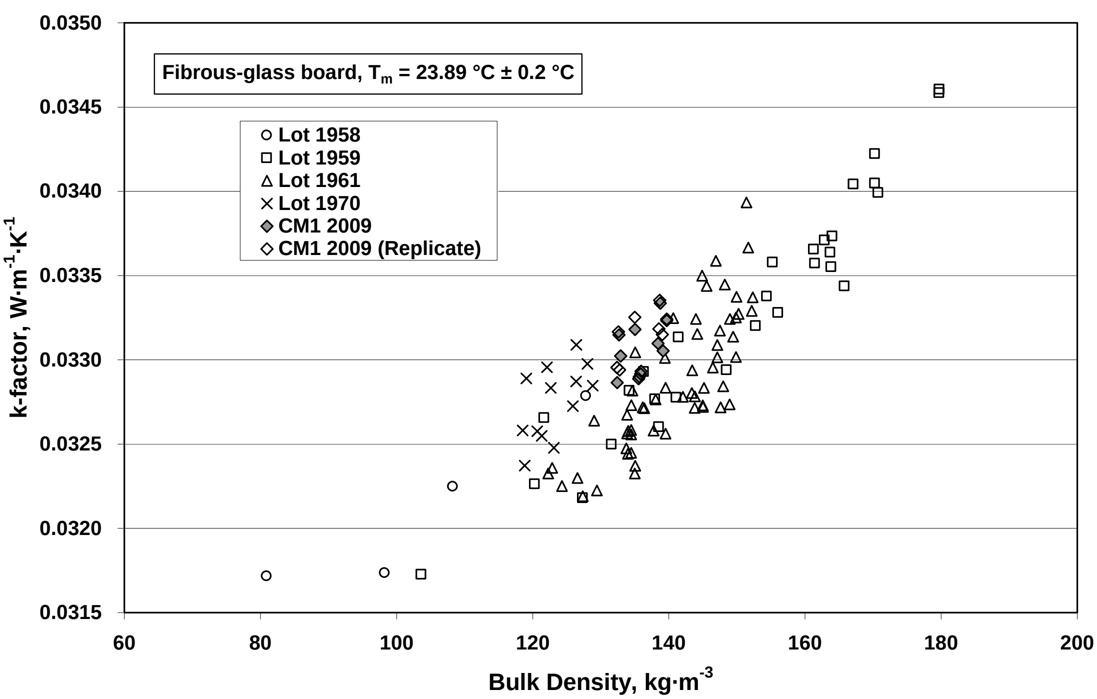

Figure 3. Thermal conductivity of glass fiberboard at 24 °C for Lots 1958, 1959, 1961, 1970 and candidate material 1 (CM1)

CONCLUSIONS

In addition to the larger variability in specimen thickness of CM2 displayed in Figure 1, bulk densities of a majority of the CM2 specimens fell below the manufacturer-specified tolerance limits. Figure 4 displays the overall average thickness and bulk density measurements for each specimen of each candidate material. The manufacturer target values and tolerance limits of each to these properties are displayed by the dashed lines.

From Figure 4, it can be observed that the manufacturing process of CM1 provides materials that consistently meet tolerance specification. For this reason, CM1 has been selected as the material of choice in the production of NIST Standard Reference Material 1450d. The thermal conductivity data for CM1 are in very good agreement with the data from previous lots of the SRM 1450 Series (Figure 3).

ACKNOWLEDGEMENTS

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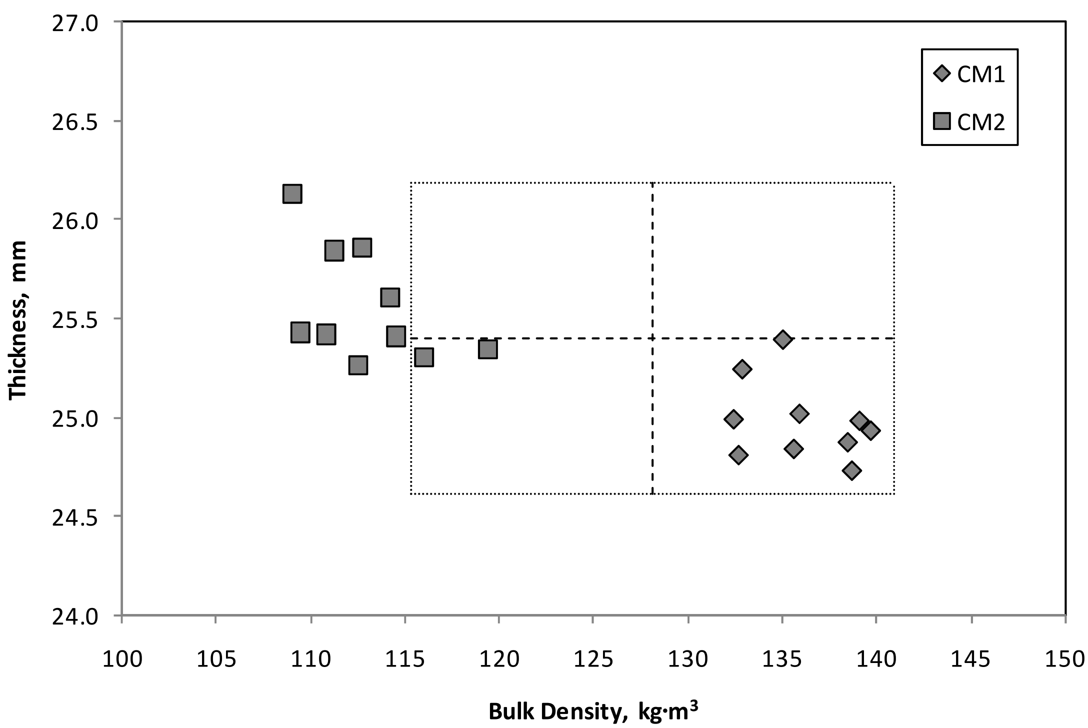

Figure 4. Overall average specimen thickness versus overall average bulk density for each of the 10 specimens from each candidate material. The target values and tolerance limits are displayed by the dashed lines.

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