



# Standard Test Method for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique)<sup>1</sup>

This standard is issued under the fixed designation C1113/C1113M; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers the determination of thermal conductivity of non-carbonaceous, dielectric refractories.

1.2 Applicable refractories include refractory brick, refractory castables, plastic refractories, ramming mixes, powdered materials, granular materials, and refractory fibers.

1.3 Thermal conductivity  $k$ -values can be determined from room temperature to 1500°C [2732°F], or the maximum service limit of the refractory, or to the temperature at which the refractory is no longer dielectric.

1.4 This test method is applicable to refractories with  $k$ -values less than 15 W/m·K [100 Btu·in./h·ft<sup>2</sup>·°F].

1.5 In general it is difficult to make accurate measurements of anisotropic materials, particularly those containing fibers, and the use of this test method for such materials should be agreed between the parties concerned.

1.6 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.7 *This standard does not purport to address 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:<sup>2</sup>

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee C08 on Refractories and is the direct responsibility of Subcommittee C08.02 on Thermal Properties.

Current edition approved Sept. 1, 2013. Published September 2013. Originally approved in 1990. Last previous edition approved in 2009 as C1113/C1113M–09. DOI: 10.1520/C1113\_C1113M-09R13.

<sup>2</sup> 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.

C134 Test Methods for Size, Dimensional Measurements, and Bulk Density of Refractory Brick and Insulating Firebrick

C201 Test Method for Thermal Conductivity of Refractories  
C865 Practice for Firing Refractory Concrete Specimens  
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

### 2.2 ISO Standard:

DIS\*8894-2 Refractory Materials - Determination of Thermal Conductivity up to 1250°C of Dense and Insulating Refractory Products According to the Hot Wire Parallel Method<sup>3</sup>

## 3. Terminology

### 3.1 Symbols:

3.1.1  $R_T$ —hot wire resistance at any temperature, ohms.

3.1.2  $R_0$ —hot wire resistance at 0°C [32°F] (from an ice bath), ohms.

3.1.3  $L$ —hot wire length, cm.

3.1.4  $T$ —sample test temperature, °C.

3.1.5  $V$ —average voltage drop across hot wire, volts.

3.1.6  $V_s$ —average voltage drop across standard resistor, volts.

3.1.7  $R_s$ —average resistance of standard resistor, ohms.

3.1.8  $I$ —average current through hot wire ( $V_s/R_s$ ), amperes.

3.1.9  $Q$ —average power input to hot wire ( $I \cdot V \cdot 100/L$ ) during test, watts/m.

3.1.10  $t$ —time, min.

3.1.11  $B$ —slope of linear region in  $R_T$  vs.  $\ln(t)$  plot.

3.1.12  $k$ —thermal conductivity, W/m·K.

3.1.13  $a$ ,  $b$ ,  $c$ —coefficients of a second degree polynomial equation relating hot wire resistance and temperature.

3.1.14  $V$ ,  $I$ , and  $Q$  are preferably measured in the linear region of the  $R_T$  versus  $\ln(t)$  plot for maximum data accuracy.

<sup>3</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

#### 4. Summary of Test Method

4.1 A constant electrical current is applied to a pure platinum wire placed between two brick. The rate at which the wire heats is dependent upon how rapidly heat flows from the wire into the constant temperature mass of the refractory brick. The rate of temperature increase of the platinum wire is accurately determined by measuring its increase in resistance in the same way a platinum resistance thermometer is used. A Fourier equation is used to calculate the k-value based on the rate of temperature increase of the wire and power input.<sup>4</sup>

#### 5. Significance and Use

5.1 The k-values determined at one or more temperatures can be used for ranking products in relative order of their thermal conductivities.

5.2 Estimates of heat flow, interface temperatures, and cold face temperatures of single, and multi-component linings can be calculated using k-values obtained over a wide temperature range.

5.3 The k-values determined are “at temperature” measurements rather than “mean temperature” measurements. Thus, a wide range of temperatures can be measured, and the results are not averaged over the large thermal gradient inherent in water-cooled calorimeters.

5.4 The k-values measured are the combination of the k-values for the width and thickness of the sample, as the heat flow from the hot wire is in both of those directions. The water-cooled calorimeter measures k-value in one direction, through the sample thickness.

5.5 The test method used should be specified when reporting k-values, as the results obtained may vary with the type of test method that is used. Data obtained by the hot wire method are typically 10 to 30 % higher than data obtained by the water calorimeter method given in Test Method C201.

#### 6. Apparatus

6.1 A block diagram of a suggested test apparatus is shown in Fig. 1. Details of the equipment are as follows:

6.1.1 *Furnace*, with a heating chamber capable of supporting two 228-mm [9-in.] straight brick. The furnace temperature may be controlled with a set point controller adjusted manually between test temperatures, with a programmable controller, or with the computer. If a programmable controller is used, and the hot wire power is applied by computer, the furnace temperature program must be synchronized with the computer program used to collect the test data. The furnace temperature should be accurate to  $\pm 5^\circ\text{C}$  [ $9^\circ\text{F}$ ] and controlled to within a  $\pm 1^\circ\text{C}$  [ $1.8^\circ\text{F}$ ] precision such that the temperature variation with time is minimized. Temperature stability measurements are not required by this test method because small temperature variations with time are difficult to measure and dependent on thermocouple placement (in air, a protection tube, or in the sample). However, if sample temperature measurements are

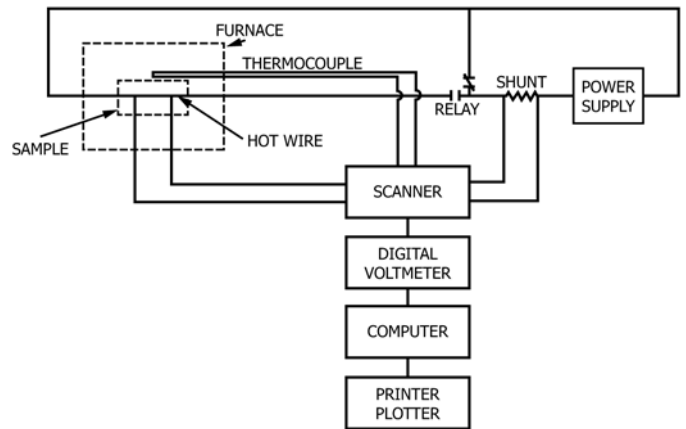


FIG. 1 Diagram of Apparatus

averaged during a 30 minute period after furnace equilibration (prior to a hot wire test), the maximum-minimum difference should preferably be less than  $1^\circ\text{C}$  [ $1.8^\circ\text{F}$ ]. In addition, if a linear regression analysis is done on the average temperature vs. time data, the rate of temperature change should preferably be less than  $0.05^\circ\text{C}$  [ $0.09^\circ\text{F}$ ]/min. Four holes with alumina protection tubes shall be provided in the kiln wall for the platinum voltage and current leads. These holes should be widely spaced to minimize electrical conductivity at elevated temperatures.

6.1.2 *Thermocouple*, to measure sample temperature.

6.1.3 *Programmable Power Supply*, capable of constant current control in the range from 0 to 10 A (0 to 50 V). During a 10-min test period, stability should be  $\pm 0.002$  A. Size the power supply according to the anticipated wire harnesses diameter and type of materials to be tested. A high (5–10 A) ampere supply is suggested for large diameter wire and/or testing of high conductivity materials. However, lower ampere supplies will give better current control for low currents used for low conductivity materials or with a smaller diameter wire harness.

6.1.4 *Shunt*, with a resistance of  $0.1\ \Omega$  rated at 15 A.

6.1.5 *Programmable Scanner*, capable of directing several different voltage inputs to the digital voltmeter. It is also used to activate a relay to turn on and off the test circuit.

6.1.6 *Relay*, with a current rating of 25 A at 24 V.

6.1.7 *Programmable Digital Voltmeter*, with auto ranging, auto calibration, and  $6\ \frac{1}{2}$  digit resolution.

6.1.8 *Computer*, capable of controlling the operation of the power supply, scanner, and digital voltmeter. It must also be able to collect and analyze the test results. Commercially available data acquisition (with an IEEE device and sequential file numbering capability) and analysis (spreadsheet with macro capability) software is acceptable; custom software is not necessary.

6.1.9 *Printer/Plotter*, capable of documenting the raw data and various calculated values. The plotter function is used to plot the resistance versus  $\ln(\text{time})$  relationship. This is used to visually determine if a linear relationship was obtained and the location of the linear region.

6.2 *Reusable Test Harness*, consisting of a straight section at least 30-cm [11.8-in.] long with two perpendicular voltage

<sup>4</sup> Morrow, G. D., “Improved Hot Wire Thermal Conductivity Technique,” *Bull. Amer. Ceram. Soc.*, 58(7), 1979, pp.687–90.