



Designation: E2585 – 09 (Reapproved 2022)

## Standard Practice for Thermal Diffusivity by the Flash Method<sup>1</sup>

This standard is issued under the fixed designation E2585; 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 practice covers practical details associated with the determination of the thermal diffusivity of primarily homogeneous isotropic solid materials. Thermal diffusivity values ranging from  $10^{-7}$  to  $10^{-3}$  m<sup>2</sup>/s are readily measurable by this from about 75 K to 2800 K.

1.2 This practice is adjunct to Test Method [E1461](#).

1.3 This practice is applicable to the measurements performed on materials opaque to the spectrum of the energy pulse, but with special precautions can be used on fully or partially transparent materials.

1.4 This practice is intended to allow a wide variety of apparatus designs. It is not practical in a document of this type to establish details of construction and procedures to cover all contingencies that might offer difficulties to a person without pertinent technical knowledge, or to stop or restrict research and development for improvements in the basic technique. This practice provides guidelines for the construction principles, preferred embodiments and operating parameters for this type of instruments.

1.5 This practice is applicable to the measurements performed on essentially fully dense materials; however, in some cases it has shown to produce acceptable results when used with porous specimens. Since the magnitude of porosity, pore shapes, and parameters of pore distribution influence the behavior of the thermal diffusivity, extreme caution must be exercised when analyzing data. Special caution is advised when other properties, such as thermal conductivity, are derived from thermal diffusivity obtained by this method.

1.6 The flash can be considered an absolute (or primary) method of measurement, since no reference materials are

required. It is advisable to use only reference materials to verify the performance of the instrument used.

1.7 This method is applicable only for homogeneous solid materials, in the strictest sense; however, in some cases it has been shown to produce data found to be useful in certain applications:

1.7.1 *Testing of Composite Materials*—When substantial non-homogeneity and anisotropy is present in a material, the thermal diffusivity data obtained with this method may be substantially in error. Nevertheless, such data, while usually lacking absolute accuracy, may be useful in comparing materials of similar structure. Extreme caution must be exercised when related properties, such as thermal conductivity, are derived, as composite materials, for example, may have heat flow patterns substantially different than uniaxial. In cases where the particle size of the composite phases is small compared to the specimen thickness (on the order of 1 to 25 % of thickness) and where the transient thermal response of the specimen appears homogenous when compared to the model, this method can produce accurate results for composite materials. Anisotropic materials can be measured by various techniques, as long as the directional thermal diffusivities (two dimensional or three dimensional) are mutually orthogonal and the measurement and specimen preparation produce heat flow only along one principle direction. Also, 2D and 3D models and either independent measurements in one or two directions, or simultaneous measurements of temperature response at different locations on the surface of the specimen, can be utilized.

1.7.2 *Testing Liquids*—This method has found an especially useful application in determining thermal diffusivity of molten materials. For this technique, specially constructed specimen enclosures must be used.

1.7.3 *Testing Layered Materials*—This method has also been extended to test certain layered structures made of dissimilar materials, where the thermal properties of one of the layers are considered unknown. In some cases, contact conductance of the interface may also be determined.

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee [E37](#) on Thermal Measurements and is the direct responsibility of Subcommittee [E37.05](#) on Thermo-physical Properties.

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1.8 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.9 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

1.10 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 ASTM Standards:<sup>2</sup>

E228 Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

E1461 Test Method for Thermal Diffusivity by the Flash Method

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 thermal conductivity,  $\lambda$ , of a solid material—the time rate of steady heat flow through unit thickness of an infinite slab of a homogeneous material in a direction perpendicular to the surface, induced by unit temperature difference. The property must be identified with a specific mean temperature, since it varies with temperature.

3.1.2 thermal diffusivity,  $\alpha$ , of a solid material—the property given by the thermal conductivity divided by the product of the density and heat capacity per unit mass.

3.2 Description of Symbols and Units Specific to This Standard:

- 3.2.1  $C_p$ —specific heat capacity, J/(kg·K).
- 3.2.2  $D$ —diameter, metres.
- 3.2.3  $k$ —constant depending on percent rise.
- 3.2.4  $K$ —correction factors.
- 3.2.5  $K_1, K_2$ —constants depending on  $\beta$ .
- 3.2.6  $L$ —specimen thickness, m.
- 3.2.7  $t$ —response time, s.
- 3.2.8  $t_{1/2}$ —half-rise time or time required for the rear face temperature rise to reach one half of its maximum value, s.
- 3.2.9  $t^*$ —dimensionless time ( $t^* = 4\alpha_s t/D_T^2$ ).
- 3.2.10  $T$ —temperature, K.
- 3.2.11  $\alpha$ —thermal diffusivity,  $m^2/s$ .
- 3.2.12  $\lambda$ —thermal conductivity, (W/m·K).
- 3.2.13  $\beta$ —fraction of pulse duration required to reach maximum intensity.

<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.

- 3.2.14  $\rho$ —density,  $kg/m^3$ .
- 3.2.15  $\Delta t_5—T(5t_{1/2}) / T(t_{1/2})$ .
- 3.2.16  $\Delta t_{10}—T(10t_{1/2}) / T(t_{1/2})$ .
- 3.2.17  $\Delta T_{max}$ —temperature difference between baseline and maximum rise, K.
- 3.3 Description of Subscripts Specific to This Standard:
  - 3.3.1  $C$ —Cowan.
  - 3.3.2  $m$ —maximum.
  - 3.3.3  $o$ —ambient.
  - 3.3.4  $R$ —ratio.
  - 3.3.5  $s$ —specimen.
  - 3.3.6  $t$ —time.
  - 3.3.7  $T$ —thermocouple.
  - 3.3.8  $x$ —percent rise.

4. Summary of Practice

4.1 A small, thin disc specimen is subjected to a high-intensity short duration radiant energy pulse (Fig. 1). The energy of the pulse is absorbed on the front surface of the specimen and the resulting rear face temperature rise (thermogram) is recorded. The thermal diffusivity value is calculated from the specimen thickness and the time required for the rear face temperature rise to reach certain percentages of its maximum value. When the thermal diffusivity of the sample is to be determined over a temperature range, the measurement must be repeated at each temperature of interest. This is described in detail in a number of publications (1, 2)<sup>3</sup> and review articles (3, 4, 5). A summary of the theory can be found in Test Method E1461, Appendix 1.

<sup>3</sup> The boldface numbers given in parentheses refer to a list of references at the end of the text.

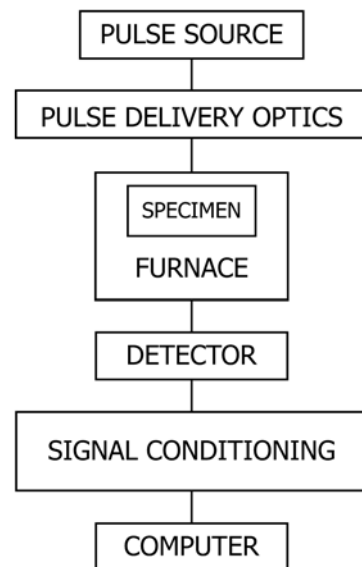


FIG. 1 Block Diagram of a Flash System

## 5. Significance and Use

5.1 Thermal diffusivity is an important property, required for such purposes under transient heat flow conditions, such as design applications, determination of safe operating temperature, process control, and quality assurance.

5.2 The flash method is used to measure values of thermal diffusivity,  $\alpha$ , of a wide range of solid materials. It is particularly advantageous because of simple specimen geometry, small specimen size requirements, rapidity of measurement and ease of handling.

5.3 Under certain strict conditions, specific heat capacity of a homogeneous isotropic opaque solid sample can be determined when the method is used in a quantitative fashion (see Test Method [E1461](#), Appendix 1).

5.4 Thermal diffusivity results, together with related values of specific heat capacity ( $C_p$ ) and density ( $\rho$ ) values, can be used in many cases to derive thermal conductivity ( $\lambda$ ), according to the relationship:

$$\lambda = \alpha C_p \rho \quad (1)$$

## 6. Interferences

6.1 In principle, the thermal diffusivity is obtained from the thickness of the sample and from a characteristic time function describing the propagation of heat from the front surface of the sample to its back surface. The sources of uncertainties in the measurement are associated with the sample itself, the temperature measurements, the performance of the detector and of the data acquisition system, the data analysis and more specifically the finite pulse time effect, the nonuniform heating of the specimen and the heat losses (radiative and conductive). These sources of uncertainty can be considered systematic, and should be carefully considered for each experiment. Errors random in nature (noise, for example) can be best estimated by performing a large number of repeat experiments. The relative standard deviation of the obtained results is a good representation of the random component of the uncertainty associated with the measurement. Guidelines for performing a rigorous evaluation of these factors are given in [\(6\)](#).

## 7. Apparatus

7.1 The essential components of the apparatus are shown in [Fig. 1](#). These are the flash source, specimen holder, environmental enclosure (optional), temperature response detector and recording device.

7.2 The flash source may be a pulse laser, a flash lamp, or other device capable to generate a short duration pulse of substantial energy. The duration of the pulse should be less than 2 % of the time required for the rear face temperature rise to reach one half of its maximum value, to keep the error due to finite pulse width less than 0.5 %, if pulse width correction [\(7, 8, 9\)](#) is not applied.

7.2.1 The pulse hitting the specimen's surface must be spatially uniform in intensity. Most pulse lasers exhibit hot spots and a substantially higher intensity in the center region of the beam than in the periphery. For this reason, systems using unmodified beams directly from a pulse laser should use beams somewhat larger in diameter than the largest diameter of the

specimens to be tested. The use of an optical fiber between the laser and the specimen improves substantially the uniformity of the beam (up to 95 %). Since this method produces almost no edge effects, a larger portion of the energy can be directed to the specimen than from natural beam lasers.

7.2.2 Most commonly used lasers are: ruby (visible red), Nd: glass, and Nd: YAG (near infrared); however, other types of lasers may be used. In some instances, properly engineered Xenon flash sources can provide comparable performance for all but the shortest rise times. Xenon flash sources, when properly focused, provide a lower cost and lower maintenance alternative to lasers for many applications.

7.3 An environmental control chamber is required for measurements above and below room temperature. This chamber must be gas or vacuum tight if operation in a protective atmosphere is desired. The enclosure shall be fitted with a window, which has to be transparent to the flash source. A second window is required if optical detection of the rear face temperature rise is used. In such cases it is recommended that the optical detector be shielded from direct exposure to the energy beam with the use of appropriate filter(s).

7.4 The furnace or cryostat should be loosely coupled (thermally) to the specimen support and shall be capable of maintaining the specimen temperature constant within 4 % of the maximum temperature rise over a time period equal to five halves of the maximum rise time. The furnace may be horizontal or vertical. The specimen support shall also be loosely coupled thermally to the specimen. Specimen supports may be constructed to house one specimen or several at a time, with the latter providing substantial improvements in data and testing speed.

7.5 The detector can be a thermocouple (see [Appendix X1](#)), infrared detector, optical pyrometer, or any other means that can provide a linear electrical output proportional to a small temperature rise. It shall be capable of detecting 0.05 K change above the specimen's initial temperature. The detector and its associated amplifier must have a response time substantially smaller than 2 % of the half-rise time value. When intrinsic thermocouples are used, the same response requirements shall apply. Electronic filters, if used, shall be verified not to distort the shape of the thermogram. Several precautions are required when using optical temperature sensing. The sensor must be focused on the center of the back surface of the specimen. It also must be protected from the energy beam, to prevent damage or saturation. When the specimen is housed in a furnace, the energy beam may bounce or shine past the edges and enter the detector. To avoid this, proper shielding is necessary. For protection against lasers, dielectric spike filters that are opaque at the selected wavelength are very useful. The viewing window and any focusing lenses must not absorb appreciably the radiation in the wavelength region of the detector. This is particularly important for infrared detectors, and means should be provided to ensure that during high temperature measurements all window surfaces are monitored and kept free of deposits, which might lead to absorption of energy. Such build-ups can lead to loss of signal intensity and may cause non-uniform specimen heating from the energy source.