Designation: E289 – 25

Standard Test Method for Linear Thermal Expansion of Rigid Solids with Interferometry[1]

This standard is issued under the fixed designation E289; 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 the determination of linear thermal expansion of rigid solids using either a Michelson or Fizeau interferometer.

1.2 For this purpose, a rigid solid is defined as a material which, at test temperature and under the stresses imposed by instrumentation, has a negligible creep, insofar as significantly affecting the precision of thermal length change measurements.

1.3 It is recognized that many rigid solids require detailed preconditioning and specific thermal test schedules for correct evaluation of linear thermal expansion behavior for certain material applications. Since a general method of test cannot cover all specific requirements, details of this nature should be discussed in the particular material specifications.

1.4 This test method is applicable to the approximate temperature range −150 °C to 700 °C. The temperature range may be extended depending on the instrumentation and calibration materials used.

1.5 The precision of measurement of this absolute method (better than ±40 nm/(m·K)) is significantly higher than that of comparative methods such as push rod dilatometry (for example, Test Methods D696 and E228) and thermomechanical analysis (for example, Test Method E831) techniques. It is applicable to materials having low and either positive or negative coefficients of expansion (below 5 µm/(m·K)) and where only very limited lengths or thickness of other higher expansion coefficient materials are available.

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

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

1.8 *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:*[2]

D696 Test Method for Coefficient of Linear Thermal Expansion of Plastics Between −30°C and +30°C with a Vitreous Silica Dilatometer

E220 Test Method for Calibration of Thermocouples by Comparison Techniques

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

E473 Terminology Relating to Thermal Analysis and Rheology

E831 Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis

E1142 Terminology Relating to Thermophysical Properties

3. Terminology

3.1 *Definitions:*

3.1.1 The following terms are applicable to this document and are listed in Terminology E473 and E1142: *coefficient of linear thermal expansion*, *thermodilatometry*, and *thermomechanical analysis*.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *mean coefficient of linear thermal expansion, α_m*—the average change in length relative to the length of the specimen accompanying a change in temperature between temperatures T_1 and T_2, expressed as follows:

[1] This test method is under jurisdiction of ASTM Committee E37 on Thermal Measurements and is the direct responsibility of Subcommittee E37.05 on Thermophysical Properties.

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

$$\alpha m = \frac{1}{L_0}\cdot\frac{L_2 - L_1}{T_2 - T_1} = \frac{1}{L_o}\cdot\frac{\Delta L}{\Delta T} \quad (1)$$

where α_m is obtained by dividing the linear thermal expansion ($\Delta L/L_0$) by the change of temperature (ΔT). It is normally expressed as µm/m·*K*. Dimensions (L) are normally expressed in mm and wavelength (λ) in nm.

3.2.2 *spalling, n*—the development of fragments, flakes, or chips usually caused by stress resulting from mechanical treatment.

3.2.3 *thermal expansivity, α_T*—at temperature *T*, is calculated as follows from slope of length *v* temperature curve:

$$\alpha_T = \frac{1}{L_i}\lim_{T_2 \to T_1}\frac{L_2 - L_1}{T_2 - T_1} = \frac{1}{L_i}\frac{dL}{dT} \text{ with } T_1 < T_i < T_2 \quad (2)$$

and expressed as µm/m·K.

3.2.3.1 *Discussion*—Thermal expansivity is sometimes referred to as instantaneous coefficient of linear expansion.

3.3 *Symbols:*

α_m = mean coefficient of linear thermal expansion, see 3.2.1, K^{-1}
α_T = expansivity at temperature *T*, see 3.2.3, K^{-1}
L_o = original length of specimen at temperature T_0, mm
L_1 = length at temperature T_1, mm
L_2 = length at temperature T_2, mm
ΔL = change in length of specimen between temperatures T_1 and T_2, nm
ΔL_s = change in length of reference specimen between T_1 and T_2, mm
N = number of fringes including fractional parts that are measured on changing temperature from T_1 to T_2
n = index of refraction of gas at temperature *T* and pressure, *P*
n_r = index of refraction of gas at reference condition of temperature 288 K and pressure of 100 kPa
n_1, n_2 = index of refractive of gas at temperature T_1 and T_2, and pressure, *P*
P = average pressure of gas during test, Pa (torr)
Note—torr = 133.3 Pa
T_o = temperature at which initial length is L_0, K
T_1, T_2 = two temperatures at which measurements are made, K
ΔT = temperature difference between T_2 and T_1, K
λ_v = wavelength of light used to produce fringes, nm

4. Summary of Test Method

4.1 A specimen of known geometry can be given polished reflective ends or placed between two flat reflecting surfaces (mirrors). Typical configurations, as shown in Fig. 1, are a cylindrical tube or a rod with hemispherical or flat parallel ends or machined to provide a 3-point support. The mirrors consist of flat-uniform thickness pieces of silica or sapphire with the surfaces partially coated with gold or other high reflectance metal. Light, either parallel laser beam (Michelson, see Fig. 2 and Fig. 3) or from a point monochromatic source (Fizeau, see Fig. 4) illuminates each surface simultaneously to produce a fringe pattern. As the specimen is heated or cooled, expansion or contraction of the specimen causes a change in the fringe pattern due to the optical pathlength difference between the reflecting surfaces. This change is detected and converted into length change from which the expansion and expansion coefficient can be determined (**1-5**).[3]

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

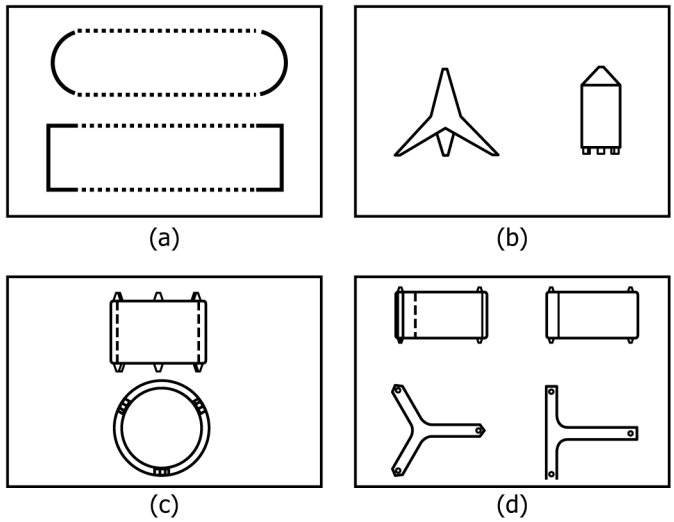

FIG. 1 Typical Specimen Configurations (a) Michelson Type, (b–d) Fizeau Type

5. Significance and Use

5.1 Coefficients of linear expansion are required for design purposes and are used particularly to determine thermal stresses that can occur when a solid artifact composed of different materials may fail when it is subjected to a temperature excursion(s).

5.2 Many new composites are being produced that have very low thermal expansion coefficients for use in applications where very precise and critical alignment of components is necessary. Push rod dilatometry such as Test Methods D696 and E228, and thermomechanical analysis methods such as Test Method E831 are not sufficiently precise for reliable measurements either on such material and systems, or on very short specimens of materials having higher coefficients.

5.3 The precision of the absolute method allows for its use to:

5.3.1 Measure very small changes in length;

5.3.2 Develop reference materials and transfer standards for calibration of other less precise techniques; and

5.3.3 Measure and compare precisely the differences in coefficient of "matched" materials.

5.4 The precise measurement of thermal expansion involves two parameters; change of length and change of temperature. Since precise measurements of the first parameter can be made by this test method, it is essential that great attention is also paid to the second, in order to ensure that calculated expansion coefficients are based on the required temperature difference. Thus in order to ensure the necessary uniformity in temperature of the specimen, it is essential that the uniform temperature zone of the surrounding furnace or environmental chamber shall be made significantly longer than the combined length of specimen and mirrors.

5.5 This test method contains essential details of the design principles, specimen configurations, and procedures to provide precise values of thermal expansion. It is not practical in a method of this type to try to establish specific details of design,