Designation: D 4535 – 85 (Reapproved 2000)

Standard Test Methods for Measurement of Thermal Expansion of Rock Using a Dilatometer[1]

This standard is issued under the fixed designation D 4535; 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 These test methods cover the laboratory measurement of the linear (one-dimensional) thermal expansion of rocks using a dilatometer.

1.2 These test methods are applicable between temperatures of 25°C to 300°C. Both bench top and confined measurement techniques are presented. Rocks of varying moisture content can be tested.

1.3 For satisfactory results in conformance with these test methods, the principles governing the size, construction, and use of the apparatus described in these methods should be followed. If the results are to be reported as having been obtained by this method, then all pertinent requirements prescribed in this method shall be met.

1.4 These test methods do not establish details of construction and procedure to cover all test situations that might offer difficulties to a person without technical knowledge concerning the theory of heat flow, temperature measurement, and general testing practices. Standardization of these test methods does not reduce the need for such technical knowledge. It is recognized also that it would be unwise, because of the standardization of this method, to resist in any way the further development of improved or new methods or procedures by research workers.

1.5 *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:*

E 83 Practice for Verification and Classification of Extensometers[2]

E 228 Test Method for Linear Thermal Expansion of Solid Materials with Vitreous a Silica Dilatometer[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *sample thermal strain,* ϵ_t— change in length of a unit length of sample when the sample is subjected to heat. The mathematical expression is:

$$\epsilon_t = (L_2 - L_1)/L_0 \quad (1)$$

where:

L_1 and L_2 = specimen lengths corresponding to temperatures T_1 and T_2, and

L_0 = the original specimen length at some reference temperature T_0.

Thermal strain is also equal to the specimen thermal displacement, δ_t, divided by the original sample length:

$$\epsilon_t = \delta_t/L_0 \quad (2)$$

3.1.2 *mean coefficient of linear expression,* α_m—between two temperatures, T_1 and T_2, is defined as follows:

$$\alpha_m = (L_2 - L_1)/[L_0(T_2 - T_1)] \quad (3)$$

where:

L_1 and L_2 = specimen lengths at temperatures T_1 and T_2, respectively. Therefore, α_m is obtained by dividing the linear thermal strain, $(L_1 - L_2)/L_0$, by the change in temperature units are inch/inch or centimetre/centimetre per temperature change in °F or °C, respectively. α_m is often expressed in parts per million per degree.

3.1.3 Upon heating ($T_2 > T_1$), an increase in the length of the rock sample will give a positive value of α_m. If a decrease in length (contraction) is observed, α_m will become negative.

4. Summary of Test Methods

4.1 The application of heat to a rock causes it to expand. This expansion divided by the original length of the rock specimens is the thermal strain from which coefficients of expansion can be calculated. This standard covers two methods for measuring rock expansion. The primary difference between the two methods is in the type of dilatometer used.

4.1.1 *Test Method I*—Test Method I is the procedure used when making unconfined or bench top measurements. The method and apparatus are similar to that described in Test

[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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[2] *Annual Book of ASTM Standards,* Vol 03.01.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

Method E 228. The rock specimen thermal displacement is measured using a dilatometer as shown in Fig. 1. The sample displacement is measured by a transducer located outside the heated area of the sample; therefore, apparent strain due to apparatus expansion and contraction is minimized.

4.1.2 *Test Method II*—Test Method II employs a dilatometric device which is located inside the heated zone, as shown in Fig. 2. This test method is most suited for the measurement of rock thermal strain under confined conditions.

4.2 In both test methods, sample expansion is measured continuously as temperature is gradually increased or allowed to stabilize at discrete temperature points.

5. Significance and Use

5.1 Information concerning the thermal expansion characteristics of rocks is important in the design of any underground excavation where the surrounding rock may be heated. Thermal strain causes thermal stresses which ultimately affect excavation stability. Examples of applications where rock thermal strain is important include: nuclear waste repositories, underground power stations, compressed air energy storage facilities, and geothermal energy facilities.

5.2 The coefficient of thermal expansion or "alpha" or rock is known to vary as the temperature changes. These methods provide continuous thermal strain values as a function of temperature, and therefore provide information on how alpha changes with temperature.

5.3 Rocks are also often anisotropic, thus displaying different thermal strains depending on the orientation of strain measurement. These methods allow for measuring strain in one direction only. If anisotropy is expected, samples with different orientations should be prepared and tested.

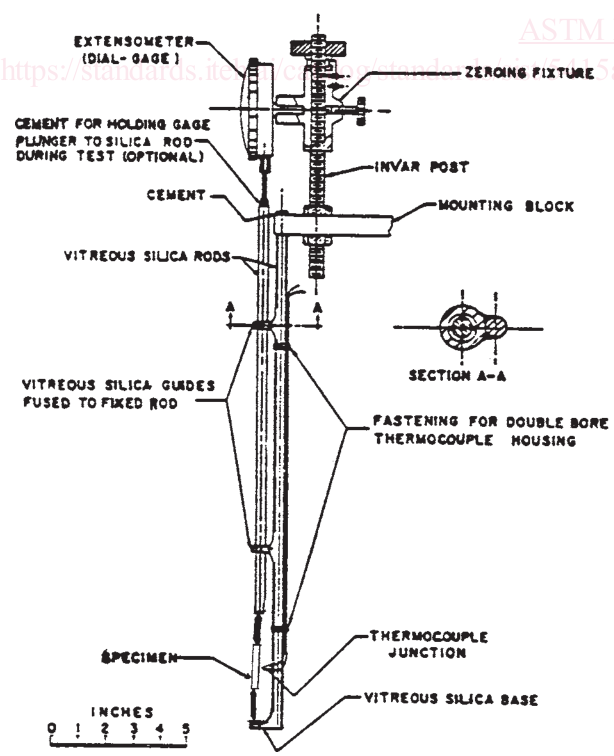

FIG. 1 Apparatus Commonly Used to Perform Bench Top (Method I) Thermal Expansion Measurements

5.4 Care should be exercised in the interpretation of thermal strain data of rocks with significant moisture content. Under certain temperature and pressure conditions, steam may be produced in the pore space. Steam may cause errors because of microcrack production or changes in the pore pressure. The phase change from water to steam in the pore space can result in several phenomena which complicate data analysis, as follows:

5.4.1 Evolved steam may change the pore pressure and thus the effective stress in the rock, resulting in anomalous strain readings.

5.4.2 Losing all the moisture may dehydrate clays in the pore space and thus change expansion characteristics, especially in layered rocks.

5.5 The researcher using this standard must use best judgment as to how to make the thermal expansion measurement so that it accurately represents the conditions in the field.

5.6 Method II is amenable to confined thermal strain determinations. Confined tests may be most appropriate when:

5.6.1 Pore pressure must be imposed in the pore space to maintain the liquid phase of water through the desired temperature range.

5.6.2 The thermal strain of the rock is sensitive to confining stress.

5.6.3 The sample is fragile or friable, or both, and cannot be machined into the shapes required for Method I.

6. Apparatus

6.1 *Dilatometer*:

6.1.1 *Method I*—The dilatometer used for bench measurements may be of the tube or rod type, as shown in Fig. 1. Those components of the dilatometer exposed to elevated temperatures should be fabricated of materials with coefficients of linear expansion that are as small as practicable.

6.1.2 *Method II*—In Method II the entire dilatometer is exposed to elevated temperature. Therefore, transducers, rods, and other components should be fabricated of materials with low thermal expansions (for example, fused silica, super invar). When the apparatus is tested with a quartz calibration specimen, the apparatus strain should be less than 20 % of the anticipated rock strain (refer to Fig. 2).

6.2 *Extensometer*—Extensometers measure length change. In principle, any accurate length measuring device with good long-term stability may be used; this includes dial gages, linear variable differential transducers, or capacitive transducers. Whichever device is selected, it must have sufficient resolution to measure 0.01 % sample strain (Refer to Practice E 83).

6.2.1 Those devices used in Method II must be fabricated of materials that allow direct exposure of the device to the anticipated temperature. Also, transducer bodies should be vented for operation in a pressure environment. At least two transducers are used, as shown in Fig. 2, and their outputs averaged.

6.3 *Furnace*—The furnace shall be large enough to contain the specimen and apparatus and maintain uniform temperature along the axis of the specimen with variations no greater than ±1°C. The mean sample temperature shall be controlled within ±1°C. The use of a programmable temperature controller that

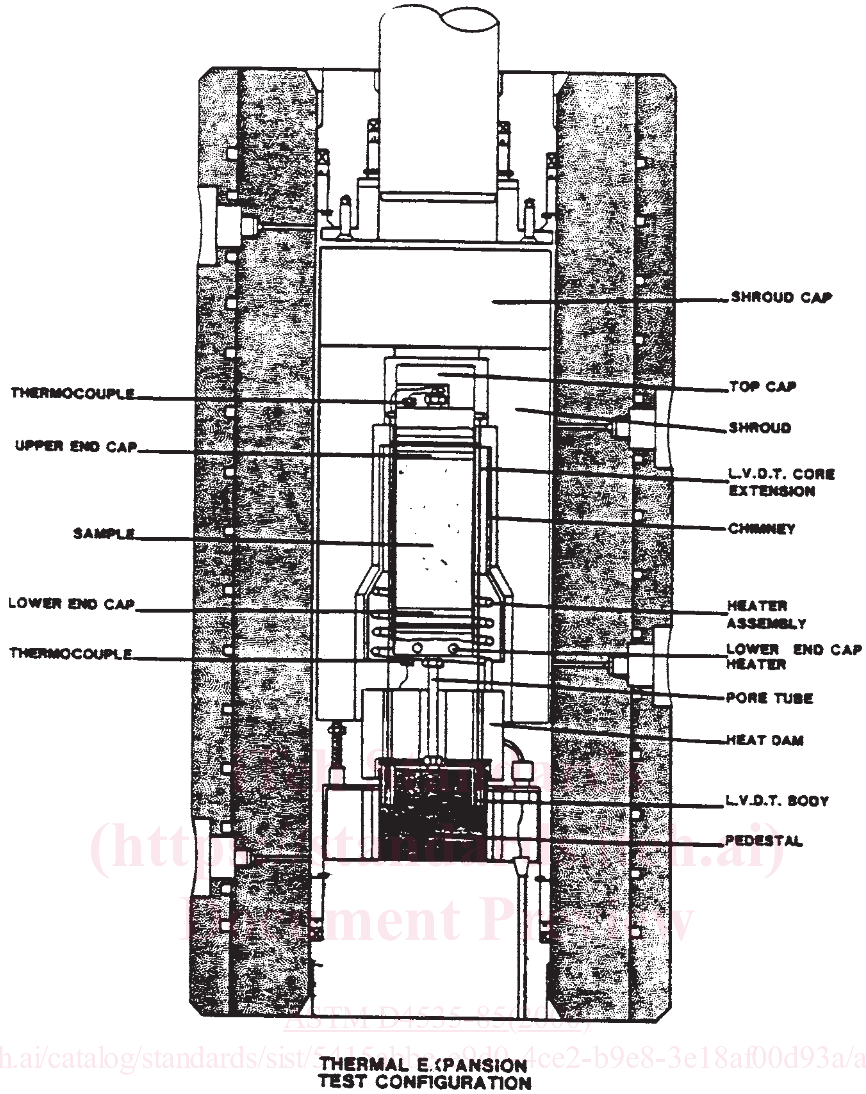

FIG. 2 Apparatus Commonly Used to Perform Confined (Method II) Thermal Expansion Measurements

can slowly increase or decrease sample temperatures at rates at least as low as 0.1°C/min is recommended.

6.4 *Temperature Measuring Instruments*— Thermocouples or platinum resistant thermometers are recommended. The exact type will depend on the temperature range of interest. In general, the temperature should be measured to within ±0.5°C with a resolution of at least± 0.2°C. Make measurements at three locations on the axis of the sample, one near each end and one at the sample midpoint.

6.5 *Micrometer*—Calipers should have an index permitting direct reading of 0.025 mm for measuring the initial length of the specimen. A high grade screw micrometer customarily used in machine shop practice is satisfactory.

7. Sampling

7.1 The number and types of rock cores tested depend partly on the intended application of the test results. For example, an initial mechanical characterization of a site might require several samples from a variety of formations, while a detailed thermo-mechanical investigation of a particular location may require many rock tests from a single formation. The final testing program will depend on the technical judgment and the experience of project personnel.

7.2 *Statistical Requirements*—It is recommended that the number of samples tested be sufficient to provide an adequate statistical basis for evaluation of the results. Rock types which are highly variable would require more tests than relatively uniform rocks, in order to evaluate the results with equal certainty.

7.3 *Moisture Condition of Samples*— The moisture condition of the rock can influence the measured thermal expansion. Test the specimens in a manner that best simulates the in situ conditions of interest. For natural conditions, the moisture content of the rock core and the chemical characteristics of the pore fluid shall be preserved between the time of recovery and