Designation: D5335 – 14

Standard Test Method for Linear Coefficient of Thermal Expansion of Rock Using Bonded Electric Resistance Strain Gauges[1]

This standard is issued under the fixed designation D5335; 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 laboratory determination of the linear (one-dimensional) coefficient of thermal expansion of rock using bonded electric resistance strain gauges. This test method is intended for evaluation of intact rock cores. Discontinuities in the rock mass, such as joints, inclusions, voids, veins, bedding, and the like can influence the thermal expansion of the rock, and judgment should be used when selecting the specimen to be analyzed in this test method.

1.2 This test method is applicable for unconfined stress states over the temperature range from 20 to 260°C.

NOTE 1—Unconfined tests performed at elevated temperatures may alter the mineralogy or grain structure of the test specimen. This alteration may change the physical and thermal properties of the test specimen.

NOTE 2—The strain gauges are mounted with epoxy. Most commercially available high temperature epoxies require elevated temperature curing. The elevated temperature required for this curing may alter the physical and thermal properties of the test specimen. Epoxy should be selected based upon the maximum expected test temperature. Room temperature curing epoxy should be used whenever practical.

1.3 The test specimens may be either saturated, dry or unsaturated. If saturated or unsaturated specimens are used, then the test temperature shall be at least 10°C less than the boiling point of the saturating fluid in order to reduce the effects of evaporation of the fluid.

NOTE 3—When testing a saturated specimen, the gravimetric water content of the specimen may change unless special precautions are taken to encapsulate the test specimen. Refer to 7.4.

1.4 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.5.1 The procedure used to specify how data are collected/recorded or calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analytical methods for engineering design.

1.6 *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 requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D6026 Practice for Using Significant Digits in Geotechnical Data

E83 Practice for Verification and Classification of Extensometer Systems

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

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

E289 Test Method for Linear Thermal Expansion of Rigid Solids with Interferometry

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved June 1, 2014. Published July 2014. Originally approved in 1992. Last previous edition approved in 2008 as D5335 – 08. DOI: 10.1520/D5335-14.

[2] 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.

*A Summary of Changes section appears at the end of this standard

3. Terminology

3.1 *Definitions*—For definitions of common technical terms, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *mean coefficient of linear thermal expansion, α_m, [D/T^1], n*—a value, often expressed in parts per million per degree obtained by dividing the linear thermal strain, $((L_2 - L_1)/L_0)$, by the change in temperature $(T_2 - T_1)$.

3.2.1.1 *Discussion*—The sign convention used for αm, is as follows: αm will be a positive value indicating an increase in the length of the rock specimen, $(T_2 > T_1)$ and α_m will be a negative value indicating a decrease or contraction of the rock specimen. The coefficient of linear thermal expansion can also be obtained by dividing the change in thermal strain $(\Delta_{\varepsilon T})$ by the change in temperature (Δ_T). ε_{T_1} and ε_{T_2} are the specimen thermal strains as a result of a temperature change from T_0 to T_1 and from T_0 to T_2, respectively.

3.2.2 *specimen thermal strain, ε_{ts}, [D], n*—the change in length, $(L_2 - L_1)$, divided by the original length, L_0, of the specimen when the specimen is subjected to heat.

3.2.2.1 *Discussion*—L_1 and L_2 are the specimen lengths at temperatures T_1 and T_2, respectively. L_0 is the original specimen length at the reference temperature T_0.

4. Summary of Test Method

4.1 In general, the application of heat to rock causes it to expand. This change in linear expansion divided by the original length of the rock specimen is the thermal strain developed in the rock specimen from which the coefficients of expansion can be calculated. A wire or foil strain gauge suitably bonded to the rock is strained the same amount as the rock specimen. This straining, or stretching, of the gauge results in a change in the electrical resistance of the gauge. Measurement of the change in the electrical resistance of the gauge is thus a measure of the change in linear dimension of the rock specimen.

4.2 The application of heat to the gauge may cause a change in the electrical resistance of the gauge. To eliminate errors due to gauge heating, a second gauge is attached to a reference specimen that is not heated. During heating of the test specimen, the output of the gauge attached to the reference specimen is subtracted from the output of the gauge attached to the test specimen.

5. Significance and Use

5.1 Information concerning the thermal expansion characteristics of rocks is important in the design of underground excavation where the temperature of the surrounding rock may be altered. Depending on the restraint conditions, thermal strain may cause thermal stress that may affect the stability of underground excavations. Examples of applications where an understanding of rock thermal strain is important include: nuclear waste repositories, underground power stations, compressed air energy storage facilities, energy foundations, and geothermal energy facilities.

5.2 The coefficient of linear thermal expansion, α, of rock is known to vary as the temperature changes. Rock thermal strain is normally not a linear function of temperature. This test method provides a procedure for continuously monitoring thermal strain as a function of temperature. Therefore, information on how the coefficient of linear thermal expansion changes with temperature is obtained.

5.3 Other methods of measuring the coefficient of linear thermal expansion of rock by averaging the thermal strain of a large specimen over a temperature range of many degrees may result in failure to determine the variation in α of that rock for one or more of the following reasons:

5.3.1 α is not always linear with temperature,

5.3.2 Some rocks are anisotropic having directional characteristics which can vary by more than a factor of two. If anisotropy is expected, specimen with different orientations should be prepared and tested.

5.3.3 α may have a negative value in one direction and, at the same time, a positive value in the others.

5.4 Both wire and foil type strain gauges have been successfully employed to measure the thermal expansion coefficients of rock. These coefficients are frequently very small, being on the order of millionths of a millimetre per millimetre for each degree Celsius. The thermal strain of rocks is about one-tenth that of plastics and one-half or one-quarter that of many metals. Therefore, measurement methods for rocks require greater precision than methods that are routinely used on plastics and metals.

NOTE 4—The quality of the results produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Bonded Strain Gauges*—The gauges shall be ASTM Class A type resistance strain gauge extensometers as described in Practice E83. The gauge length shall be at least ten times the largest grain in the rock. Care shall be exercised to have the same length and type of connecting wires on all specimens.

6.2 *Strain-Measuring System*—Any type having sensitivity of at least 5×10^{-6} with an accuracy of at least ±0.1 % of the reading and a linearity of at least ±0.1 % of the interval.

6.3 *Reference Specimen*—The reference specimen shall have a maximum coefficient of linear thermal expansion of 0.5×10^{-6} m/(m · °C) and have minimum dimensions of at least twice the length of the strain gauge.

NOTE 5—Suitable reference materials include titanium silicate, borosilicate glass, stainless steel, fused silica, and ultra-low expansion glass, that have expansion coefficients of less than 0.5×10^{-6}m/(m · °C) over the temperature range from 0 to 200°C.

6.4 *Temperature Measurement System*—The system chosen to monitor and record temperature depends primarily on the test apparatus and the maximum test temperature. Special limits of error thermocouples or platinum resistance thermometers (RTDs) are recommended. The temperature sensor (transducer) shall be accurate to 0.2°C or better with a resolution of 0.05°C or better.

6.5 *Heating System*—The heating unit (furnace) shall be large enough to contain the test calibration and reference specimens such that the gauge length specified in 6.1 can be maintained at a constant temperature over its length to 0.1°C. It shall also incorporate controls so that specimens may be heated or cooled at a rate not greater than 1°C/min while still maintaining the constant temperature along the gauge length. If the heating unit consists of a liquid bath, then the specimens shall be encapsulated to prevent penetration of the fluid into the specimens.

6.6 *Specimen Size Measurement Devices*—Devices used to measure the length and diameter of the specimen shall be capable of measuring the desired dimension to within 0.1 % of its actual length.

6.7 *Epoxy*—Commercially available high temperature or room temperature epoxy may be used; however the type selected shall be based upon the maximum expected test temperature. See Note 2.

7. Sampling

7.1 Rock samples can be in the form of block or core samples. The number and types of rock samples needed depends partly on the intended application of the test results. For example, an initial mechanical characterization of the site might require several samples from a variety of formations, while a detailed thermo-mechanical evaluation of a specific rock type or particular location may require many tests from a single formation. The final testing program will depend on the technical judgment and experience of project personnel. Additional information may be found in Practice D2113, which describes rock core drilling and sampling of rock for site investigations.

7.2 *Statistical Requirements*—The number of samples and specimens tested shall be sufficient to provide an adequate statistical basis for evaluation of the results. Rock types that are highly variable will require more tests than relatively uniform rocks in order to evaluate the results with equal uncertainty.

7.2.1 The number of samples and specimens required to obtain a specific level of statistically valid results may be determined using test method E122. However, it may not be economically practicable to achieve specific confidence levels and professional judgment may be required.

7.3 Discontinuities in the rock mass, such as joints, inclusions, voids, veins, bedding, and the like shall be avoided if practicable as their presence can influence the thermal expansion of the rock. Micro-cracks may be produced during sampling or test preparation.

7.4 *Moisture Condition of Samples*—The moisture condition of the rock can influence the measured thermal expansion. The samples shall be preserved to prevent changes in water content. It is recommended that specimens be tested in both natural (saturate or unsaturated) and dry conditions.

7.5 *Anisotropy*—The thermal expansion coefficient of many rocks is dependent on direction; therefore, in order to assess the degree of anisotropy, the thermal expansion must be measured in several directions.

7.6 *Documentation*—Since the thermal expansion of most rocks is anisotropic, it is important that the field orientation of each sample is recorded. The orientation of each sample shall be marked on the sample and carry suitable markings through each cutting until the final specimen is ready for testing. These markings on the sample and specimen shall indicate compass direction, up/down directions, and orientation with respect to geologic structure.

8. Preparation of Test Specimens

8.1 Take the samples and machine them into the proper geometry as discussed in 8.2.

8.1.1 Do not degrade the rock during machining. Prevent mechanical and thermal fracture damage to the rock fabric by appropriately slow machining processes and the use of proper coolant. Select coolant fluids based upon chemical compatibility with the rock; for example, tap water may be adequate for granite or other hard rock, whereas saturated brine is adequate for salt, or mineral oil may be best for expansive shales.

8.1.2 Use a segmented diamond saw for cutting core or block samples into right circular cylinders or right prisms. Right circular cylinders are easily produced by cutting a core sample at two locations as required by 8.1, parallel to each other and at right angles to the longitudinal axis. Apply cooling fluid continuously to cool the blade and flush cuttings from the cut. If required, laboratory core drilling of the rock block samples can be done to obtain drill cores.

8.1.3 The areas on the specimen where the strain gauges are to be mounted shall be smooth to within 0.025 mm.

8.2 *Dimensions and Geometry*—In general, the proper geometry of a test specimen shall be right circular cylinder or right prism having a length to diameter ratio of 2 to 1. The minimum dimensions shall be adequate to accommodate the strain gauges as specified in 6.1. The length of the specimen shall be at least ten times the largest grain in the rock. Measure and record the length and diameter of the specimen to 0.001 mm. Take a minimum of three length measurements 120° apart and at least three diameter measurements at the quarter points of the height. Determine the average length and diameter of the specimen.

8.3 *Moisture Condition of Specimens*—Test the specimens in a manner that best simulates the in situ conditions of interest. For natural conditions, the moisture content of the test specimen shall be preserved between the time of recovery and testing. Determine and record the gravimetric water content of representative material contiguous to the test specimen in accordance with Test Methods D2216.

8.3.1 If the specimen is to be tested dry, dry at 80°C in a heating unit as described in 6.5, for 24 h. At no time during the drying process shall the specimen be subjected to heating or cooling rates greater than 1°C/min. Determine and record the water content of this specimen in accordance with Test Methods D2216.

8.3.1.1 An alternative drying schedule may be used in those instances where a heating unit is not available and it is not of interest to know the test specimen response to the first application of heat. In such a case, heat the specimen to 105 ±