Designation: E143 – 20

Standard Test Method for Shear Modulus at Room Temperature[1]

This standard is issued under the fixed designation E143; 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 shear modulus of structural materials. This test method is limited to materials in which, and to stresses at which, creep is negligible compared to the strain produced immediately upon loading. Elastic properties such as shear modulus, Young's modulus, and Poisson's ratio are not determined routinely and are generally not specified in materials specifications.

1.2 For materials that follow nonlinear elastic stress-strain behavior, the value of tangent or chord shear modulus is useful for estimating the change in torsional strain to corresponding stress for a specified stress or stress-range, respectively. Such determinations are, however, outside the scope of this standard. (See for example Ref (**1**).)[2]

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

1.4 *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.*

1.5 *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:*[3]

E6 Terminology Relating to Methods of Mechanical Testing

E8/E8M Test Methods for Tension Testing of Metallic Materials

E111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus

E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

E2624 Practice for Torque Calibration of Testing Machines

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions that appear in Terminology E6 apply to this test method, including accuracy, chord modulus, creep, eccentricity, Poisson's ratio, proportional limit, resolution, shear modulus, shear strain, stress-strain curve, stress-strain diagram, tangent modulus, testing machine, torsional stress, yield strength, and Young's modulus.

3.1.2 *shear modulus, G,* [FL^{-2}], *n*—the ratio of shear stress to corresponding shear strain below the proportional limit, also called torsional modulus and modulus of rigidity.

3.1.2.1 *Discussion*—The value of shear modulus can depend on the direction in which it is measured if the material is not isotropic. Wood, many plastics, and certain metals are markedly anisotropic. Deviations from isotropy should be suspected if the shear modulus, *G*, differs from that determined by substituting independently measured values of Young's modulus, *E*, and Poisson's ratio, μ, in the relation

$$G = \frac{E}{2(1+\mu)} \tag{1}$$

3.1.2.2 *Discussion*—When reporting values of shear modulus, the stress range over which it is measured should be stated.

3.1.3 *torque,* [FL], *n*—a moment (of forces) that produces or tends to produce rotation or torsion.

3.1.4 *torsional stress* [FL^{-2}], *n*—the shear stress in a body, in a plane normal to the axis or rotation, resulting from the application of torque.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *angle of twist (torsion test)*—the angle of relative rotation measured in a plane normal to the torsion specimen's longitudinal axis over the gauge length.

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[1] This test method is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.04 on Uniaxial Testing.

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

[3] 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**

4. Summary of Test Method

4.1 The cylindrical or tubular test specimen is loaded either incrementally or continuously by applying an external torque so as to cause a uniform twist within the gauge length.

4.1.1 Changes in torque and the corresponding changes in angle of twist are determined either incrementally or continuously. The appropriate slope is then calculated from the shear stress-strain curve, which may be derived under conditions of either increasing or decreasing torque (increasing from pretorque to maximum torque or decreasing from maximum torque to pretorque).

5. Significance and Use

5.1 Shear modulus is a material property useful in calculating compliance of structural materials in torsion provided they follow Hooke's law, that is, the angle of twist is proportional to the applied torque. Examples of the use of shear modulus are in the design of rotating shafts and helical compression springs.

5.2 The procedural steps and precision of the apparatus and the test specimens should be appropriate to the shape and the material type, since the method applies to a wide variety of materials and sizes.

5.3 Precise determination of shear modulus depends on the numerous variables that may affect such determinations.

5.3.1 These factors include characteristics of the specimen such as residual stress, concentricity, wall thickness in the case of tubes, deviation from nominal value, previous strain history, and specimen dimension.

5.3.2 Testing conditions that influence the results include axial position of the specimen, temperature and temperature variations, and maintenance of the apparatus.

5.3.3 Interpretation of data also influences results.

6. General Considerations

6.1 Shear modulus for a specimen of circular cross-section is given by the equation[4]

$$G = \frac{TL}{J\theta} \tag{2}$$

where:

G = shear modulus of the specimen,
T = torque,
L = gauge length,
J = polar moment of inertia of the section about its center, and
θ = angle of twist, in radians.

6.1.1 *For a solid cylinder:*

$$J = \frac{\pi D^4}{32} \tag{3}$$

where:

D = diameter.

6.1.2 *For a tube:*

$$J = \frac{\pi}{32}\left(D_o^4 - D_i^4\right) \tag{4}$$

where:

D_o = outside diameter, and
D_i = inside diameter.

7. Apparatus

7.1 The torsion testing machine shall conform to the requirements of Practice E2624.

7.2 *Grips*—The ends of the specimen shall be gripped firmly between the jaws of a testing machine that have been designed to produce a state of uniform twist within the gauge length. In the case of tubes, closely fitting rigid plugs, such as are shown in Fig. 11 (Metal Plugs for Testing Tubular Specimens) of Test Methods E8/E8M, may be inserted in the ends to permit tightening the grips without crushing the specimen. The grips shall be such that axial alignment can be obtained and maintained in order to prevent the application of bending moments. One grip shall be free to move axially to prevent the application of axial forces.

7.3 *Twist Gauges*—The angle of twist may be measured by two pairs of lightweight but rigid arms, each pair fastened diametrically to a ring attached at three points to the section at an end of the gauge length and at least one diameter removed from the grips. The relative rotational displacement of the two sections may be measured by mechanical, optical, or electrical means; for example, the displacement of a pointer on one arm relative to a scale on the other **(2),** or the reflection of a light beam from mirrors or prisms attached to the arms **(3).** Readings should be taken for both sets of arms and averaged to eliminate errors due to bending of the specimen (see 12.3.2).

8. Test Specimens

8.1 *Selection and Preparation of Specimens:*

8.1.1 Specimens shall be chosen from sound, clean material.

NOTE 1—Slight imperfections near the surface, such as fissures that would have negligible effect in determining Young's modulus, can cause appreciable errors in shear modulus.

8.1.2 In the case of machined specimens take care to prevent changing the properties of the material at the surface of the specimen.

8.1.3 Specimens in the form of solid cylinders should be straight and of uniform diameter for a length equal to the gauge length plus two to four diameters (see 12.2.1).

8.1.4 In the case of tubes, the specimen should be straight and of uniform diameter and wall thickness for a length equal to the gauge length plus at least four outside diameters (see 12.2.1 and 12.3.2).

8.2 *Length*—The gauge length should be at least four diameters. The length of the specimen shall be sufficient for a free length between grips equal to the gauge length plus two to four diameters, unless otherwise prescribed in the product specification. However, the ratio of free length to diameter shall not be so large that helical twisting of the axis of the specimen takes place before the determination is completed.

9. Procedure

9.1 *Measurement of Specimens*—Measure diameter to give an accurate determination of polar moment of inertia, J, for the

[4] See any standard text in Mechanics of Materials.

gauge length. In addition, in the case of tubular specimens, determine the average wall thickness at each end to ±0.0025 mm.

NOTE 2—In the case of thin-walled tubes, a survey of thickness variation by more sensitive devices, such as pneumatic or electric gauges, can help achieve the required accuracy.

9.2 *Alignment*—Take care to ensure axial alignment of the specimen.

NOTE 3—Procedures for alignment are described in detail in Practice E1012. Although E1012 is for a specimen under uniaxial loading, it provides guidance for machine setup and fixturing for other loading regimes.

9.3 *Torque and Angle of Twist:*

9.3.1 Record simultaneous measurements of torque and angle of twist.

9.3.2 The torques used in determining the shear modulus shall be within the verified range of torques for the torsion testing machine, as defined in Practice E2624.

9.4 *Speed of Testing*—Maintain the speed of testing high enough to make creep negligible.

9.5 *Temperature*—Record the temperature. Avoid changes in temperature during the test.

10. Interpretation of Results

10.1 The shear modulus should be determined by linear regression of the stress-strain curve.

10.1.1 Due to possible small offsets at zero torque and small variations in establishing the load path in the specimen during the first small increment of torque, the readings at zero torque and the first small increment of torque may be omitted from the calculation, see Fig. 1, and the regression line may be allowed to intercept the stress axis away from the origin.

10.1.2 Because the uncertainties in shear strain are generally larger than those in shear stress, the regression should be computed with shear strain as the dependent variable.

10.2 The shear modulus may be determined by the strain deviation method (**4-6**).

11. Report

11.1 *Test Specimen*—describe the test specimen material, alloy, heat treatment, mill batch, number, grain direction, as applicable, and any relevant information regarding the sample that possibly influenced its mechanical properties.

11.2 *Test Specimen Configuration*—Include a sketch of the test specimen configuration or reference to the specimen drawing.

11.3 *Test Specimen Dimensions*—Report the actual measured dimensions for each test specimen.

11.4 *Test Fixture*—Describe the test fixture or refer to fixture drawings.

11.5 *Testing Machine and Twist Gauges*—Include the manufacturer, make, model, serial number, and torque range of the testing machine and twist gauges.

11.6 *Speed of Testing*—Report the test rate and mode of control.

11.7 *Temperature*—Report the temperature.

11.8 *Stress-Strain Diagram—Torque-Twist Deviation Diagram*—Include either the stress-strain diagram showing both shear stress and shear strain or the torque-twist deviation diagram showing both torque and twist deviation, with scales, specimen number, test data, rate and other pertinent information.

11.9 *Shear Modulus*—report the value as described in Section 10.

12. Precision and Bias

12.1 No interlaboratory test program has been conducted, and no indication of precision (repeatability or reproducibility) exists. No reference standards exist. Therefore no estimate of bias can be obtained.

12.2 Many parameters can influence the accuracy of this test method. Some of these parameters pertain to the uniformity of the specimen, for example, its straightness and eccentricity, the

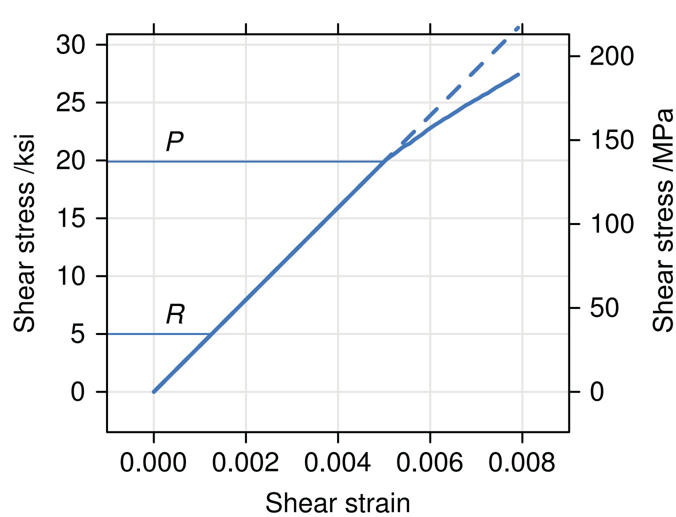

FIG. 1 Shear Stress-Strain Diagram Showing a Straight Line, Corresponding to the Shear Modulus, Between *R*, a Pretorque Stress, and *P*, the Proportional Limit