Designation: E328 – 20

# Standard Test Methods for
Stress Relaxation for Materials and Structures[1]

This standard is issued under the fixed designation E328; 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.

## INTRODUCTION

These test methods cover a broad range of testing activities. To aid in locating the subject matter pertinent to a particular test, the standard is divided into a general section, which applies to all stress-relaxation tests for materials and structures. This general section is followed by letter-designated parts that apply to tests for material characteristics when subjected to specific, simple stresses, such as uniform tension, uniform compression, bending or torsion. To choose from among these types of stress, three factors should be considered:

*(1)* When the material data are to be applied to the design of a particular class of component, the stress during the stress-relaxation test should be similar to that imposed on the component. For example, tension tests are suitable for bolting applications and bending tests for leaf springs.

*(2)* Tension and compression stress-relaxation tests have the advantage that the stress can be reported simply and unequivocally. During bending stress-relaxation tests, the state of stress is complex, but can be accurately determined when the initial strains are elastic. If plastic strains occur on application of force, stresses can usually be determined within a bounded range only. Tension stress-relaxation tests, when compared to compression stress-relaxation tests, have the advantage that it is unnecessary to guard against buckling. Therefore, when the test method is not restricted by the type of stress in the component, tension stress-relaxation testing should be used.

*(3)* Bending stress-relaxation tests, when compared to tension and compression stress-relaxation tests, have the advantage of using lighter and simpler apparatus for specimens of the same cross-sectional area. Strains are usually calculated from deflection or curvature measurements. Since the specimens can usually be designed so that these quantities are much greater than the axial deformation in a direct stress test, strain is more easily measured and more readily used for machine control in bending stress-relaxation tests. Due to the small forces normally required and the simplicity of the apparatus when static fixtures are sufficient, many specimens can be placed in a single oven or furnace when tests are made at elevated temperatures.

## 1. Scope*

NOTE 1—The method of testing for the stress relaxation of plastics has been withdrawn from this standard, and the responsibility has been transferred to Practice D2991.

1.1 These test methods cover the determination of the time dependence of stress (stress relaxation) in materials and structures under conditions of approximately constant constraint, constant test environment, and negligible vibration. In the procedures, the material or structure is initially constrained by externally applied forces, and the change in the external force necessary to maintain this constraint is determined as a function of time.

1.2 Specific methods for conducting stress-relaxation tests on materials subjected to tension, compression, bending and torsion stresses are described in Parts A, B, C, and D, respectively. These test methods also include recommendations for the necessary testing equipment and for the analysis of the test data.

1.3 Bending stress-relaxation tests to determine relaxation properties by using ring-shaped specimens machined from bulk material have been thoroughly developed and widely used to determine stress-relaxation properties (**1**).[2] These tests are outside the scope of these test methods.

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[1] These test methods are 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.

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

1.4 The long time periods required for these types of tests are often unsuited for routine testing or for specification in the purchase of material. However, these tests are valuable tools in obtaining practical design information on the stress relaxation of materials subjected to constant constraint, constant test environment, and negligible vibration, and in investigations of the fundamental behavior of materials.

1.5 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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

1.7 *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]

D2991 Test Method for Stress-Relaxation of Plastics (Withdrawn 1990)[4]

E4 Practices for Force Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E8/E8M Test Methods for Tension Testing of Metallic Materials

E9 Test Methods of Compression Testing of Metallic Materials at Room Temperature

E139 Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials

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

## 3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of terms common to mechanical testing that appear in Terminology E6 apply to this test method, including calibration, eccentricity, gauge length, indicated temperature, modulus of elasticity, Poisson's ratio, proportional limit, reduced parallel section, residual stress, shear modulus, specified temperature, and testing machine.

3.1.2 *stress relaxation, n*—the time-dependent decrease in stress in a solid under given constraint conditions.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *initial stress,* $\sigma_0$, [$FL^{-2}$ ], *n*—the stress introduced into a specimen by imposing the given constraint conditions before stress relaxation begins.

3.2.1.1 *Discussion*—This is sometimes called instantaneous stress.

3.2.2 *relaxed stress* [$FL^{-2}$ ], *n*—the initial stress minus the remaining stress at a given time during a stress-relaxation test.

3.2.3 *remaining stress* [$FL^{-2}$ ], *n*—the stress remaining at a given time during a stress-relaxation test.

3.2.4 *spherometer, n*—an instrument used to measure circular or spherical curvature.

3.2.5 *stress-relaxation curve, n*—a plot of either the remaining time or relaxed stress as a function of time.

3.2.6 *stress-relaxation rate* [$FL^{-2}$ $T^{-1}$], *n*—the absolute value of the slope of the stress-relaxation curve at a given time.

3.2.7 *zero time,* $t_0$, *n*—the time when the given stress or constraint conditions are initially obtained in a stress-relaxation test.

## 4. Summary of Test Methods

4.1 In each of the various methods of stress application described in the applicable specific sections, the specimen is subjected to an increasing force until the specified initial strain is attained (see *zero time,* $t_0$, in 3.2.7 and in Fig. 1). For the duration of the test, the specimen constraint is maintained constant. The initial stress is calculated from the initial force (moment, torque) as measured at zero time, the specimen geometry, and the appropriate elastic constants, often using simple elastic theory. The remaining stress may be calculated from the force (moment or torque) determined under constraint conditions either continuously (4.1.1), periodically (4.1.2), or by elastic springback at the end of the test period (4.1.3).

4.1.1 Readings are taken continuously from a force indicator while the apparatus adjusts the force to maintain constraint within specified bounds.

4.1.1.1 Most force-, moment-, or torque-measuring devices depend on the elasticity of the device to measure the quantities involved. Therefore, when using such devices, maintain the total strain constant within an upper and lower bound as shown in Fig. 2.

4.1.2 The force required to lift the specimen just free of one or more constraints during the test period is measured.

4.1.3 The elastic springback is measured after removing the test stress at the end of the test period.

4.2 With 4.1.1 and 4.1.2, a single specimen may be used to obtain data for a curve of stress versus time. With 4.1.3, the same specimen may be used to determine the remaining or relaxed stress after various time intervals, if it can be demonstrated for a given material that identical results are obtained in either using untested or reloaded specimens. Otherwise, an individual specimen shall be used for each point on the curve.

4.3 The stress-relaxation rate of a stress-relaxation curve, Fig. 3, may be determined from slope of either the remaining stress or the relaxed stress as a function of time.

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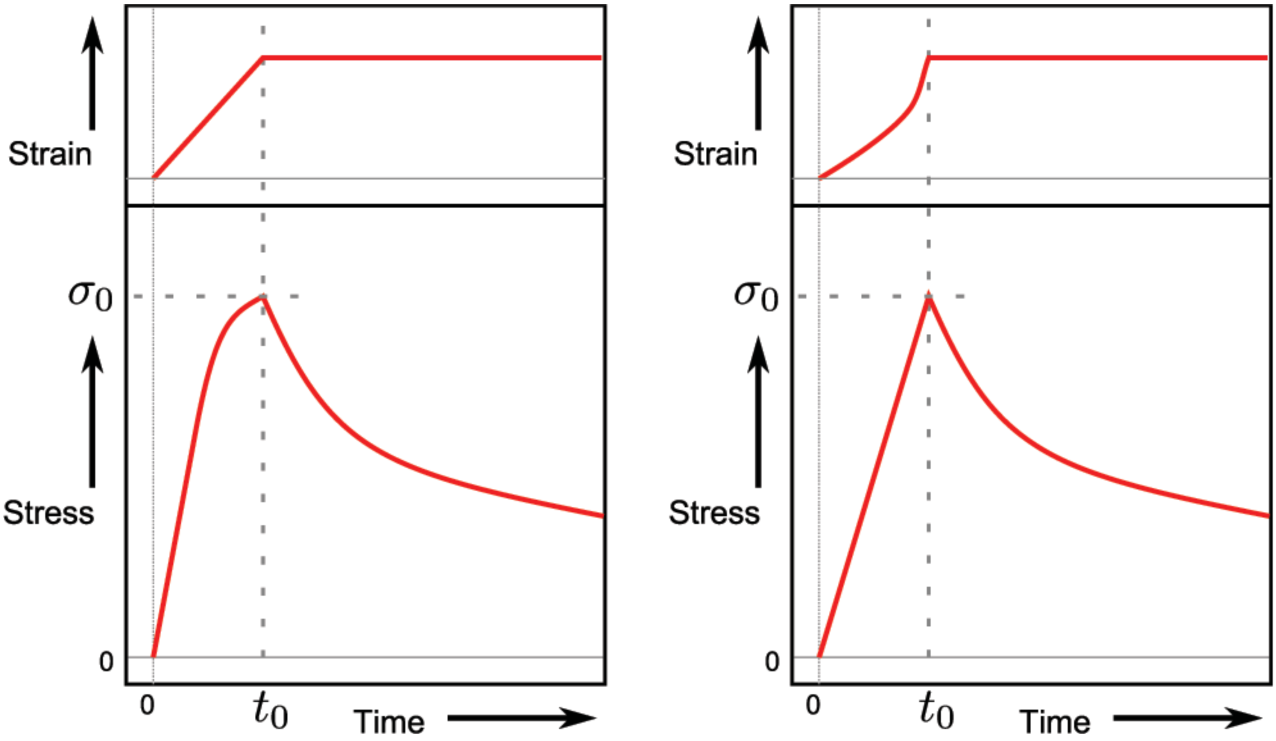
[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.



(a) constant strain rate

(b) constant force application rate

FIG. 1 Characteristic Behavior During Force-Application Period in a Stress-Relaxation Test

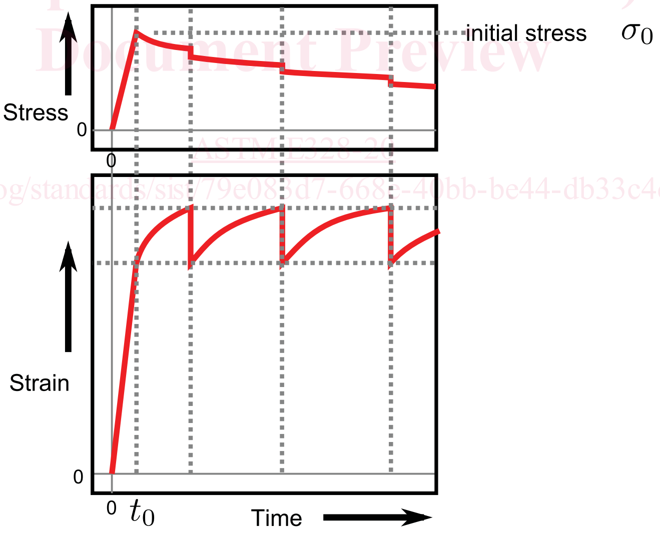


FIG. 2 Derivation of Stress-Relaxation Curve from Continuous Stress-Relaxation Technique

## 5. Significance and Use

5.1 Stress-relaxation test data are necessary when designing most mechanically fastened joints to ensure the permanent tightness of bolted or riveted assemblies, press or shrink-fit components, rolled-in tubes, etc. Other applications include predicting the decrease in the tightness of gaskets, in the hoop stress of solderless wrapped connections, in the constraining force of springs, and in the stability of wire tendons in prestressed concrete.

5.2 The ability of a material to relax at high-stress concentrations such as are present at notches, inclusions, cracks, holes, and fillets can be predicted from stress-relaxation data. Such test data are also useful to judge the heat-treatment condition necessary for the thermal relief of residual internal stresses in forgings, castings, weldments, machined or cold-worked surfaces, etc. The tests outlined in these methods are limited to conditions of approximately constant constraint and test environment.

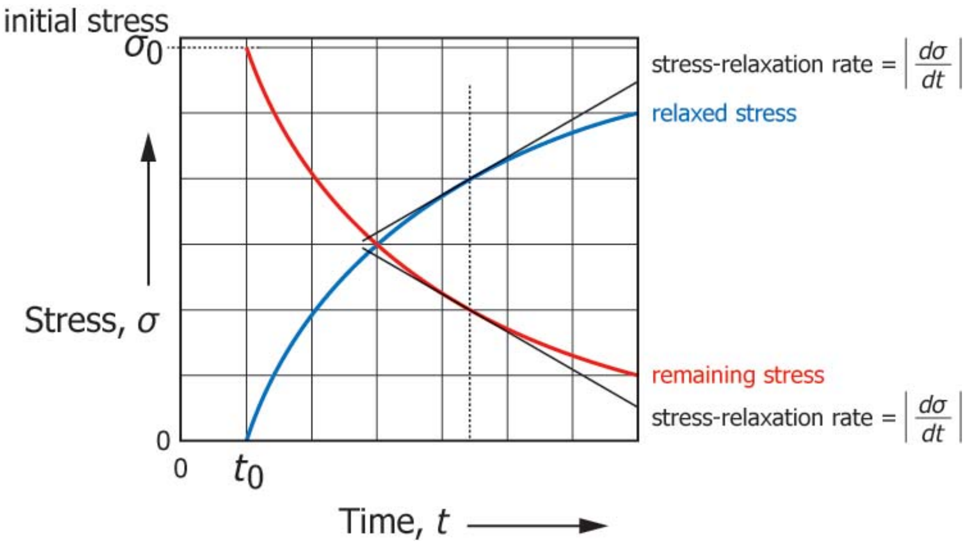


FIG. 3 Typical Stress-relaxation Curve

5.3 The general stress-relaxation test is performed by isothermally applying a force to a specimen with fixed value of constraint. The constraint is maintained constant, and the constraining force is determined as a function of time. The major problem in the stress-relaxation test is that constant constraint can be very difficult to maintain. The effects on test results are very significant, and considerable attention shall be given to minimize the constraint variation. Also, experimenters should determine and report the extent of variation in each stress-relaxation test so that this factor can be taken into consideration.

5.4 There are many methods of performing the stress-relaxation test, each with a different starting procedure. However, the constraint is usually obtained initially by the application of an external force at either a specific force-application rate or a specific strain rate. The two methods will produce the characteristic behavior shown in Fig. 1 when the initial stress, $\sigma_0$, exceeds the proportional limit. Some testing machines, while reaching the constraint value, do not produce either a constant force-application rate or constant strain rate, but something in between. However, the general characteristics of the data will be similar to those indicated. The stress-application rate in either case should be reasonably rapid, but without impact or vibration, so that any relaxation during the stress-application period will be small.

5.5 The stress-relaxation test starts at zero time, $t_0$, in Fig. 1.

NOTE 2—This zero time is the reference time from which the observed reduction in force to maintain constant constraint is based. Selection of this time does not imply that the force-application procedure and period are not significant test parameters which are important in the application of the data.

## 6. Apparatus

6.1 See the appropriate paragraph under each section.

6.2 The equipment should be located in a draft-free, constant-temperature laboratory, ±5 °F (±3 °C).

## 7. Temperature Control and Measurement

7.1 Maintain the test environment (controlled-temperature room, furnace, or cold box) at a constant temperature by a suitable automatic device. This is the most important single factor in a stress-relaxation test since the stress-relaxation rate, dimensions, and constraint conditions of the specimen depend upon the temperature. Any type of heating or cooling that permits close temperature control of the test environment may be used.

7.2 The indicated temperature should be recorded, preferably continuously or at least periodically. Indicated temperature variations of the specimens from the specified temperature due to all causes, including cycling of the controller or position along the specimen gauge length, should not exceed ±5 °F (±3 °C) or ±0.5 %, whichever is greater. These limits should apply initially and for the duration of the test.

7.3 The combined strain resulting from differential thermal expansion (associated with normal temperature variation of the test environment) between the test specimen and the constraint and other variations in the constraint (such as elastic follow up) should not exceed ±0.000025 in./in. (mm/mm).

7.4 Temperature measurement should be made in accordance with Practice E139.

## 8. Vibration Control

8.1 Since stress-relaxation tests are quite sensitive to shock and vibration, the testing machine and mounting should be located so that the specimen is isolated from vibration.

## 9. Test Specimens

9.1 The test specimens should be of a shape most appropriate for the testing method and end use. Wire may be tested in the "as-received" condition. Metal plate, sheet, strip, bar, or rod may be machined to the desired shape.

9.2 Residual stresses can significantly alter the stress-relaxation characteristics of the material, so care should be exercised in machining to prevent alteration of the residual stresses.

9.3 Test specimens shall have a uniform cross-section throughout the gauge length and meet the following tolerances:

| Nominal Diameter or Width | Tolerance, % of Diameter or Width |
|---|---|
| 0.100 in. (2.5 mm) | ±0.5 |
| 0.250 in. (6.4 mm) | ±0.4 |
| 0.375 in. (9.5 mm) | ±0.3 |
| 0.500 in. (12.7 mm) | ±0.2 |

## 10. Test Environment

10.1 If the specified temperature is different from ambient, specimens previously fitted with strain gages or extensometers should be exposed to the specified temperature for a period of time sufficient to obtain dimensional stability before starting the tests.

10.2 The stress-relaxation test may be started immediately upon achieving thermal equilibrium.

## 11. Guide for Processing Test Data

11.1 The remaining stress, relaxed stress, or applied force may be plotted against time or log time. Log stress versus log time plots may also be employed.

11.2 For convenience in comparing the relative stress-relaxation characteristics of materials, the ratio "Fraction Initial Stress Relaxed" may be plotted against time. This ratio is the difference between the initial stress and the remaining stress at any time divided by the initial stress.

## 12. Report

12.1 The report should include as much of the following information as is appropriate:

12.1.1 *Material Being Tested:*

12.1.1.1 Chemical composition,

12.1.1.2 Microstructure,

12.1.1.3 Mechanical properties,

12.1.2 Specimen geometry,

12.1.3 Testing machine or apparatus,

12.1.4 Strain measurement method,

12.1.5 Indicated temperature measurement method,

12.1.6 Atmosphere.

12.1.7 *Stress-Relaxation Test Data:*

12.1.7.1 Initial stress and strain data,

12.1.7.2 Final stress and strain data,

12.1.7.3 Plot of data.

## A. METHOD FOR CONDUCTING TENSION STRESS-RELAXATION TESTS

## 13. Scope

13.1 This test method covers the determination of the time-dependent decrease in stress in a specimen subjected to an uniaxial constant tension strain under conditions of uniform test environment and negligible vibration. It also includes recommendations for the necessary testing equipment.

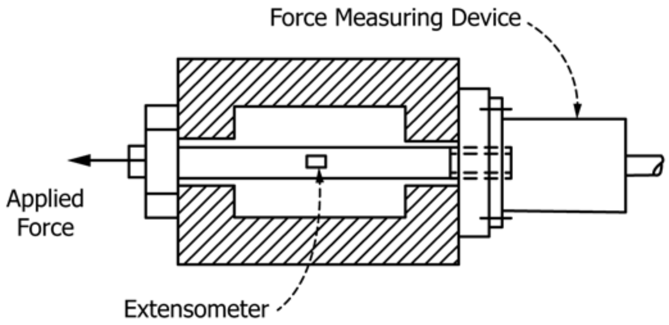


FIG. 4 Tension Stress-Relaxation Test Using Periodic Force Measurement

## 14. Summary of Test Method

14.1 The specimen is subjected to an increasing tensile force until the specified initial strain is attained. The initial and remaining stresses are determined by either of the methods in 4.1.

## 15. Apparatus

15.1 The testing machine shall have an accuracy of 1 % throughout the working range (see Practices E4), and should be calibrated under both decreasing and increasing force applications.

15.2 The testing machine shall incorporate means of adjusting the force in a continuous and automatic manner in order to maintain constant constraint, so that the strain on the specimen is maintained within ±0.000025 mm/mm (in./in) (see Fig. 4).

15.3 Axiality of force application is extremely important and should be checked using the procedure outlined in Practice E1012. Nonaxiality, so measured, should not exceed 15 % in elastic strain readings.

## 16. Test Specimens

16.1 Test specimens of the type, size, and shape described in Test Methods E8/E8M and Practice E139 are generally suitable. The cross section should be uniform throughout the length of the reduced parallel section. To facilitate control of the limiting strain, the gauge length should be longer than those specified in Test Methods E8/E8M. The following round specimen dimensions, for example, have been used successfully:

| Specimen | Gauge Diameter | Gauge Length |
|---|---|---|
| 1 | 0.375 in.<br>(9.07 mm) | 7.000 in.<br>(177.8 mm) |
| 2 | 0.375 in.<br>(9.07 mm) | 6.000 in.<br>(152.4 mm) |
| 3 | 0.252 in.<br>(6.40 mm) | 4.000 in.<br>(101.6 mm) |
| 4 | 0.500 in.<br>(12.70 mm) | 6.000 in.<br>(152.4 mm) |

16.2 Specimens of circular cross-section may have either threaded or shouldered ends for gripping. The threads or shoulders should be concentric with the specimen axis to within + 0.0005 in. ( + 0.01 mm).

16.3 Test specimen surfaces should be smooth and free from nicks and scratches. Eccentricity in the specimen should be minimized, and the force should be applied axially. In machining, precautions should be taken to avoid deformation by bending.

## 17. Grips

17.1 The grips and gripping technique should be designed to minimize eccentricity in loading in the test specimen.

## 18. Procedure

18.1 Mount the specimen in the testing machine and minimize axial misalignment. At room temperature, the strain on opposite sides of the test specimen shall not differ from the average by more than 15 %. Attach the thermocouples and extensometer to the specimen. Heat the specimen to the specified temperature, avoid overheating (Section 7), and hold at this temperature for a period sufficient to reach thermal equilibrium and dimensional stability. Apply the initial force rapidly without shock. The zero time, $t_0$, occurs when the desired test stress is achieved.

18.2 Maintain the limiting strain constant during the duration of the test.

18.3 Any temperature disturbance causing the indicated temperature of the specimen to rise above or below the limits specified in 7.2 is cause for rejection of the test. Exception may be made to this where the time above or below specified temperature is so short that it will not significantly influence the stress-relaxation characteristics of the material under test.

18.4 After the specified time has elapsed, determine changes in force or stress.

## 19. Guide for Processing Test Data

19.1 See Section 11.

## 20. Report

20.1 See Section 12.

## 21. Precision and Bias

21.1 *Precision*—Sufficient multilaboratory tests have not been performed to establish the reproducibility of this test method. These are long-term tests unsuited for routine testing or for specifications in the purchase of material.

21.2 *Bias*—There is no basis for defining the bias for this test method.

## B. METHOD FOR CONDUCTING COMPRESSION STRESS-RELAXATION TESTS

## 22. Scope

22.1 This test method covers the determination of the time-dependent decrease in stress in a specimen subjected to a long-duration, uniaxial, constant compression strain in a uniform test environment and negligible vibration. It also includes recommendations for the necessary testing equipment.

## 23. Summary of Test Method

23.1 The specimen is subjected to an increasing compressive force until the specified initial strain is attained. The initial and remaining stress are determined by either of the methods in 4.1.

NOTE 3—Specimen geometry and frictional end effects play an important role in producing a deviation from the idealized specimen deformation. An initially cylindrical specimen ideally would remain a cylinder, but, because of friction, the specimen cross section is larger midway between the bearing blocks than at either bearing block. The slenderness ratio of the specimen recommended in this procedure is intended to minimize such effects. A more detailed study of these effects is presented by Cook and Larke. (**2**)

## 24. Apparatus

24.1 An apparatus (Fig. 5) similar to that described in Part A, may be used with the following additional requirements. Axiality of force application is extremely important and should be checked using the procedure outlined in Test Methods E9. Nonaxiality upon attaining the specified initial force or strain should not exceed a difference of 10 % in elastic-strain readings on opposite sides of a flat specimen. Measure this difference at the surfaces, which are assumed to be parallel, symmetric to, and as remote as possible from the force-application axis. Round specimens shall be measured at three points spaced 120° apart along the circumference.

24.2 *Testing Machine*—This device shall have no instability in compression within the force range being used. The platens of the testing machine shall remain essentially parallel and free of sidewise motion.

24.3 *Bearing Surfaces*—The bearing surfaces of the heads of the testing machine shall be plane, parallel, and maintained in good condition so that there will be substantially no tilting of the bearing blocks throughout the test (see Test Methods E9).

24.4 *Bearing Blocks*—Both ends of a compression specimen shall bear on blocks with surfaces flat and parallel within 0.0002 in./in. (or mm/mm). The bearing blocks shall be made of suitably hard material such that the blocks will suffer no appreciable permanent deformation during the test. Suitable types of bearing blocks are described in Test Methods E9.

24.5 *Alignment Device*—A suitable alignment device, such as that shown in Test Methods E9, should be used.

## 25. Test Specimens

25.1 Test specimens of the type, size, and shape described in Test Methods E9 are generally suitable. Solid cylindrical specimens with an $L/D$ (length/diameter ratio) of 8 to 10 should be used. Other test specimens of special materials or for special forms of material may be used.

25.2 Thin-sheet specimens described in Test Methods E9 may be used when appropriate anti-buckling fixtures for lateral support are used.

25.3 *Preparation of Specimens:*

25.3.1 Specimens for compression stress-relaxation tests of metals should be prepared in accordance with Test Methods E9. Care in machining should be exercised so that residual stresses are minimized.

25.3.2 Test specimen surfaces should be smooth and free from nicks and scratches. Special care should be exercised to minimize eccentricity in the specimen. In machining and handling, precautions should be taken to avoid deformation by bending.

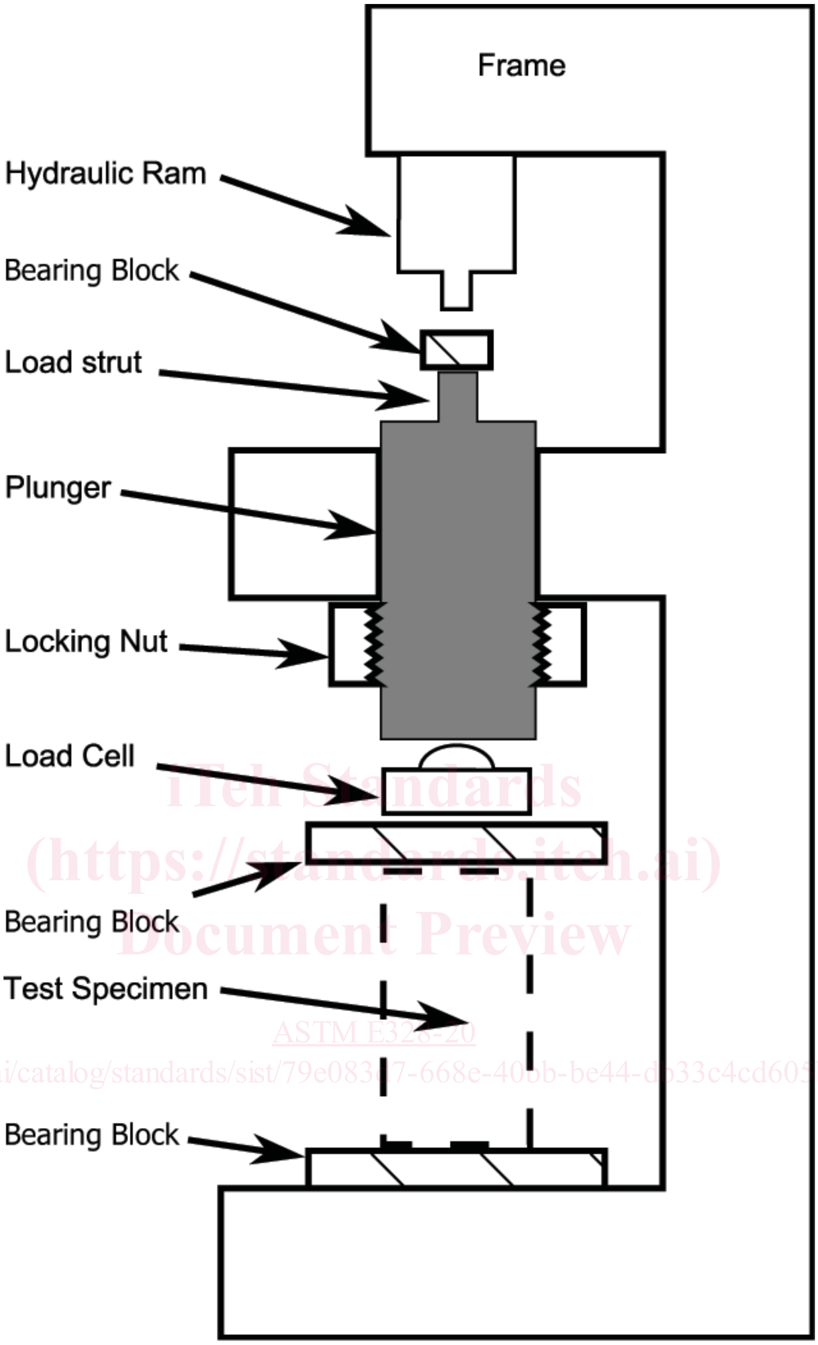


FIG. 5 Compression Stress-Relaxation Test

## 26. Procedure

26.1 Mount the specimen, preferably in an alignment device (see 24.5), minimize axial misalignment, and attach the extensometer and thermocouples. Axiality of force application should be in accordance with 24.1. For elevated-temperature tests, heat the specimen to the specified temperature without overheating (see Section 7). Maintain the specimen at the specified temperature for a time sufficient to reach thermal equilibrium and dimensional stability (see 7.3) before applying initial stress.

26.2 Apply the initial stress without shock. The stress-application rate shall not exceed 100 ksi/min (690 MPa/min). Define the instant that the desired initial stress is attained as the zero time.

26.3 Maintain the total strain constant within the limits specified in 7.3.

26.4 After the specified time has elapsed, determine the changes in force or stress.