Designation: B1008 – 18

Standard Test Method for Stress-Strain Testing for Overhead Electrical Conductors[1]

This standard is issued under the fixed designation B1008; 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 measurement of the elastic and short-term creep characteristics of conductors for overhead power lines.

1.2 Stress-strain data from tests performed in accordance with IEC 61089 are compliant with this standard.

1.3 Stress-strain data from prior Aluminum Association testing procedures are compliant with this standard.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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

1.6 *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]

E4 Practices for Force Verification of Testing Machines

E83 Practice for Verification and Classification of Extensometer Systems

E220 Test Method for Calibration of Thermocouples By Comparison Techniques

2.2 *Aluminum Association Document:*[3]

Aluminum Association Guide for Stress-Strain and Creep Testing of Conductors, 1999

2.3 *IEC Document:*[4]

IEC 61089:1991 Appendix B, Stress-strain Test Method

3. Terminology

3.1 *Definitions:*

3.1.1 *banding clamps, n*—any of several means for locking together all strands of a conductor or core sample.

3.1.2 *composite conductor, n*—a conductor made of two distinct elements, a single wire or stranded core primarily used for reinforcement or support and an outer stranded component of a second, more conductive material.

3.1.3 *conductor stress-strain, n*—elastic and short-term creep behavior of a conductor.

3.1.4 *creep, n*—permanent elongation of a material under stress, for a given temperature and time.

3.1.5 *elastic strain, n*—elongation caused by stress that is completely recovered when the stress is released.

3.1.6 *final modulus, n*—a linear relationship between stress and strain after the conductor has experienced its maximum strain.

3.1.7 *gauge length (gauge section), n*—the distance over which the strain is measured.

3.1.8 *gauge rod, n*—the rigid frame used to set the gauge length.

3.1.9 *homogeneous conductor, n*—a conductor made of a single wire or stranded using strands of the same material.

3.1.10 *initial modulus, n*—a fitted curve through test data that describes the expected behavior of the conductor during loading.

3.1.11 *modulus of elasticity (MOE, elastic modulus, E), n*—the slope of the linear, elastic portions of the stress-strain data for a conductor or conductor component.

[1] This test method is under the jurisdiction of ASTM Committee B01 on Electrical Conductors and is the direct responsibility of Subcommittee B01.02 on Methods of Test and Sampling Procedure.

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[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.

[3] Available from Aluminum Association, 1400 Crystal Dr., Suite 430, Arlington, VA 22202, http://www.aluminum.org.

[4] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, 1st Floor, P.O. Box 131, CH-1211, Geneva 20, Switzerland, http://www.iec.ch.

3.1.11.1 *virtual stress (for composite conductors), n*—stress in a conductor component multiplied by the area fraction of that component.

3.1.12 *one-hour creep, n*—permanent elongation of the conductor sample after holding it for an hour at various stress levels.

3.1.13 *one-hour modulus, n*—see **initial modulus**.

3.1.14 *plastic strain, n*—permanent deformation after the stress is removed.

3.1.15 *rated breaking strength (RBS), n*—a minimum theoretical tensile value assigned to a conductor calculated from the relevant product specifications.

3.1.16 *rated tensile strength (RTS), n*—see **RBS**.

3.1.17 *sample length, n*—overall length of the conductor, inclusive of the end sections used for gripping.

3.1.18 σ_{core}, *n*—initial load target, in psi (MPa), for the core stress-strain test.

3.1.19 $\sigma_{composite}$, *n*—initial load, in psi (MPa), applied during the composite stress-strain test.

3.1.20 *strain*—fractional change in the original length of a conductor.

3.1.21 *stress, n*—tension in a conductor or conductor component, divided by the solid area of that conductor or conductor component.

3.1.22 *yield, n*—permanent elongation that occurs at and above the nominal yield strength of the conductor or conductor component.

4. Summary of Test Method

4.1 Conductor and, if present, the conductor core are subjected to a series of loading and unloading at progressively higher stress levels to determine the elastic and short-time creep characteristics of composite and homogeneous conductors.

5. Significance and Use

5.1 To model the mechanical characteristics of overhead electrical conductor, stress-strain characteristics must be determined. The most accurate method for determination of these characteristics is a laboratory stress-strain test. These mechanical characteristics can then be used to determine the strain response of a conductor to mechanical loads, and thus predict the sag of the conductor. This can then be used to determine the required installation parameters to provide safe clearance and tension for the conductor usage.

6. Interferences

6.1 *Error Due to Ambient Temperature Change*—Magnitude of the error depends on the ambient temperature profile of the lab and the materials and the relative thermal response times for the gauge rod and the sample. Provided the laboratory is temperature-controlled per the requirements of this standard, the typical strain measurement error from this source is 5 strain-ppm (0.0005 strain%).

6.2 *Errors in the Tension Measurement*—Strain is approximately linear with tension. Therefore the 1 % of reading allowed in the tension measurement translates directly to an additional 1 % of reading error in the strain measurement.

6.3 *Error in Straightening the Sample Prior to Test*—Error from slack due to conductor sag may be considered negligible provided the conductor is supported as specified in 7.7.

6.4 Even with the best possible test accuracy, users should recognize that there are sag prediction errors due to differences in test sample properties versus the properties of the conductor following handling and installation. Prudent line designers provide a safety factor to allow for known uncertainties in sag predictions, including uncertainties in the stress-strain measurement and normal variation in the properties of different conductor lots.

7. Apparatus

7.1 A controlled actuator shall be used to load the conductor in the sequence described in this standard. The actuator may be hydraulic, mechanical lead screw, or any other method capable of ramping smoothly to a target load. Upon reaching the target load, any over-shoot shall be less than 1 % of the target load. See Fig. 1.

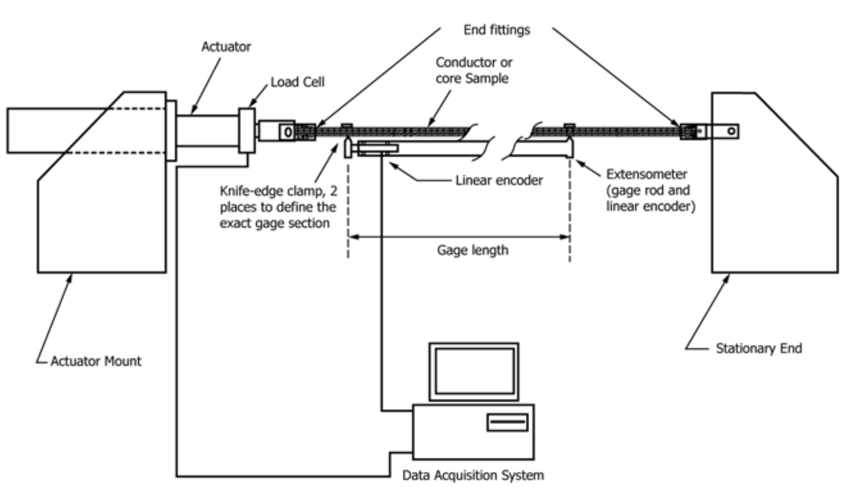

FIG. 1 Elements of the Stress-strain Test Apparatus

7.2 The frame shall be long enough to test samples with lengths specified in 9.3.

7.3 Temperature measurements shall be taken of ambient, sample surface and gauge rod.

7.4 Strain shall be measured with an accuracy of ±0.001 strain% (10 strain-ppm). Resolution of the recorded data shall be 0.00005 strain% (0.5 strain-ppm) or lower.

NOTE 1—This issue has caused confusion because the measurement (strain) and the error are both expressed in percent or ppm. To be clear: the allowable error values in this section are absolute error in strain%, and strain-ppm, and not percent error on the measured value of strain.

7.5 Actuator displacement shall be measured using an instrument meeting the specifications of 11.4.

7.6 Time, tension, strain, actuator position, and all temperature channels must be recorded, as a minimum, at frequency of once per second. During hold periods, the frequency can be reduced to once per five minutes.

7.7 The sample shall be supported in a straight line with a maximum sag of ¼ in. (6 mm) between any two supports. See X2.5 for best practices.

7.8 The ambient temperature during the test shall be between 15 and 40°C, and preferably stable at or near 23°C (73°F). The ambient temperature shall be stable within ±1°C for the duration of the test.

8. Hazards

8.1 Standard industrial safety precautions are appropriate during sample handling and preparation. Coiled samples may whip unexpectedly, and therefore the ends should be restrained. Eye protection is recommended during all phases of sample preparation and testing.

8.2 Chemical and respiratory hazards may exist when handling potting compounds for cast resin end fittings.

8.3 Sample rupture is possible during loading tests. Therefore, safety cages for the testing machine are recommended.

9. Sampling, Test Specimens, and Test Units

9.1 *Conductor Samples:*

9.1.1 The test samples shall be taken from standard production and representative of the production process.

9.1.2 Samples removed from the production line shall have temporary clamps applied inboard of each cut to prevent shifting of any strand or layer relative to the core.

9.1.3 Samples removed from shipping reels shall not include end sections if there is evidence that any strand or layer has shifted and the manufacturing pre-stress has been released.

9.1.4 The end termination used for testing shall prevent shifting on any conductor component. Appendix X2 contains acceptable methods.

9.1.5 The conductor manufacturer, at their sole discretion, may direct the acceptable design for the end termination suitable for their product.

9.1.6 The method used to cut the conductor shall not cause the conductor core or any strand to slip inside the clamp(s).

9.1.7 Samples shall be transported as straight sections, preferably inside a protective tube, or coiled with a coil diameter not less than 40 times the conductor diameter.

9.2 *Core Samples:*

9.2.1 The core sample shall be either taken from a composite sample prepared in accordance with 9.1 (with the aluminum removed), or taken directly from the core pay-off reel.

9.2.2 *End Preparation:*

9.2.2.1 The core sample may be prepared identical to the composite sample, and the aluminum layers removed prior to the test. Alternately, the aluminum may be removed first, and the bare core prepared for the test.

9.2.2.2 The core sample may be taken directly from the original payout reel.

9.3 *Sample Gauge Length:*

9.3.1 The gauge length where strain is measured may not include the 12 in. (30 cm) nearest to the fitting. Minimum gauge length shall be 400× the sample diameter not to exceed 500 in. Shorter gauge lengths may be used provided the laboratory provides justification, demonstrating the accuracy requirements are met.

10. Preparation of Apparatus

10.1 Calibration status and proper operation of the controls shall be verified prior to the start of the test.

11. Calibration and Standardization

11.1 Calibration of the tension instrument shall conform to the requirements of Practices E4.

11.2 Calibration of the strain instrument shall conform to the requirements of Practice E83.

11.3 Calibration of temperature instruments shall be in accordance with Test Method E220, and temperature shall be recorded with a resolution of 0.1°C.

11.4 Actuator displacement shall be measured using an instrument with an accuracy of ±0.004 in (0.1 mm) and resolution of 0.0005 in (0.01 mm).

12. Conditioning

12.1 The sample, the gauge rod, and all instruments shall be at thermal equilibrium with a stable lab ambient during all phases of the stress-strain test.

13. Procedure

13.1 *Composite Conductor:*

13.1.1 Install the sample and apply an initial load of 8 % of the conductor RBS or 1000 lb (4.45 kN), whichever is less.

13.1.2 Remove sag by supporting the weight of the sample (see 7.7).

13.1.3 Install the extensometer and set to zero strain while the conductor is at initial load.

13.1.4 Increase load smoothly to 30 % of the conductor RBS within two minutes but not less than one minute. Hold load at 30 % RBS for 30 ± 0.25 min,

13.1.5 Return to the initial load at the same rate as used during the increase to load (Note 2).

NOTE 2—Initial load may be modified to 50 % of the prior load hold target, if necessary, to avoid excessive bird caging of the aluminum strands for conductors with annealed aluminum strands and a low-modulus core.

13.1.6 Increase load smoothly to 50 % of the conductor rating at the same rate used for the ramp to 30 % RBS. Hold for 60 ± 0.25 min.

13.1.7 Return to the initial load (Note 2).

13.1.8 Increase load smoothly to 70 % of the conductor rating at the same rate used for the ramp to 30 % RBS. Hold for 60 ± 0.25 min.

13.1.9 Return to the initial load (Note 2).

13.1.10 Increase load smoothly to 85 % of the conductor rating at the same rate used for the ramp to 30 % RBS. Hold for 60 ± 0.25 min.

13.1.11 Return to the initial load (Note 2).

13.1.12 Remove the temperature and strain instruments. Inspect the sample and its end fittings and document any unusual conditions (bird caging, broken strands, or movement of any strand in the end grips, for example).

13.1.13 After documentation and disposition of any findings under 13.1.12, pull the sample to rupture at a rate of not greater than 50 % RBS/min and not less than 10 % RBS/min. Simultaneous recording of tension and actuator position are required, as a minimum, every 2.5 % of RBS during the final tensile test. The maximum load reached prior to rupture shall be recorded. See Fig. 2.

NOTE 3—Load hold times are designed to simulate creep during short-time load events during transmission line operation. Long-term creep effects are simulated by creep testing.

13.2 *Conductor Core:*

13.2.1 Determine the initial tension using Eq 1 (the goal is to stress the core as closely as practical to the stress it experienced during the composite stress-strain test):

$$\sigma_{core} = \sigma_{composite}(E_{composite} / E_{core}) \quad (1)$$

where:

σ_{core} = initial load target, in psi, for the core stress-strain test

$\sigma_{composite}$ = initial load, in psi, applied during the composite stress-strain test

$E_{composite}$ = elastic modulus, in psi, found during the composite conductor test

E_{core} = elastic modulus, in psi, for the core

NOTE 4—For composite cores, the manufacturer should provide values for initial moduli. For steel cores, the initial moduli may be taken as:

27.5×10^6 for single-wire steel cores
27.0×10^6 for 7-wire steel cores
26.5×10^6 for 19-wire steel cores

13.2.2 Set the strain indicator to zero with the core at the initial tension.

13.2.3 Subject the core to the same initial strains and hold periods as the core experienced during the composite conductor test. It is best accomplished by pulling the core sample to the strain value recorded at the start of each hold during the composite test, and maintain tension constant for the duration of the hold period.

13.2.4 After the final hold period, return to the initial tension. Inspect the sample and its end fittings and document any unusual conditions (bird caging, broken strands, or movement of any strand in the end grips, for example).

13.2.5 Remove any delicate instruments.

13.2.6 Pull the sample to rupture at a rate of not greater than 50 % of rating/min and not less than 10 % of rating/min. Simultaneous recording of tension and actuator position are required, as a minimum, every 2.5 % of RBS during the final tensile test. The maximum load reached prior to rupture shall be recorded.

14. Calculation or Interpretation of Results

14.1 An example of the calculation and interpretation of the results is included in Appendix X1.

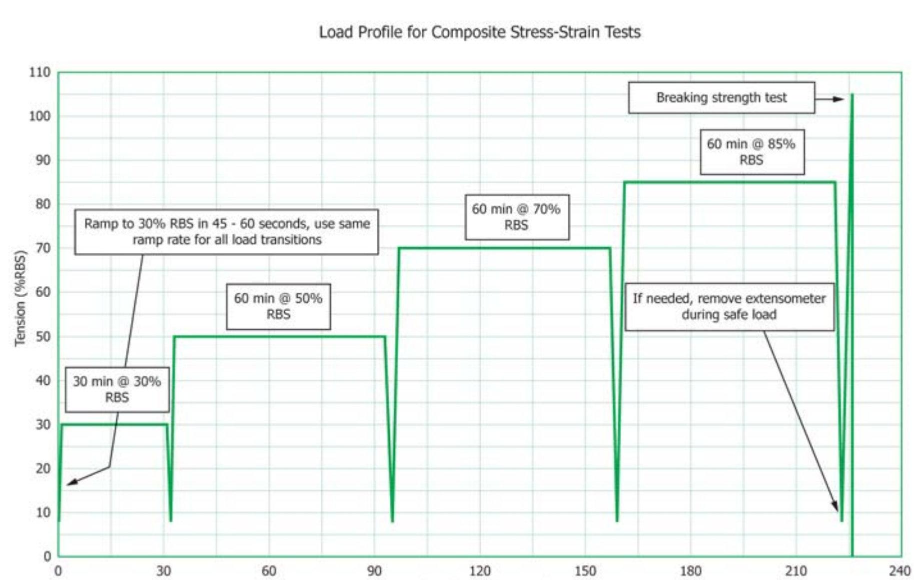

FIG. 2 Load Profile for Composite Stress-strain Test

15. Report

15.1 The report shall contain, as a minimum, the following information:

15.1.1 Date of the test and person(s) responsible for the test results.

15.1.2 Identity and source of the sample material, including basic physical dimensions (nominal and actual strand diameters and lay lengths).

15.1.3 Method(s) used for end preparation.

15.1.4 Anomalous conditions that affect any of the test results, including control excursions, slippage or distortion of the end grips, or temperature excursions greater than the maximum allowable under this standard.

15.1.5 Plots of the recorded test data, including the following:

15.1.5.1 Time versus recorded load and recorded strain for the composite test.

15.1.5.2 Time versus recorded load and recorded strain for the core test, if required.

15.1.5.3 Method employed for temperature compensation of the data, if required.

15.1.5.4 Stress versus strain, and the method used for removing the effect of the bias tension from the results.

15.1.5.5 Construction of the stress-strain graphical model.

15.1.5.6 Coefficients of the equations for the outer component and core components using the following format:

(1) Outer Component:

(a) K0: coefficient for the constant of the initial modulus equations.

(b) K1: coefficient for the linear term of the initial modulus equations.

(c) K2: coefficient for the "x^2" term of the initial modulus equations.

(d) K3: coefficient for the "x^3" term of the initial modulus equations.

(e) K4: coefficient for the "x^4" term of the initial modulus equations.

(f) Elasticity: coefficient for the final modulus equation.

(g) Ambient Temperature: temperature at which the test was conducted.

15.1.5.7 *Core Component:*

(a) K0: coefficient for the constant of the initial modulus equations.

(b) K1: coefficient for the linear term of the initial modulus equations.

(c) K2: coefficient for the "x^2" term of the initial modulus equations.

(d) K3: coefficient for the "x^3" term of the initial modulus equations.

(e) K4: coefficient for the "x^4" term of the initial modulus equations.

(f) Elasticity: coefficient for the final modulus equation.

16. Precision and Bias

16.1 *Load (Tension)*—Bias shall be in accordance with Practices E4. A precision of ±1 lb (2 N) is suggested for tensions up to 10 000 lb (4.4 kN), and ±10 lb (20 N) for tensions above 10 000 lb (4.4 kN).

16.2 *Stress*—Stress shall be computed based load (tension) and nominal area. Stress is not a direct measurement, and therefore precision and bias do not apply.

16.3 *Strain*—Recent advances in extensometry have significantly improved the accuracy of strain measurements. Commercially available instrumentation allow for linear resolution on the order of one micron. With measurement quality now available, the dominant factors affecting the strain measurement are the error in removing sample sag/slack, and the spurious thermal and elastic strains in the sample and in the gauge rod. Bias for the new generation of instrumentation has not been established. The strain measurement accuracy goal of 10 strain-ppm is based on what is considered reasonably achievable with the present generation of instruments and best practices. A precision of 0.5 strain-ppm is achievable with commercially-available instrumentation

16.4 *Temperature*—Stable temperature is required to avoid spurious thermal effects in the strain measurement. Bias in the temperature measurement is of no consequence, provided repeatability and a precision of ±0.1°C is achieved

17. Keywords

17.1 conductor; modulus; strain; stress

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL CALCULATION, INTERPRETATION AND REPORT

X1.1 Composite Conductor Stress Strain

X1.1.1 Plot elapsed time versus all of the raw test data, and verify the following:

X1.1.1.1 Load ramp rate and tension holds are in accordance with the required test profile requirements (see Fig. 2).

X1.1.1.2 Strain data and load data track in a reasonable manner.

X1.1.1.3 Document any anomalies including strand breaks or slippage of a conductor component or strand in the end fittings.

X1.1.1.4 Check the temperature data, and correct strain data for temperature effects, if required. Temperature corrections are needed if the gauge reference rod and the conductor sample are made of different materials and the temperature changes by more than ±2°C during the test.

X1.1.2 Plot the raw test data, with strain in percent on the X-axis, and stress in psi on the Y-axis (see Fig. X1.1).

X1.1.2.1 Construct the initial modulus curve through the initial value (0, initial stress), and the final reading of each load hold period (see Fig. X1.2).

X1.1.2.2 Fit a 4th-order polynomial equation to the curve defined in 15.1.5.6 (see Fig. X1.2).

X1.1.2.3 Using the fit equation and a mathematical problem solver, solve for the intercept between the fit curve and the X-axis. Hint: point is (-xxx, 0) on the fit curve (see Fig. X1.3).

X1.1.2.4 Alternately, compute the intercept using a linear fit to the elastic region at the start of loading.

X1.1.2.5 Add the strain found in X1.1.2.3 or X1.1.2.4 to the strain data recorded during the test. Plot the new strain values and the original stress values to obtain a stress-strain curve with the starting point shifted to (0,0), as required by physics. This step is necessary to remove the error due to the starting load when the strain instrument was set to zero (see Fig. X1.3). Fit a 4th order polynomial equation through the shifted data points. This equation defines the initial modulus for the conductor.

X1.1.2.6 Construct a shifted initial modulus curve through the modified test data. Extrapolate the fit equation to 1 % strain, and verify the extrapolated data behaves as expected.

X1.1.2.7 Construct the final modulus line through the best linear region during the unloading from the 85 % load hold. Determination of final modulus can be optionally made after unloading at 50 or 70 % load hold, by agreement between client and supplier.

X1.1.3 *Core Stress-strain:*

X1.1.3.1 Follow the same steps as X1.1, and construct the core stress-strain chart.

X1.1.4 *Stress-strain Model and Coefficients:*

X1.1.4.1 Plot composite stress-strain curve-fit equation with strain on the x-axis, and stress on the y-axis (see Fig. X1.4).

X1.1.4.2 Normalize the core stress-strain data by multiplying all core stress values by the core fraction (core area divided by total conductor area). Plot the virtual core stress-strain data on the chart with the composite data.

X1.1.4.3 Subtract the normalized core curve from the composite curve. The result is the virtual aluminum stress. Plot the aluminum data on the stress-strain chart, and verify the following (see Fig. X1.4):

(1) Composite initial curves should pass through (0,0). Core and aluminum initial curves should also start at the origin.

(2) Final composite should intersect final core at the same strain that the aluminum final reaches zero stress

(3) Final composite and final core are the same line.

X1.1.5 List the coefficients for the linear and polynomial equations in a format suitable for pasting into the appropriate line design or analysis program. Note that the computer programs based on the Alcoa Graphical Method operate by summing the contribution of the aluminum and core components, and therefore the composite curve is not used(see Fig. X1.4).

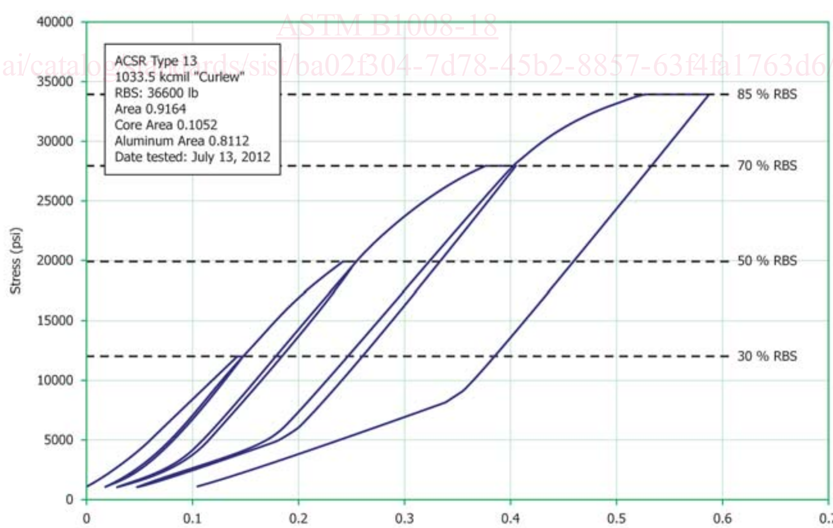

FIG. X1.1 Example Composite Stress Strain Data