Designation: D6992 – 16

Standard Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method[1]

This standard is issued under the fixed designation D6992; 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 accelerated testing for tensile creep, and tensile creep-rupture properties using the Stepped Isothermal Method (SIM).

1.2 The test method is focused on geosynthetic reinforcement materials such as yarns, ribs of geogrids, or narrow geotextile specimens.

1.3 The SIM tests are laterally unconfined tests based on time-temperature superposition procedures.

1.4 Tensile tests are to be completed before SIM tests and the results are used to determine the stress levels for subsequent SIM tests defined in terms of the percentage of Ultimate Tensile Strength (T_{ULT}). Additionally, the tensile test can be designed to provide estimates of the initial elastic strain distributions appropriate for the SIM results.

1.5 Ramp and Hold (R+H) tests may be completed in conjunction with SIM tests. They are designed to provide additional estimates of the initial elastic and initial rapid creep strain levels appropriate for the SIM results.

1.6 This method can be used to establish the sustained load creep and creep-rupture characteristics of a geosynthetic. Results of this method are to be used to augment results of Test Method D5262 and may not be used as the sole basis for determination of long term creep and creep-rupture behavior of geosynthetic material.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 *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:*[2]

D2990 Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics

D4439 Terminology for Geosynthetics

D4595 Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method

D5262 Test Method for Evaluating the Unconfined Tension Creep and Creep Rupture Behavior of Geosynthetics

3. Terminology

3.1 For definitions related to geosynthetics see Terminology D4439.

3.2 For definitions related to creep see Test Methods D2990 and D5262.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *creep modulus—in SIM analysis*, the load divided by the percent strain at any given point in time.

3.3.2 *dwell time*—time during which conditions (particular load) are held constant between temperature steps.

3.3.3 *mean test temperature*—the arithmetic average of all temperature readings of the atmosphere surrounding the test specimen for a particular temperature step, starting at a time not later than established temperature ramp time, and finishing at a time just prior to the subsequent temperature reset.

3.3.4 *offset modulus method or pointing*—data analysis method used to normalize any prestrain in the samples by shifting the origin of a stress versus strain curve to an axis origin of coordinates; that is, to coordinates (0,0).

3.3.5 *ramp and hold (R+H) test*—a creep test of very short duration; for example, 100 to 1000 s.

[1] This test method is under the jurisdiction of ASTM Committee D35 on Geosynthetics and is the direct responsibility of Subcommittee D35.02 on Endurance Properties.

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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.

3.3.6 *shift factor*—the displacement along the log time axis by which a section of the creep or creep modulus curve is moved to create the master curve at the reference temperature. Shift factors are denoted by the symbol AT when the displacements are generally to shorter times (attenuation) or the symbol AT when the displacements are generally to longer times (acceleration).

3.3.7 *stepped isothermal method (SIM)*—a method of exposure that uses temperature steps and dwell times to accelerate creep response of a material being tested under load.

3.3.8 *tensile creep*—time-dependent deformation that occurs when a specimen is subjected to a constant tensile load.

3.3.9 *tensile creep-rupture*—time dependent rupture that terminates a creep test at high stress levels.

3.3.10 *time-temperature superposition*—the practice of shifting viscoelastic response curves obtained at different temperatures along a horizontal log time axis so as to achieve a master curve covering an extended range of time.

3.3.11 *ultimate tensile strength (T_{ULT})*—short term strength value used to normalize creep rupture strengths.

3.3.12 *viscoelastic response*—refers to polymeric creep, strain, stress relaxation or a combination thereof.

4. Summary of Test Method

4.1 *SIM*—A procedure whereby specified temperature steps and dwell times are used to accelerate viscoelastic creep characteristics during which strain and load are monitored as a function of time.

4.1.1 *Tensile Creep*—Constant tensile load in conjunction with specified temperature steps and dwell times are used to accelerate creep strain response.

4.1.2 *Tensile Creep-Rupture*—A tensile creep test where high stress levels are used during testing to ensure rupture, while specified temperature steps and dwell times are used to accelerate creep strain response characteristics. Strain is monitored as a function of time.

4.2 *Tensile Tests*—Test specimens are rapidly loaded over a short period to achieve rupture. The selection of a suitable tensile test is dependent upon the type of material tested (see Section 8). Tensile tests to support creep and creep-rupture tests are performed under the same control of loading or strain rate as used to load or strain the test specimens during creep or creep rupture tests.

4.3 *R+H*—Test specimens are ramp loaded at a predetermined loading rate to a predetermined load and held under constant load (short term creep test).

5. Significance and Use

5.1 Use of the Stepped Isothermal Method decreases the time required for creep to occur and the obtaining of the associated data.

5.2 The statements set forth in 1.6 are very important in the context of significance and use, as well as scope of the standard.

5.3 Creep test data are used to calculate the creep modulus of materials as a function of time. These data are then used to predict the long-term creep deformation expected of geosynthetics used in reinforcement applications.

NOTE 1—Currently, SIM testing has focused mainly on woven and knitted geogrids and woven geotextiles made from polyester, aramid, polyaramid, poly-vinyl alcohol (PVA) and polypropylene yarns and narrow strips. Additional correlation studies on other materials are needed.

5.4 Creep rupture test data are used to develop a regression line relating creep stress to rupture time. These results predict the long term rupture strength expected for geosynthetics in reinforcement applications.

5.5 Tensile testing is used to establish the ultimate tensile strength (T_{ULT}) of a material and to determine elastic stress, strain and variations thereof for SIM tests.

5.6 Ramp and Hold (R+H) testing is done to establish the range of creep strains experienced in the brief period of very rapid response following the peak of the load ramp.

6. Apparatus

6.1 *Grips*—Grips for SIM and R+H tests should be the same as the grips for ultimate strength tensile tests. Neither slippage nor excessive stress causing premature rupture should be allowed to occur.

6.2 *Testing Machine*—A universal testing machine or a dead-weight loading system with the following capabilities and accessories shall be used for testing.

6.2.1 Load measurement and control,

6.2.2 Strain measurement and control,

6.2.3 Time measurement,

6.2.4 Environmental temperature chamber to facilitate control of test conditions,

6.2.4.1 Temperature measurement and control facilities,

6.2.5 Other environmental measurement and control, and

6.2.6 Computer data acquisition and control.

7. Sampling

7.1 The specimens used for tensile, R+H and SIM tests should all be taken from the same sample.

7.2 Remove sufficient test specimens for tensile testing in accordance with the selected tensile testing procedure (see Section 8).

7.3 Remove one test specimen from the sample for each SIM test.

7.4 Remove one test specimen from the sample for each R+H test.

8. Test Specimens

8.1 Geogrid specimens should be single ribs, unless otherwise agreed upon.

8.2 Yarn specimens of geogrids or geotextiles should be single ply or multiple ply strands, unless otherwise agreed upon.

8.3 Geotextile specimens should be 50 mm wide strips, unless otherwise agreed upon.

NOTE 2—Single geogrid ribs and narrow strip specimens are preferred to determine the effect of applied load on the tensile creep properties of the material separate from the effect of sample width on the tensile properties of the material. However, correlation between narrow geotextile strips or single geogrid ribs to wider representative specimens should be established.

8.4 The length of the test specimen is determined by the type of grip used. Refer to specific tensile test procedure for guidance.

8.5 *Number of Tests:*

8.5.1 A single specimen is usually sufficient to define a master creep or relaxation curve using the SIM. However, if only a single SIM test is to be performed, the location of the onset of creep strain or modulus curve should be confirmed using at least two short term creep (R+H) tests.

8.5.2 Generally 12 to 18 specimens are needed to define a stress-rupture curve representing multiple rupture times. Fewer specimens would be needed to define a specific region of the curve, for example the percent T_{ULT} at 1×10^6 h (= 110 year) rupture life.

9. Conditioning

9.1 Tensile and SIM testing shall be conducted using 20 ± 1°C as the reference or temperature standard. If the laboratory is not within this range, perform tensile tests in a suitable environmental chamber capable of controlled cooling and heating. The environmental chamber should have a programmable or set-point controller so as to maintain temperature to 20 ± 1°C. When agreed to, a reference temperature other than 20°C can be utilized. Also, when agreed to, the results of testing under this standard can be shifted from one reference temperature to another.

9.2 Allow the specimen adequate time to come to temperature equilibrium in the laboratory or environmental chamber. Generally this can be accomplished within a few hours (see Note 3).

9.3 Record the relative humidity in the laboratory or environmental chamber for all tests.

10. Selection of Test Conditions

10.1 The standard environment for testing is dry, since the effect of elevated temperature is to reduce the humidity of ambient air without special controls.

10.2 The standard reference temperature is 20°C unless otherwise agreed to. The individual reference temperature for each SIM test is the average achieved temperature of the first isothermal dwell.

10.3 Testing temperatures are to be within ±2°C of the target test temperatures. It is critically important that the test specimen has equilibrated throughout its thickness so as to avoid nonisothermal conditions. Initial trials are necessary to establish this minimum equilibrium time.

NOTE 3—Laboratory experience has suggested that the use of calibrated thermocouples located near, affixed to or embedded within the test specimen may facilitate a successful temperature compliance test for the specimen material. It is suggested that the laboratory perform the planned SIM temperature steps using an unloaded sacrificial test specimen and, with the use of these thermocouples, measure the temperature change of the specimen at its thickest or most mass-dense region. The time required for the specimen to reach the target temperature is recorded and used as the minimum dwell time. The upper limit of the temperature ramp time is not known. Successful tests with some materials have been run with temperature ramp times of up to four minutes.

10.4 Test temperatures are to be maintained within ±1.0°C of the mean achieved temperature.

10.4.1 Temperature steps and dwell times must be such that the steady state creep rate at the beginning of a new step is not so different from that of the previous that it cannot be established within the identified ramp time.

11. Procedures

11.1 The same or similar load or strain control shall be applied to the tensile tests and the load ramp portion of R+H and SIM (creep and creep-rupture) tests. The load rate control (in units of kN per min) that is applied shall achieve a narrow range of strain rates expressed in percent per minute, as agreed upon. Generally 10 ± 3 % per min (or 20 ± 3 % per min for European practice) will be satisfactory.

NOTE 4—A linear ramp of load versus time will not generally result in a linear strain versus time relationship because stress versus strain curves are not linear for most geosynthetic materials.

11.2 Achieve the test loads for R+H and SIM tests within ±2 % of the target loads, and maintain any achieved load within ±0.5 % of its values for the duration of the test. A brief overshoot of the target load that is within ±2 % of the target load and limited to a 1 to 2 s time duration is acceptable for load control systems.

11.3 Replicate test loads for R+H and SIM tests should be within ±0.5 % of the average of the achieved loads for a test set.

11.4 Pretensioning up in accordance with the governing tensile test is acceptable. The method used to define zero strain is to be identified and reported.

11.5 The same or similar grips shall be used for tensile, R+H and SIM tests. Care should be taken to use grips that do not initiate failure or incur slippage at stress levels which may produce specimen rupture (for example, at loads greater than 55 % of T_{ULT} for polyester).

11.6 Inspect grips to ensure loading surfaces are clean and that padding, if used, is free of defects and is secured properly.

11.7 Inspect the specimen installation to be sure the material is properly aligned with the grips and with the loading axis.

11.8 Ensure that the load cell used is calibrated properly such that it will accurately measure the range of tensile loads anticipated.

NOTE 5—The complete heating sequence (i.e., 7 to 8 cycles of 10 000 seconds each, using the temperature steps defined below) shall be run with all the apparatus components installed, but without any specimen, before running the actual test. The measurement given by the load cell shall be analyzed to verify it is not influenced by the heat transferred to the load cell during the test through connectors, hot air flow or any other reason. This observation is specific to each load cell, connector, adaptor, and clamping system used in a specific configuration.

11.9 Ensure that the extensometer used (if any) is calibrated properly such that it will accurately measure the range of tensile strains anticipated. If rupture is anticipated, take precautions to ensure that the rupture event will not damage the extensometer or create a hazard for the machine operator.

11.10 Unless otherwise agreed upon, a 100 mm gauge length shall be used for geosynthetic products and a 250 to 300 mm gauge length shall be used for precursor yam products.

11.11 Time, load and extension data shall be collected at a minimum rate of two readings per second during the initial loading ramp portions of tests and a minimum rate of two readings per minute during constant load portions of tests. If load is applied by means of dead weights, with or without a lever, regular measurement of load after the ramp is not necessary.

11.12 The environmental chamber and temperature cooler shall be capable of maintaining the specimen temperature within ±1°C in range of 0 to 100°C, and of changing the specimen temperature by up to 15°C, within the identified ramp time (see Note 3).

11.13 Unless otherwise agreed upon, the temperature steps for SIM applied to polyester geosynthetics shall not exceed 14°C, The temperature steps for polyolefin geosynthetics shall not exceed 7°C.

NOTE 6—Examples that have been successful are a 14°C step with a 10 000 s dwell for PET, and a 7°C step with a 10 000 s dwell for HDPE.

11.14 Unless otherwise agreed upon, the isothermal dwell time for all SIM tests shall not be less than 10 000 s. Unless otherwise agreed upon, the total time for SIM tests not terminated in rupture shall not be less than 60 000 s.

11.15 The temperature data acquisition rate during SIM shall be a minimum of once per minute.

11.16 If desired, accelerated tensile property tests can be conducted in liquid, vapor, or gaseous mixtures to simulate unique environmental exposures.

12. Calculation

12.1 *Tensile Results:*

12.1.1 Calculate the tensile strength (T_{ULT}) and elongation of the sample.

12.1.2 Plot stress and secant modulus versus strain. It is recommended that the offset modulus method be used to "point" the curves.

NOTE 7—The offset modulus method is described in Test Method D4595, Appendix X2 and has been used in a number of examples in Thornton, J. S., Sprague, C. J., Kloupmaker, J., and Wedding, D. B., "The Relationship of Creep Curves to Rapid Loading Stress-Strain Curves for Polyester Geogrids," *Geosynthetics '99*, Vol. 01.2, Industrial Fabrics Association International, Roseville, MN, April 28-30, 1999, pp. 735-744.

12.1.3 Compute the stress levels to be achieved in R+H and creep and creep rupture tests in percent of UTS.

12.1.4 When specified, identify the range of elastic strains that correspond with the stress levels to be achieved in R+H, creep and creep-rupture tests.

12.2 *Ramp and Hold (R+H) Results:*

12.2.1 Plot stress and secant (creep) modulus versus strain, and strain and secant (creep) modulus versus linear and log time. Use the offset modulus method to point the curves as described in 12.1.2.

12.2.2 Identify the elastic strains at the ramp peaks and the initial rapid creep strain levels for comparison to the ramp and initial creep portions of the SIM results.

12.3 *SIM Test Results (see Appendix for Examples):*

12.3.1 Compute and plot stress and secant (creep) modulus versus strain for each specimen, using the offset modulus method to point the curve. Then plot creep strain, creep modulus, stress and temperature as a function of linear time. Inspect these plots to identify that the test objectives were achieved.

12.3.2 Plot creep modulus (or strain) versus log time after rescaling the elevated temperature segments to achieve slope matching as follows: The semi-logarithmic slopes of a modulus (or strain) curve at the beginning of a higher temperature dwell step should be adjusted to match the slope of the end of the preceding lower temperature by subtracting a time "t" from each of the dwell times of higher temperature steps.

12.3.3 Re-plot the creep modulus (or strain) versus log time after rescaling as above and after employing vertical shifts of the modulus (or strain) data for each elevated temperature to account for system thermal expansion.

12.3.4 Report the creep modulus and strain versus log time curves as rescaled and vertically shifted above and after employing horizontal shifts of the elevated temperature dwell segments to the right of the initial reference temperature dwell segment. The result of this final manipulation should be a smooth master curve for each specimen subjected to SIM. Identify ruptures, if any, at the termination of the master curve.

12.3.5 The rescaling, vertical shifting and horizontal shifting steps generally require some iteration to achieve smooth master curves.

12.3.6 Prepare a plot of the logarithm of the cumulative shift factor versus temperature.

12.3.7 For a creep rupture test series, plot rupture stress as a percentage of (T_{ULT}) versus log (accelerated) time to rupture. Perform linear regression analysis on the data set, selecting time as the dependent variable. If specified, compute the 90 % or 95 % one-sided confidence limits for the creep rupture data.

12.3.8 If specified, determine the instability strain limit (strain and time) as the onset of tertiary creep for each creep-rupture data point and plot this strain value versus log (accelerated) time to instability strain.

12.3.9 Compute the mean temperature and a measure of temperature variation such as standard deviation or extreme values for each temperature step.

13. Report (see Appendix for Examples)

13.1 Report the material type and structure along with the brand name and style nomenclature and the structure (yarn, rib, fabric strip, etc.) of the geosynthetic product. Report the tensile strength of the product. If the tensile strength value is provided by the manufacturer then this should be so stated.

13.2 Document the tests performed and the electronic data files wherein original data is stored.

13.3 Complete and provide the graphs specified in Section 12, and provide tables for creep-rupture values.

13.4 Results generated under this standard shall be stated as having been measured by SIM testing protocol per this test method.

14. Keywords

14.1 creep; creep-rupture; geosynthetics; ramp and hold test; rapid loading tensile test; stepped isothermal method; time-temperature superposition

APPENDIX

(Nonmandatory Information)

X1. Examples of Graphs

X1.1 The following table and graphs are typical of those used in the report section of the SIM test procedure. Figs. X1.1-X1.8 show the results for a polyester yam before and after scaling and shifting.

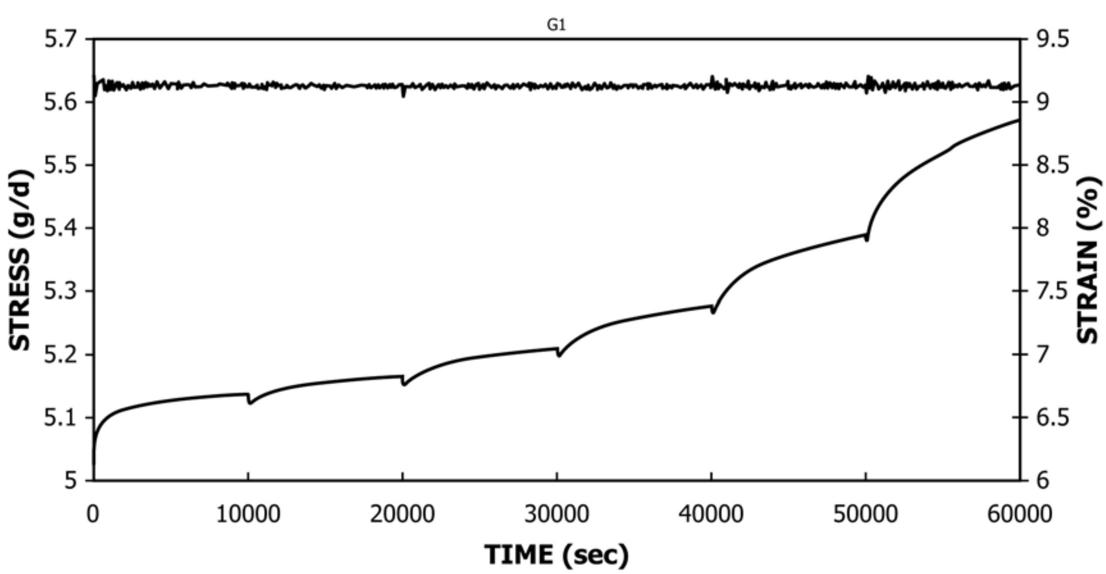

FIG. X1.1 Stress and Creep Strain versus Linear Time

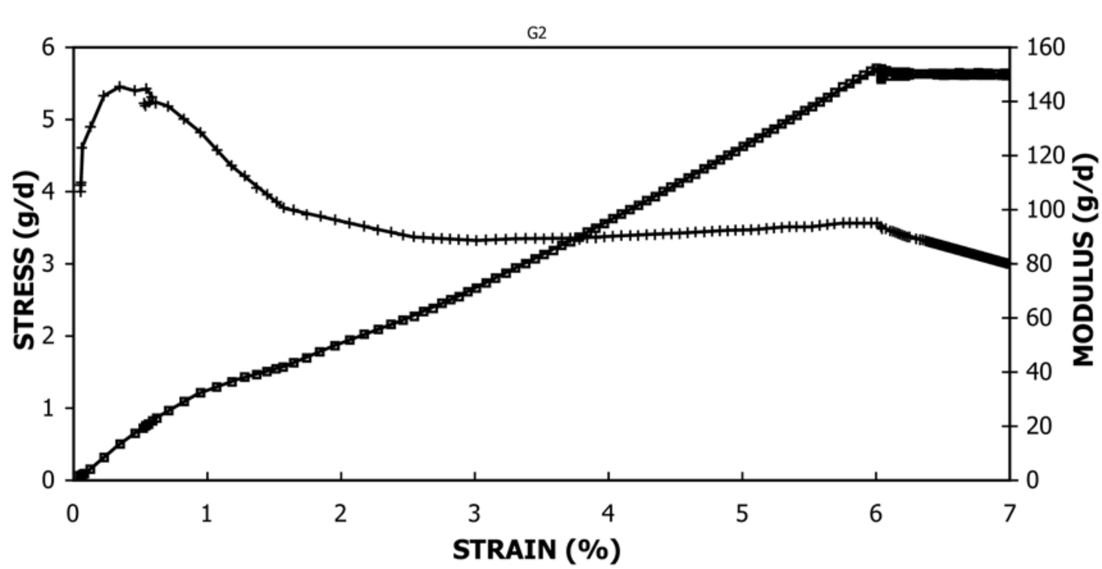

FIG. X1.2 Stress and Secant Modulus versus Strain

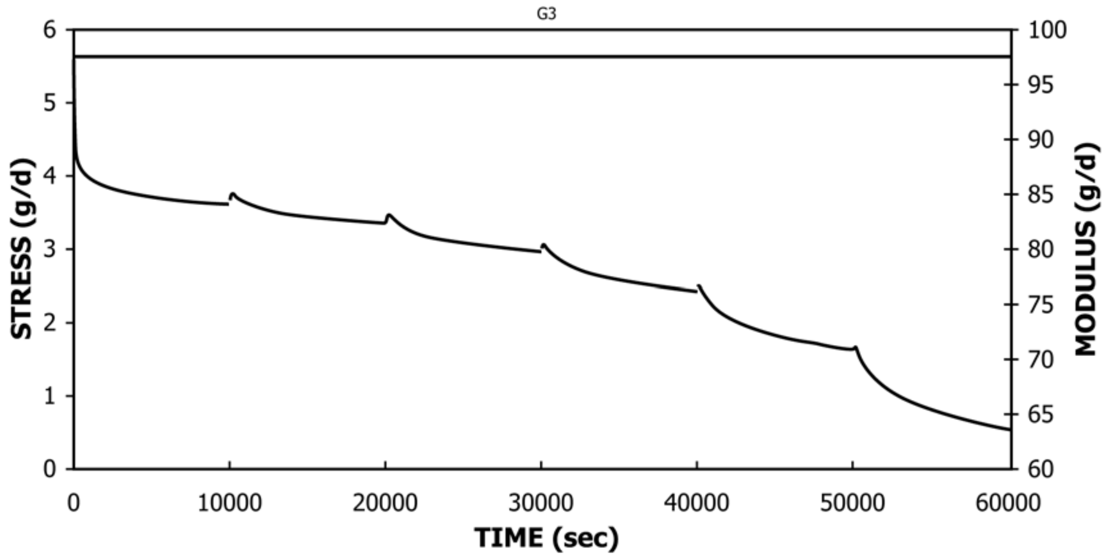

FIG. X1.3 Stress and Creep Modulus versus Linear Time

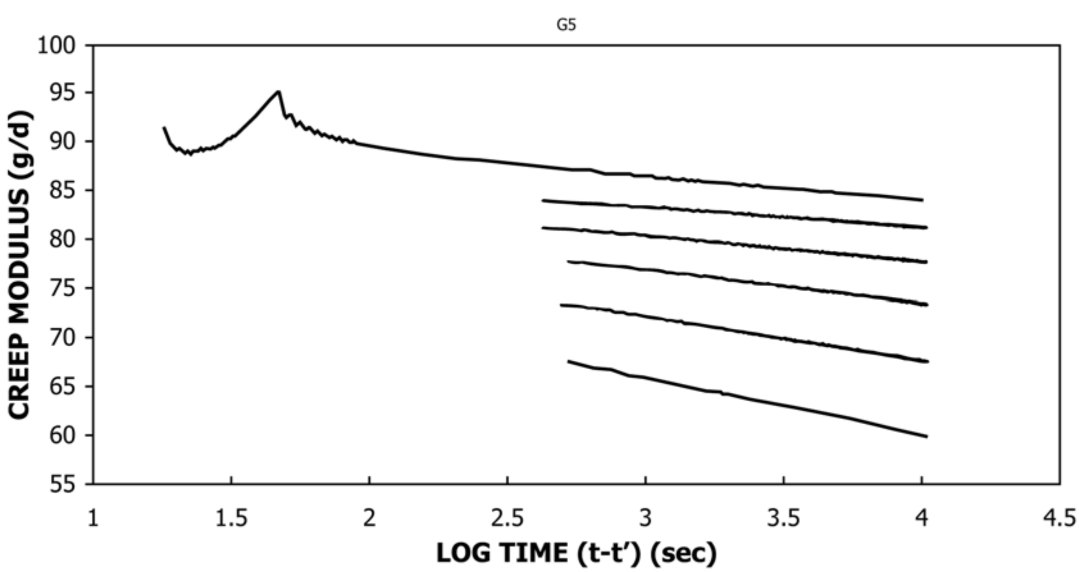

FIG. X1.4 Creep Modulus versus Log Time After Rescaling

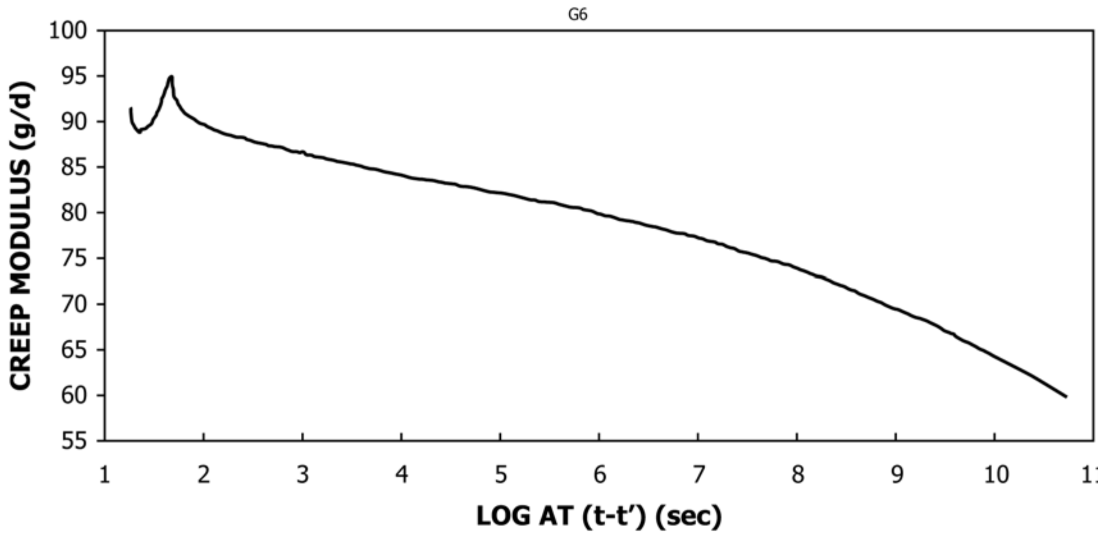

FIG. X1.5 Master Creep Modulus versus Log Time Curve at the Step One Reference Temperature

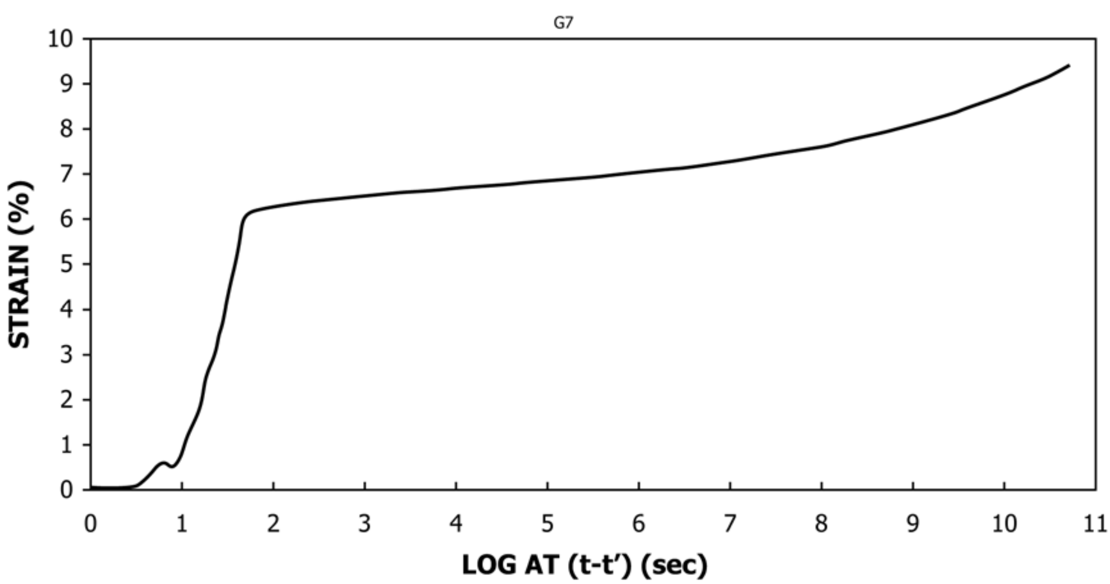

FIG. X1.6 Master Creep Strain versus Log Time at the Step One Reference Temperature

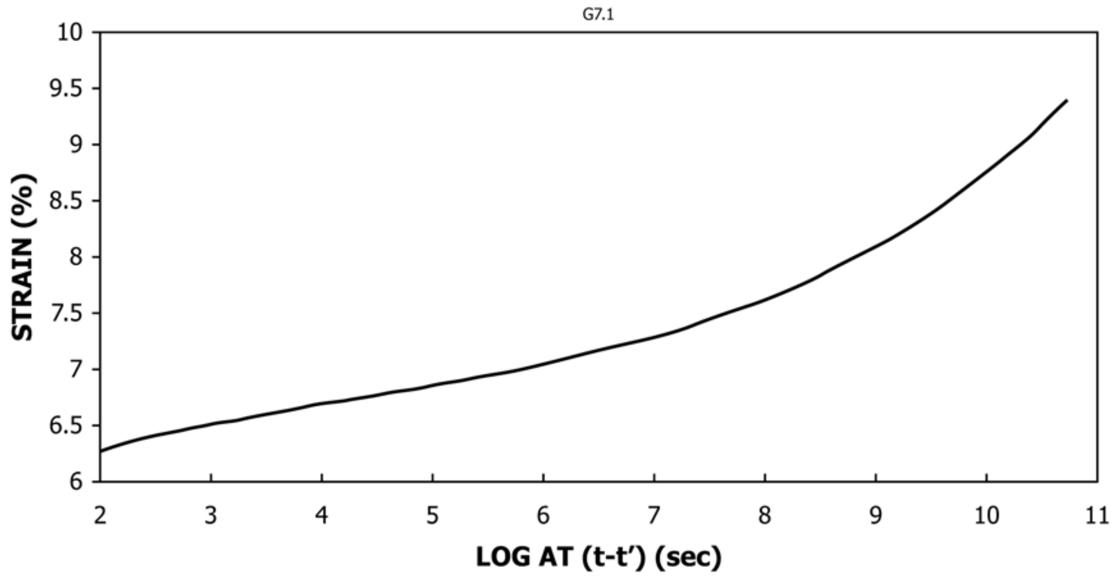

FIG. X1.7 Figure X.6 with Re-scaled Y-axis

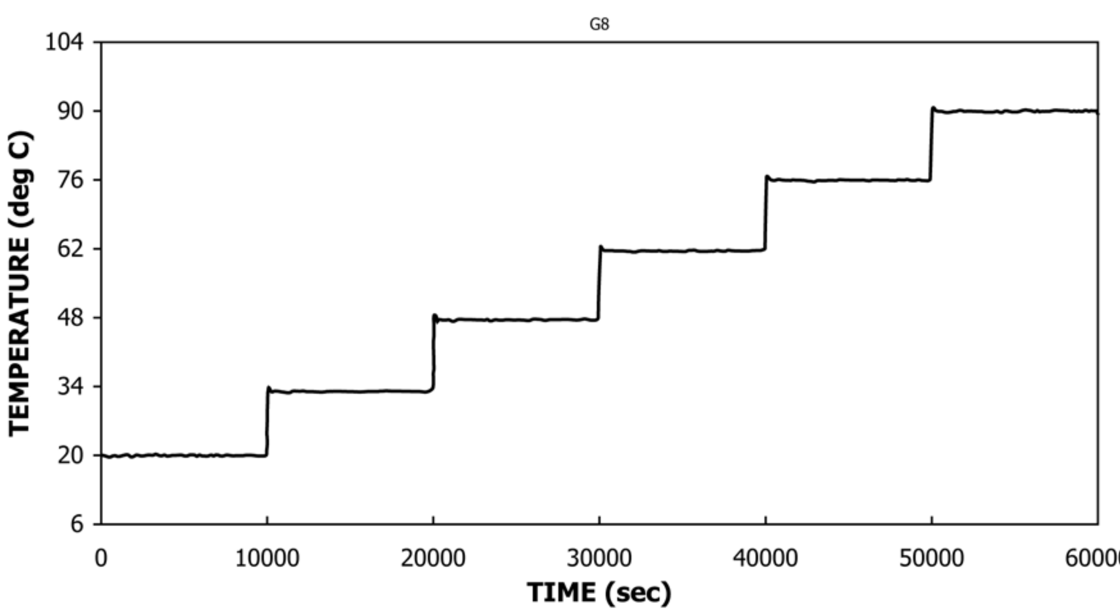

FIG. X1.8 SIM Temperature Steps versus Time Steps