1272-kcmil, 3M^{TM} Composite Conductor

Room-temperature Creep

3M Company
Purchase Orders 0000797065 and 0000869779

NEETRAC Project Number: 03-068

September, 2003
Revised May, 2005

National Electric Energy Testing, Research & Applications Center
NEETRAC
A Research Center of
The Georgia Institute of Technology

Requested by: Mr. Colin McCullough
3M

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Reviewed by: Dale Callaway

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Summary:

3M contracted with NEETRAC for creep testing on 1272-kcmil, 3M^{TM} Composite Conductor in accordance with the 1999 Aluminum Association guideline. This report provides the test data summary and conductor property coefficients for room temperature creep tests.

Samples:

1) Four (4) samples of 1272-kcmil, 3M^{TM} Composite Conductor cut from a reel received from 3M on December 3, 2002.

References:

1) "Proprietary Information Agreement …." Dated 3/27/01.
2) Aluminum Association Guide, Rev. 1999, "A Method of Stress-Strain Testing of Aluminum Conductors and ACSR and A Test Method for Determining the Long Time Creep of Aluminum Conductors in Overhead Lines".
3) 3M Purchase Order 0000797065 (1272 ACCR creep test initiation).
4) 3M Purchase Order 0000869779 (1272 ACCR creep test completion)
5) E-mail dated 6/7/01 from Colin McCullough with details on conductor and core strand properties.
6) NEETRAC Project 02-024, "1272 ACCR Creep Test Initiation".
7) PRJ 03-068, NEETRAC Project Plan.

Equipment Used:

1) Limitorque creep actuators (2 required)
2) Creep frame extensometer (2 required), Control #'s CN 3041 and CN 3042
3) Creep system LabView data acquisition system, Control # CN 3040
4) National Instruments AT-MIO-16XE-50 computer interface
5) Lebow 25,000 lb load cells (2 required), Model 3124-25K (creep tests), Control #'s CN 3056 and CN 3057
6) Omega Engineering DMD load cell conditioners (2 required), used to condition HBM load cells

Procedure:

Testing was conducted in accordance with NEETRAC procedures entitled "PRJ03-024 (initiation) and PRJ03-068 (completion). Work was accomplished on two projects for administrative reasons that did not affect the technical work. The procedures control all technical and quality management details for the project.

Creep Tests:

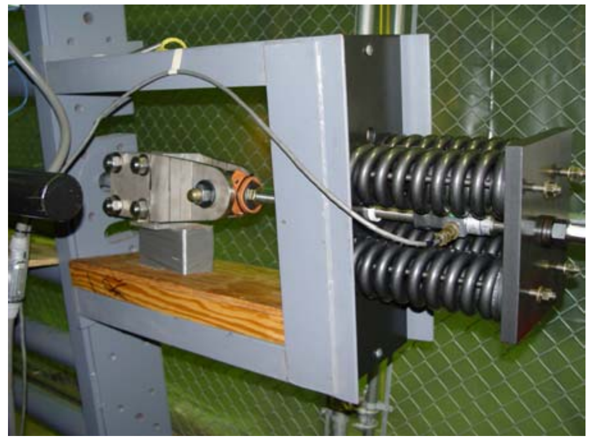
Creep tests were conducted in accordance with the Aluminum Association guide, dated 1999, entitled "A Test Method for Determining the Long Time Tensile Creep of Aluminum Conductors in Overhead Lines". Samples were terminated using special cast-resin terminations, using a process that prevents "bird caging", and thereby preserves the "as-manufactured" distribution of load among the conductor strands and layers. The free-span sample length (between the terminations) is 19 feet. The active gage section is set at 18 feet, +/- 1/16". Load was maintained by a motor-operated lead screw under feedback control. Compression springs were used at the opposite end from the lead screw to provide a cushion for the lead screw, and to minimize tension changes in the event of power outages. Tension was typically maintained within +/- 20 lbs. of setpoint by the system.

Creep test data are extremely temperature sensitive. The test equipment is designed to be somewhat self-compensating. This is accomplished by making the gage reference of the same material as the sample – typically aluminum. Low thermal expansion of MMC caused thermal effects on the gage rod to appear in the test data. Room temperature controls maintained temperature typically within 2^{o} C to minimize temperature effects. Temperature and load compensation are applied to the raw creep data to minimize the effects of load and temperature changes. Compensation smoothes the data, but the creep coefficients change very little as a result of compensation. Both the raw and compensated data are shown on the creep graphs. Compensated data are used for development of the creep equations.

The testing procedure requires that the extensometer be zeroed at the instant that test load is reached. This is accomplished by setting the gage to zero with the sample at 4% RBS, and reading the actual gage length based on the elongation at the instant target load is reached. The adjustment from the nominal to the actual starting gage length changes measured creep by less that 0.1%.

The NEETRAC creep frame was fitted with larger load cells and upgraded hardware to raise the rating to cover loads needed for the 1272 conductor. Photographs 1 and 2 show the revised creep test arrangement. Photograph 1 shows a long view of the creep test frame and the lead screw drive system. Photograph 2 shows a detail of the buffer springs and the load cell used to measure and control sample tension. A second change was implementation of a rapid loading system that takes the conductor to target load smoothly and rapidly. Previously the creep actuators were used to pull the samples to the target tension. The process took several minutes, and time to load was not consistent among the samples. The new loading system was implemented to improve the repeatability of the test.

Photograph 1, long view of creep frame showing lead screw drive



Photograph 2, end opposite drive screw showing buffer springs, load cell, and sample end termination

Results:

Data files containing test data were processed using Microsoft Excel® software to obtain engineering values and graphical presentation. Graphs showing data for each test are shown in Appendix 2.

The Aluminum Association advises that the best-fit line for the data should be used when a straight line is not exhibited on the creep data. Logarithmic equations are a good match for the data from 10 hours to 1000 hours. Creep data for the first 10 hours are difficult to model, because initial conductor condition and loading rate have a significant effect on initial creep. The logarithmic fit equations should work quite well at predicting creep for in-service conductor, provided that the conductor is held at tension for approximately one hour before final termination. It is unlikely that during actual construction a crew will finish termination in less than one hour. Therefore, for most installations, the creep equations will be conservative (predict more creep than actually occurs).

Fits using power equations are shown on the charts, but appear not to match the test data as well as the logarithmic equations.

Test duration was as long as practical based on demand for the equipment, with a target minimum of 1000 hours. Actual durations for the four samples were:

15% RBS:	1101.5 hours
20% RBS:	1027.4 hours
25% RBS	1415.6 hours
30% RBS	1415.5 hours

Figure 1 shows the best-fit creep curves, and the equations for those curves, based on "zero creep" at the moment the target load was reached. Curve fitting was applied to the data from one hour onwards to avoid the short-term creep effects from initial loading that may manifest in the first hour of data.

The following formulas describe the creep properties of the conductor:

Logarithmic Fits:

Creep at 15% RBS:	Creep % = 0.00119*Ln(time in hours)
Creep at 20% RBS:	Creep % = 0.00175*Ln(time in hours)
Creep at 25% RBS:	Creep % = 0.00263*Ln(time in hours)
Creep at 30% RBS:	Creep % = 0.00321*Ln(time in hours)

Power Law Fits:

Creep at 15% RBS:	Creep % = $0.0030301*(\text{time in hours})^{0.1756432}$
Creep at 20% RBS:	Creep % = $0.0031651*(\text{time in hours})^{0.2151232}$
Creep at 25% RBS:	Creep % = $0.0043626*(\text{time in hours})^{0.2127399}$
Creep at 30% RBS:	Creep % = $0.0080399*(\text{time in hours})^{0.1698278}$

Acknowledgement:

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Disclaimer:

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of Energy.

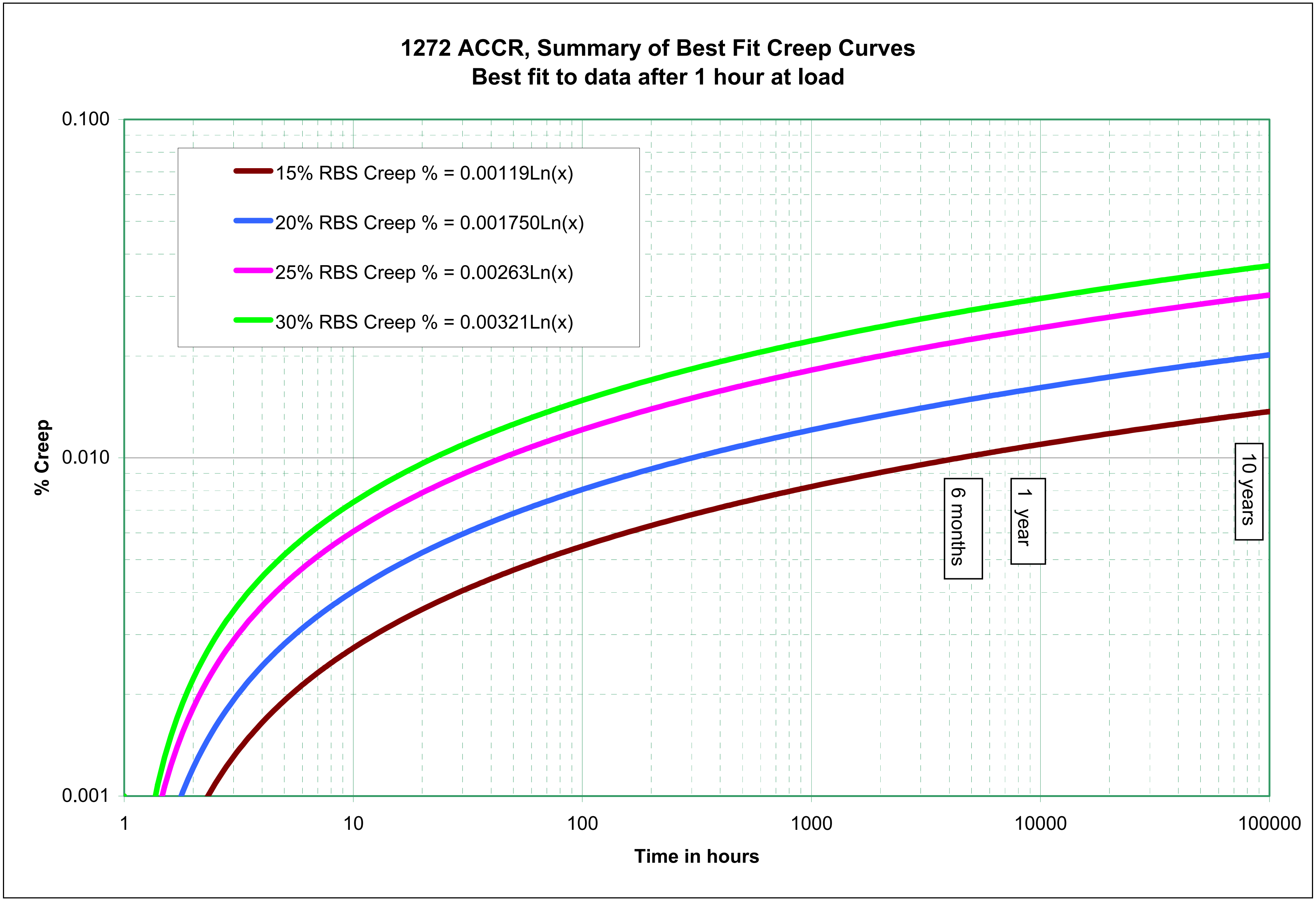

Figure 1, Creep fit and projections based on data starting one hour after reaching load target

Appendix 1, Calibration and Error Analysis for Creep Tests

Mechanical load:

Equipment is certified to exceed requirements of ASTM E4-2003 (+/-1%). "As-found" accuracy is within 0.5%.

Creep (Elongation):

Creep frame extensometer indicator resolves 0.00005". For the 18 ft. gage section, resolution is 0.00005"/216", or 0.000023% (0.23 PPM). Sensor accuracy is +/- 0.0002", or 0.92 PPM. This is a digital measurement. Data are transmitted via digital communication with a PC serial port. Therefore, there is no calibration drift and minimal temperature sensitivity for the transducer. However, the elongation instrument has other error sources that need to be counted. Here is an estimate for those errors:

> Effect of load measurement errors: linear (0.5% of reading)
>
> Effect of mechanical deflections of the gage rod: The gage rod is a 2" x 6" x 1/8" x 19' aluminum box beam, which is extremely stiff. The only bending force is friction in the guide bearings for the displacement sensor. The error is less than 1.0 PPM.
>
> Effect of thermal expansion of the sample and gage rod: For the MMC tests, the aluminum gage rod has a thermal expansion coefficient of 23 PPM/ ^{o}C, while the conductor's nominal expansion coefficient is 17.5 PPM/ ^{o}C. This means that thermal elongation of the gage rod affects the data with an error of approximately 7 PPM/ ^{o}C. Using nominal values for temperature compensation resulted in significant smoothing of the test data. Therefore, compensated data was used for all coefficient calculations.
>
> Effect of starting gage length:
> An error of +/- 1/16" is possible. This is 0.02% of reading, and can be safely neglected.
>
> Effect of delays in the data acquisition system:
> Serial communication results in approximately 8 second cycle time for data acquisition. This is trivial for the creep measurement, but significant when loading rate is high. Data are recorded during and unloading phases of the test, but that data is not considered reliable.

Overall accuracy is calculated based on root-mean squared error estimation. Given the assumptions above, the creep measurement is considered accurate within 1% of reading, plus or minus 2 parts per million. There are instantaneous errors of larger magnitude due to temperature change. These errors are averaged out during the daily temperature cycles. The Aluminum Association specifications do not provide accuracy requirements, but suggest that the resolution of the measurement should be 10 PPM. The system employed has resolution of 0.23 PPM (0.00005 inches in 18 ft).

Appendix 2
Creep Graphs Showing:

Recorded data
Compensated Data
Tension
Temperature
Fit Curves
Fit Equations

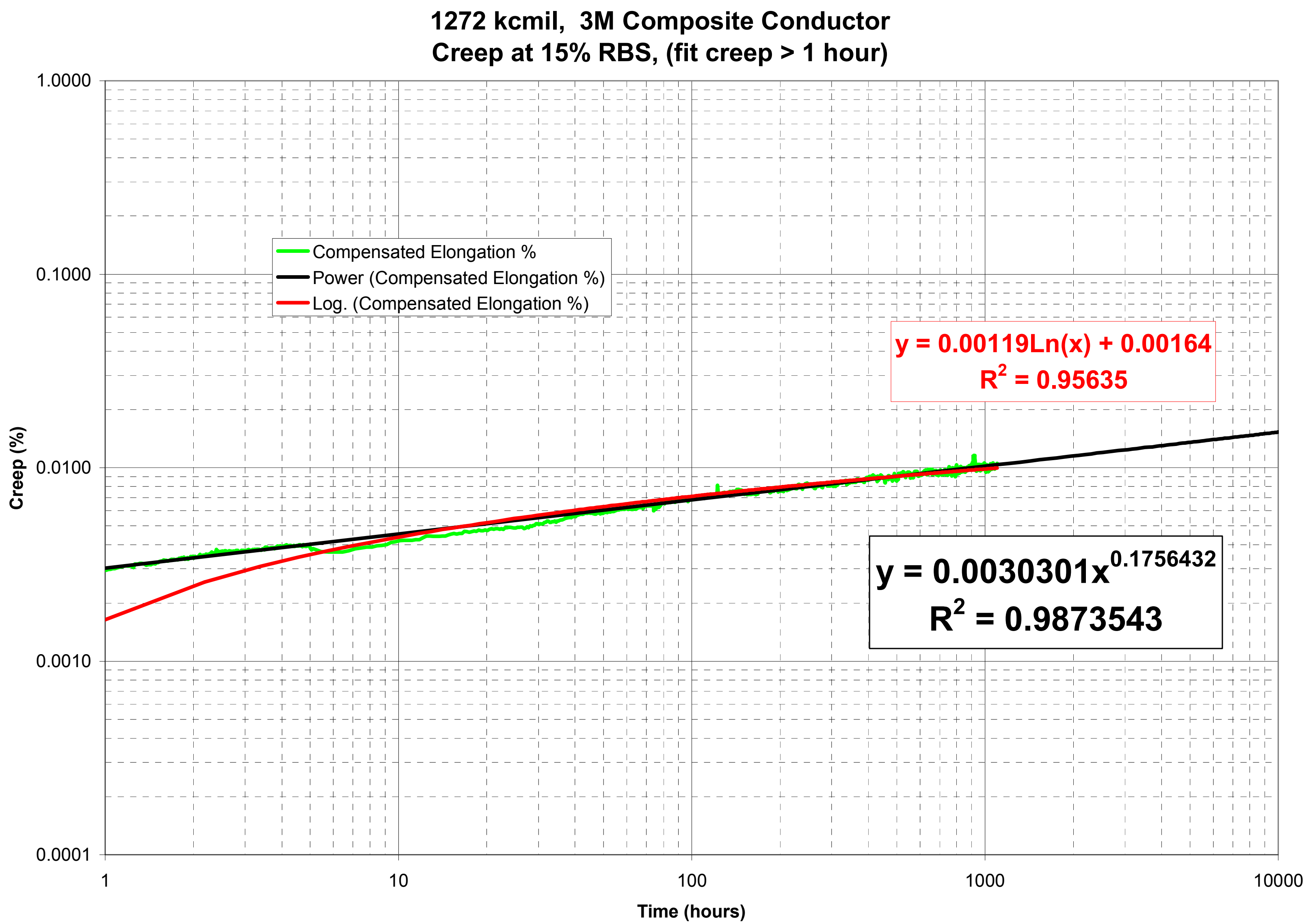

Figure 2, Room Temperature 15% RBS Raw Creep Data, Compensated Data, Tension, Temperature, and Fit Curves
Fit equations are based on data starting one hour after reaching target load

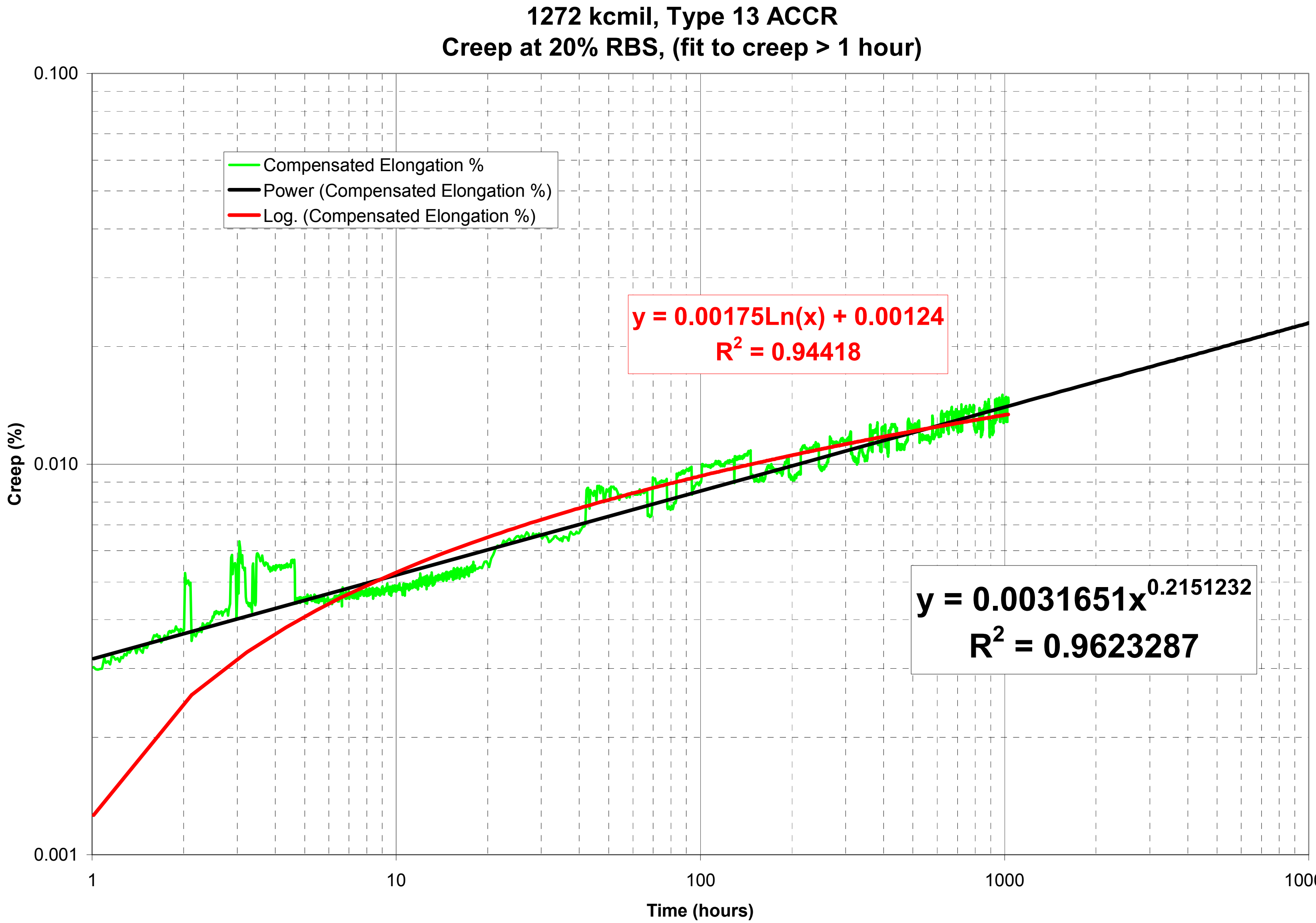

Figure 3, Room Temperature 20% RBS Raw Creep Data, Compensated Data, Tension, Temperature, and Fit Curve equations are based on data starting one hour after reaching target load

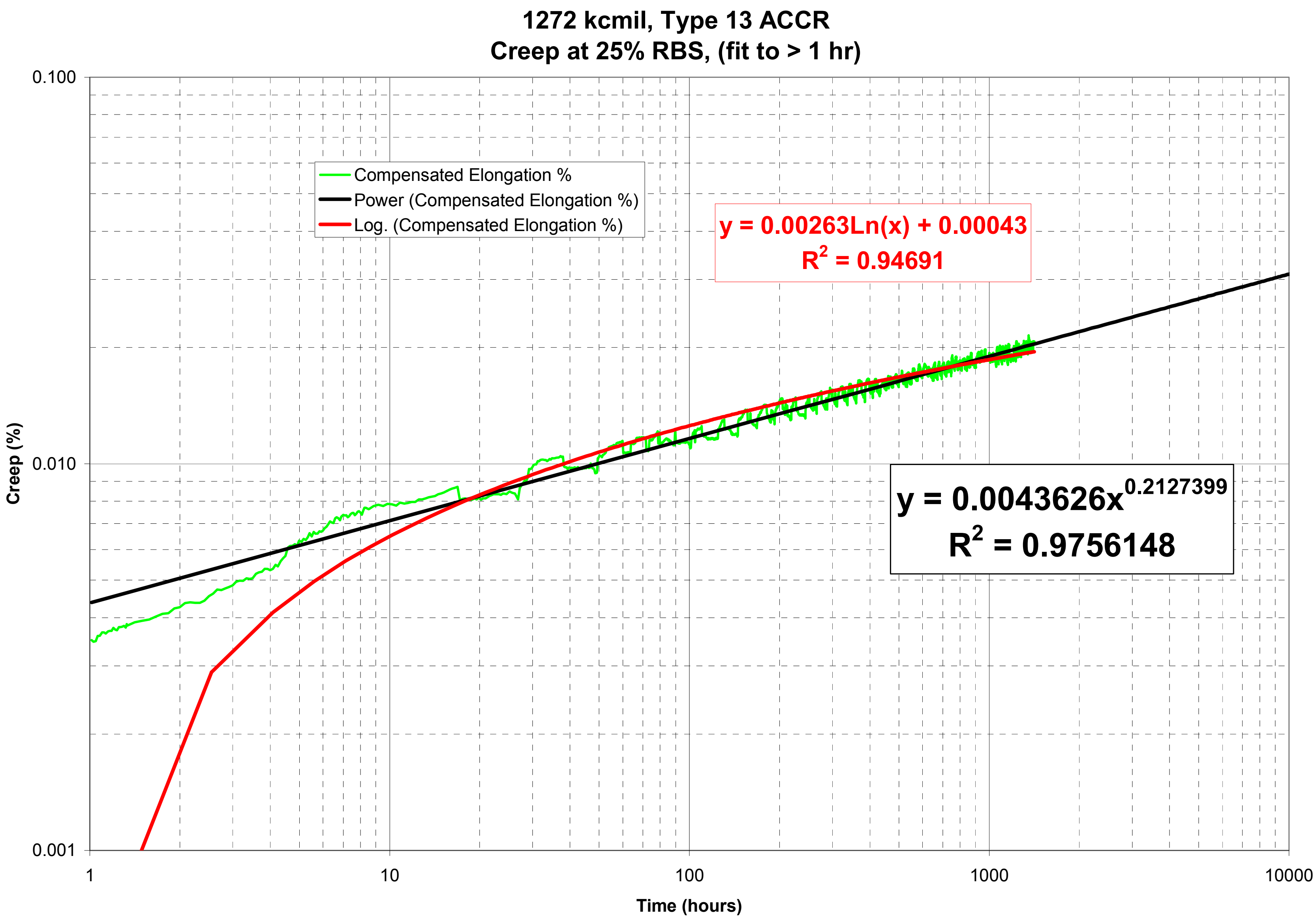

Figure 4, Room-Temperature 25% RBS, Compensated Creep Data and Fit Curve
Creep is referenced to zero one hour after reaching target load

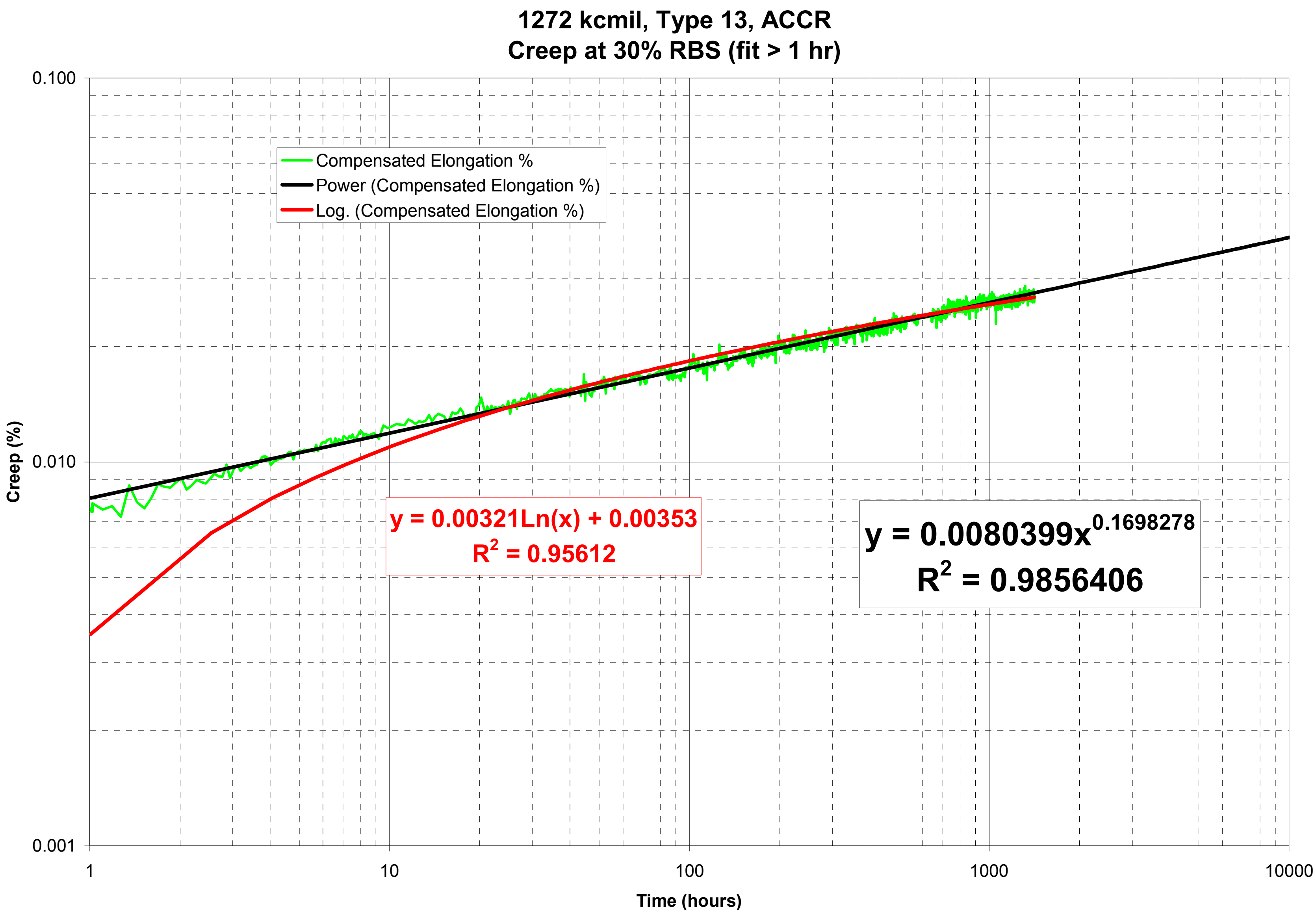

Figure 5, Room-Temperature 30% RBS, Compensated Creep Data and Fit Curve
Fit equations are based on data starting one hour after reaching target load