795 kcmil, $3M^{TM}$ Composite Conductor

Room-temperature Creep

3M Company
Purchase Order 0000630183

NEETRAC Project Number: 02-241

February, 2003
Revised May, 2005

Requested by: Mr. Colin McCullough
3M

Principal Investigator: Paul Springer III, P.E.

Reviewed by: Dale Callaway

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Summary:

3M contracted with NEETRAC for creep testing on 795-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 795 kcmil 3M^{TM} Composite Conductor cut from a reel received from 3M on June 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 0000630183
4) E-mail dated 6/7/01 from Colin McCullough with details on conductor and core strand properties.
5) PRJ 02-241, 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) HBM 10,000 lb load cells (2 required), Model USB-XX108 (creep tests), Control #'s CN 3018 and CN 3019
6) Omega Engineering DMD load cell conditioners (2 required), used to condition HBM load cells
7) Yokogawa Model DC100 data acquisition system, Control # CN 3022

Procedure:

Testing was conducted in accordance with a NEETRAC procedure entitled "PRJ02-241, CONFIDENTIAL – MMC Conductor Evaluation". The procedure controls 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 (outside 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.

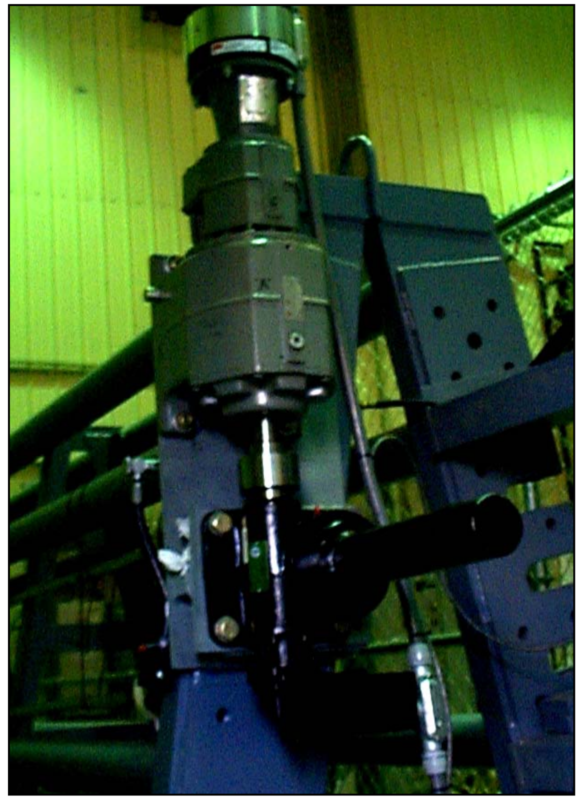
Creep test data are extremely temperature sensitive. The test equipment is designed to be somewhat self-compensating. This is accomplished by making the gage reference of the same material as the sample – typically aluminum. Low thermal expansion of MMC caused thermal effects on the gage rod to appear in the test data. Room temperature controls were upgraded during the project, and temperature effects are less prominent in the later data (25% RBS and 30% RBS creep tests). Temperature and load compensation is 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. Actual gage length at the start of the load hold phase is calculated from test data recorded during initial tensioning.

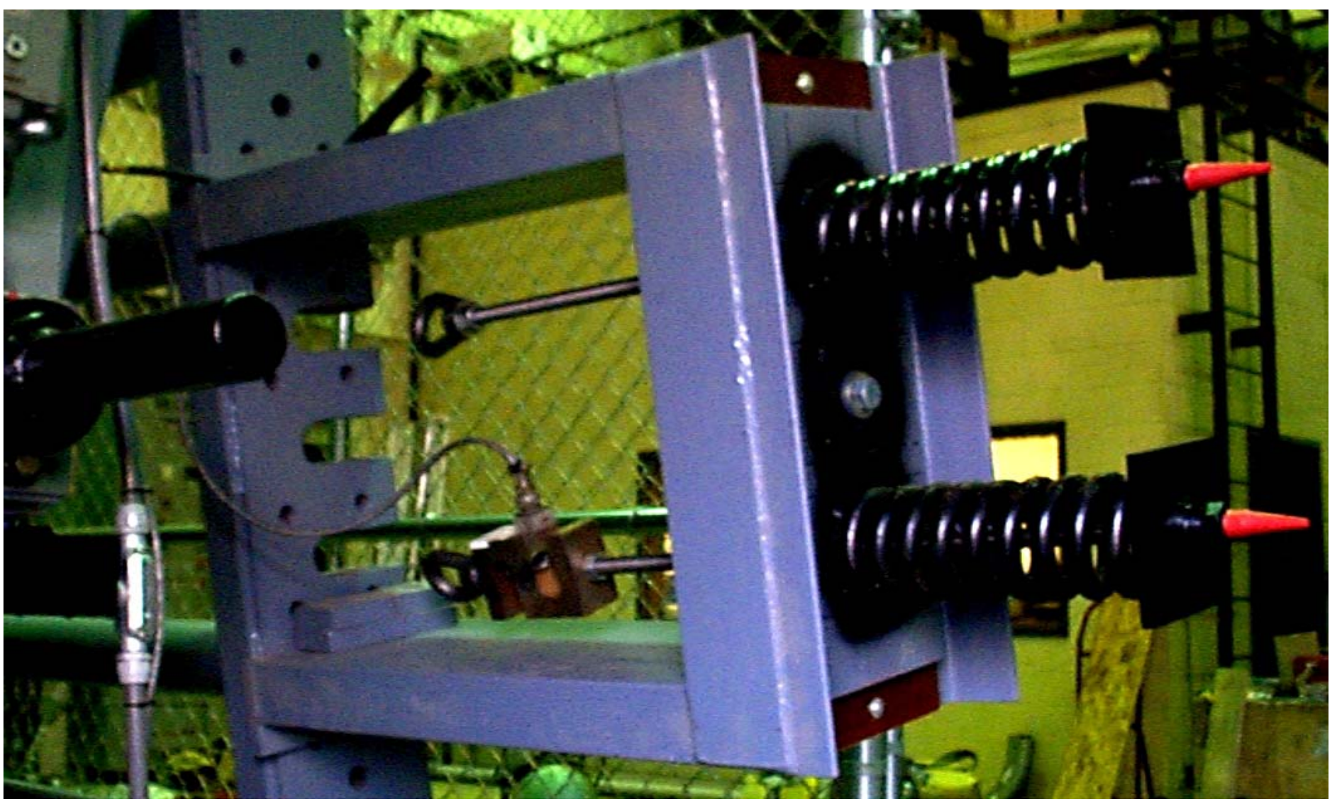
The 30% RBS sample was pulled to near the target load, and then was slackened to correct an equipment problem. As a result, the 30% creep test has less initial creep than the other samples. Figure 1 shows the discrepancy resulting from this change in sample history: the creep curve has a lower offset than expected. This problem was addressed by computing creep and the gage length by fitting data taken after one hour into the load hold phase of the test. Creep referenced to one hour and beyond may be a better representation of field conditions, where conductor typically spends time at tension during the sagging process. Conductor stringing procedures may need to include a conditioning step to prevent excess sag due to short-term creep. Creep equations based on fitting data from one hour onwards (logarithmic fits) and 100 hours onward (power fits) are shown in this report.

Photographs 1 through 3 show the creep test set-up, immediately prior to installing the conductor. Photograph 1 shows the long view of the creep test frame. Photograph 2 shows the lead-screw end. Photograph 3 shows the termination using compression springs.

Photograph 1
Long View of Creep Frame



Photograph 2
Lead Screw, Motor, and Gearbox



Photograph 3
Compression Springs and Load Cell (this design was changed to a double spring for the 30% RBS test)

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 initial loading rate have a significant effect on initial creep. The logarithmic equations fit the data well from one hour to the end of the test. Power law equations fit the data poorly at the initial stages of the creep test, but fit the data quite well from 100 hours onwards. Best fits for log and power law equations are provided in this report. Recommendation of fit equations for long-term creep predictions is beyond the scope of this project.

Test duration was as long as practical based on demand for the equipment, with a goal of meeting the guide's minimum of 1000-hour duration. Actual durations are:

15% RBS:	1007.4 hours
20% RBS:	1070.9 hours
25% RBS	2281.2 hours
30% RBS	1411.8 hours

The following formulas describe the logarithmic fit creep properties of the conductor:

Creep at 15% RBS: Creep % = 0.00134*Ln(time in hours)

Creep at 20% RBS: Creep % = 0.00165*Ln(time in hours)

Creep at 25% RBS: Creep % = 0.00261*Ln(time in hours)

Creep at 30% RBS: Creep % = 0.00281*Ln(time in hours)

The following formulas describe the power law creep properties of the conductor, using only data after the first 100 hours at load:

Creep at 15% RBS: $\text{Creep\%} = 0.004315(\text{Hours})^{0.149978}$

Creep at 20% RBS: $\text{Creep\%} = 0.008428(\text{Hours})^{0.113931}$

Creep at 25% RBS: $\text{Creep\%} = 0.007532(\text{Hours})^{0.150308}$

Creep at 30% RBS: $\text{Creep \%} = 0.006678(\text{Hours})^{0.180946}$

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.

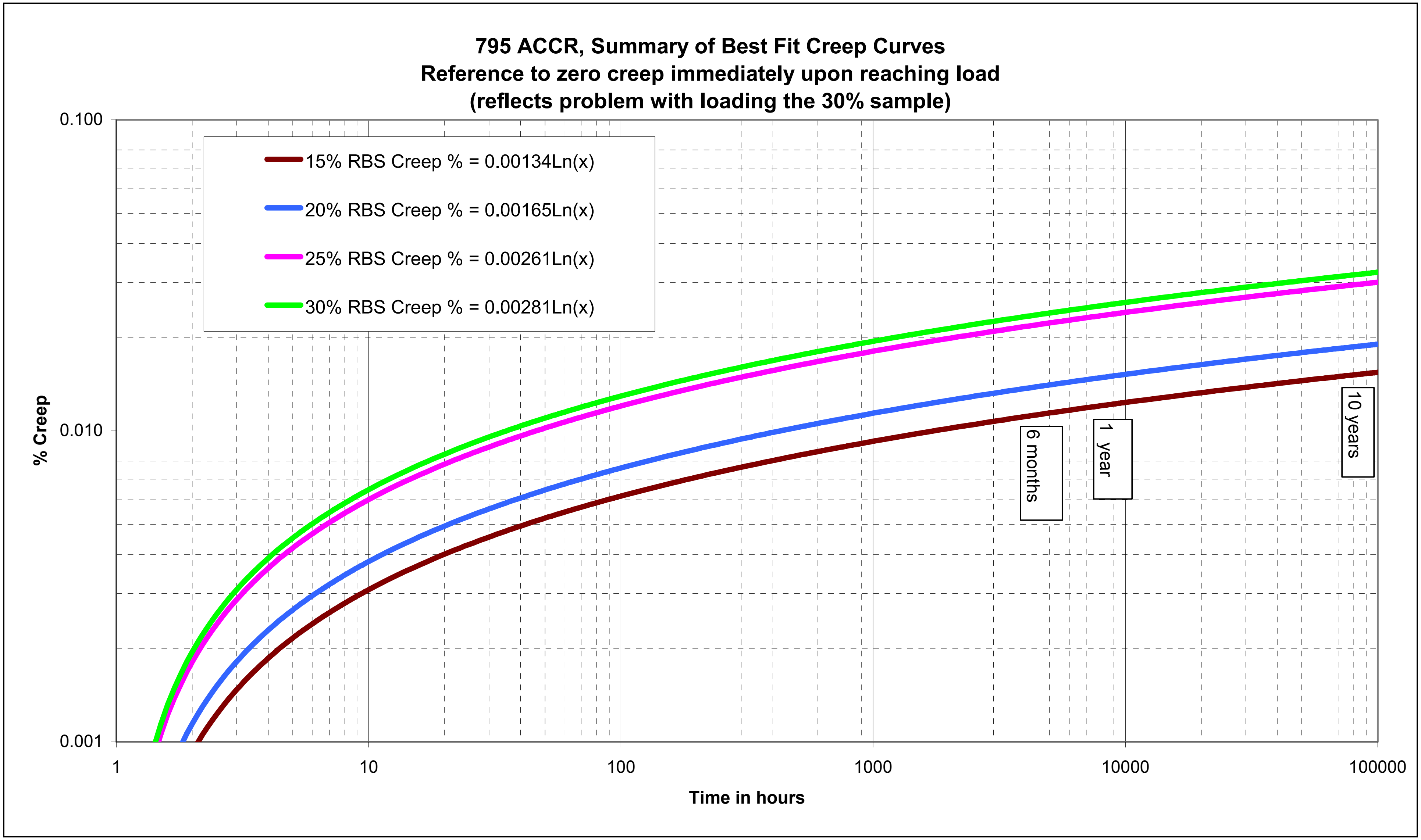

Figure 1, Creep fit and projections based on zero creep at load target (30% RBS data affected by problems during initial loading)

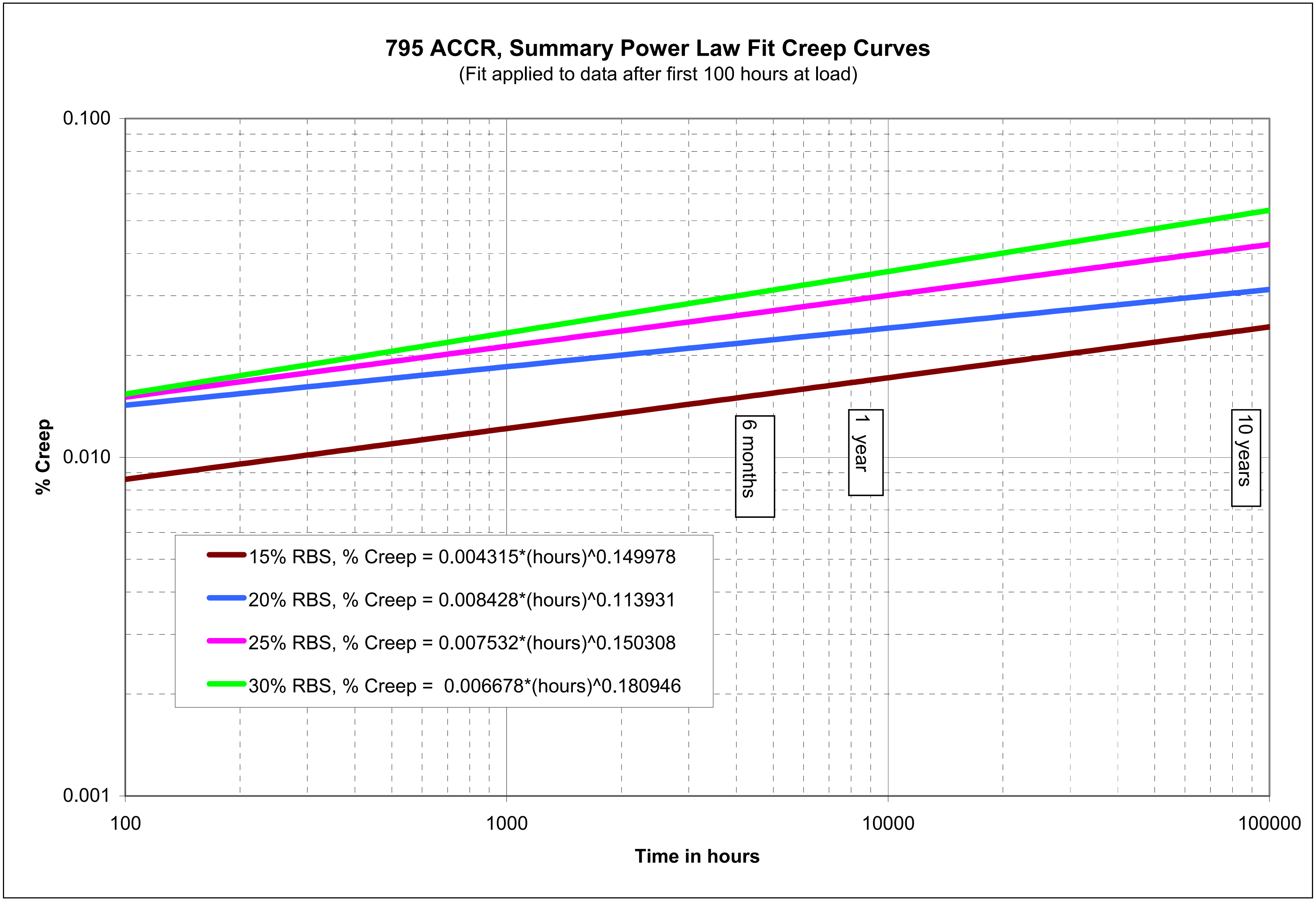

Figure 2 Creep fit and projections based on data after 100 hours, power fit

Appendix 1, Calibration and Error Analysis for Creep Tests

Mechanical load:

Equipment is certified to exceed requirements of ASTM E4-1998 (+/-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.

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

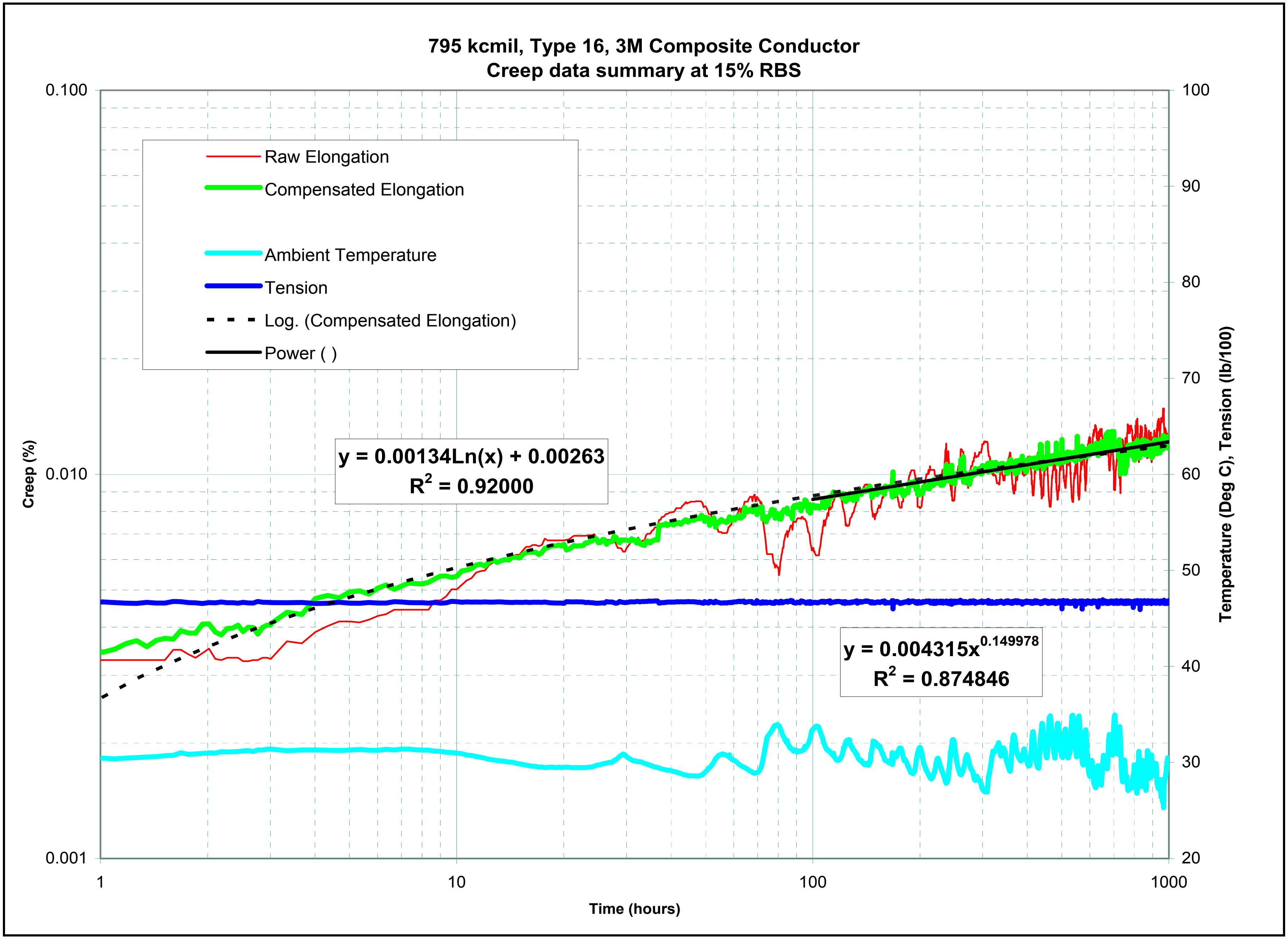

Figure 3, Room Temperature 15% RBS Raw Creep Data, Compensated Data, Tension, Temperature, and Fit Curves

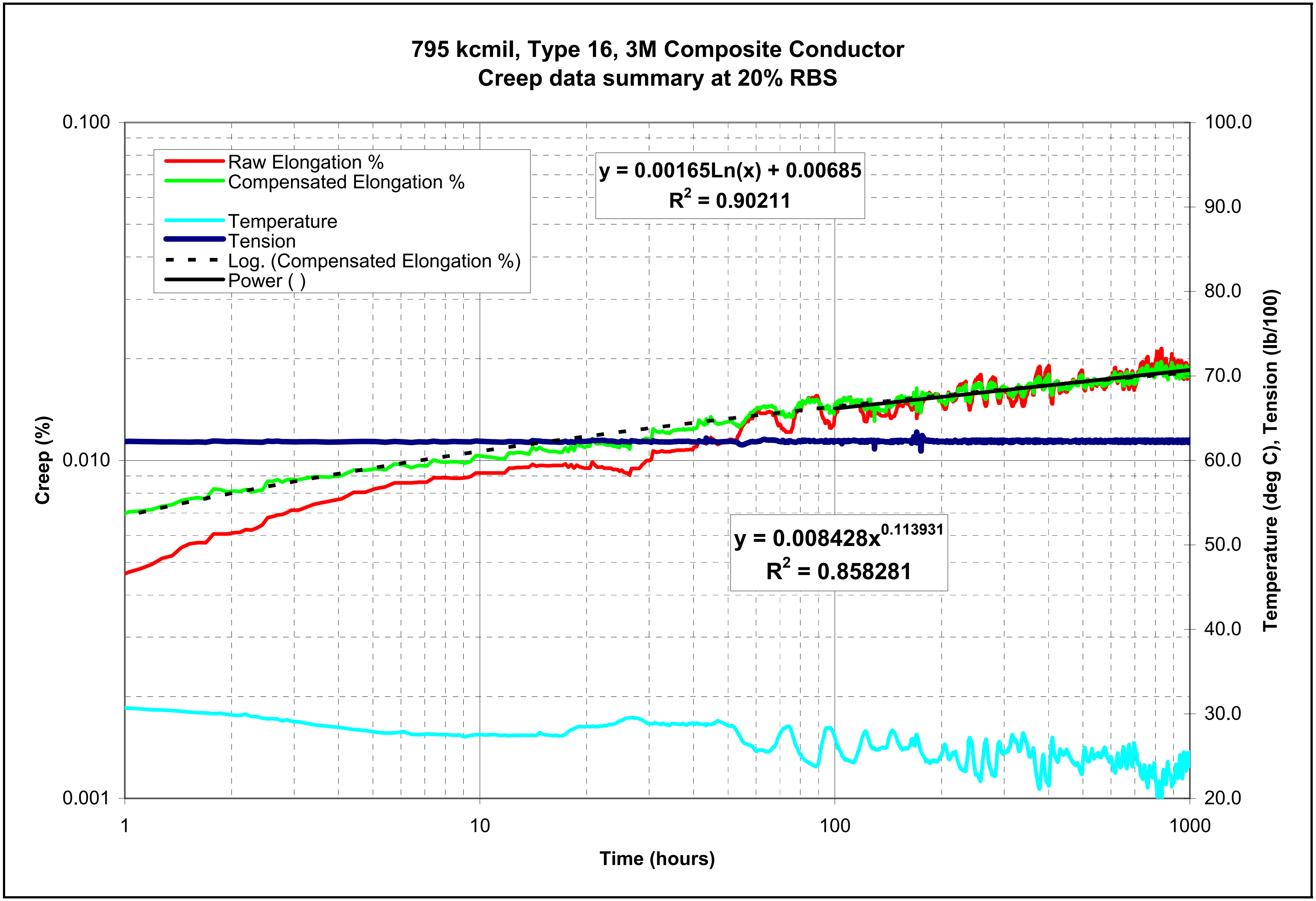

Figure 4, Room Temperature 20% RBS Raw Creep Data, Compensated Data, Tension, Temperature, and Fit Curve

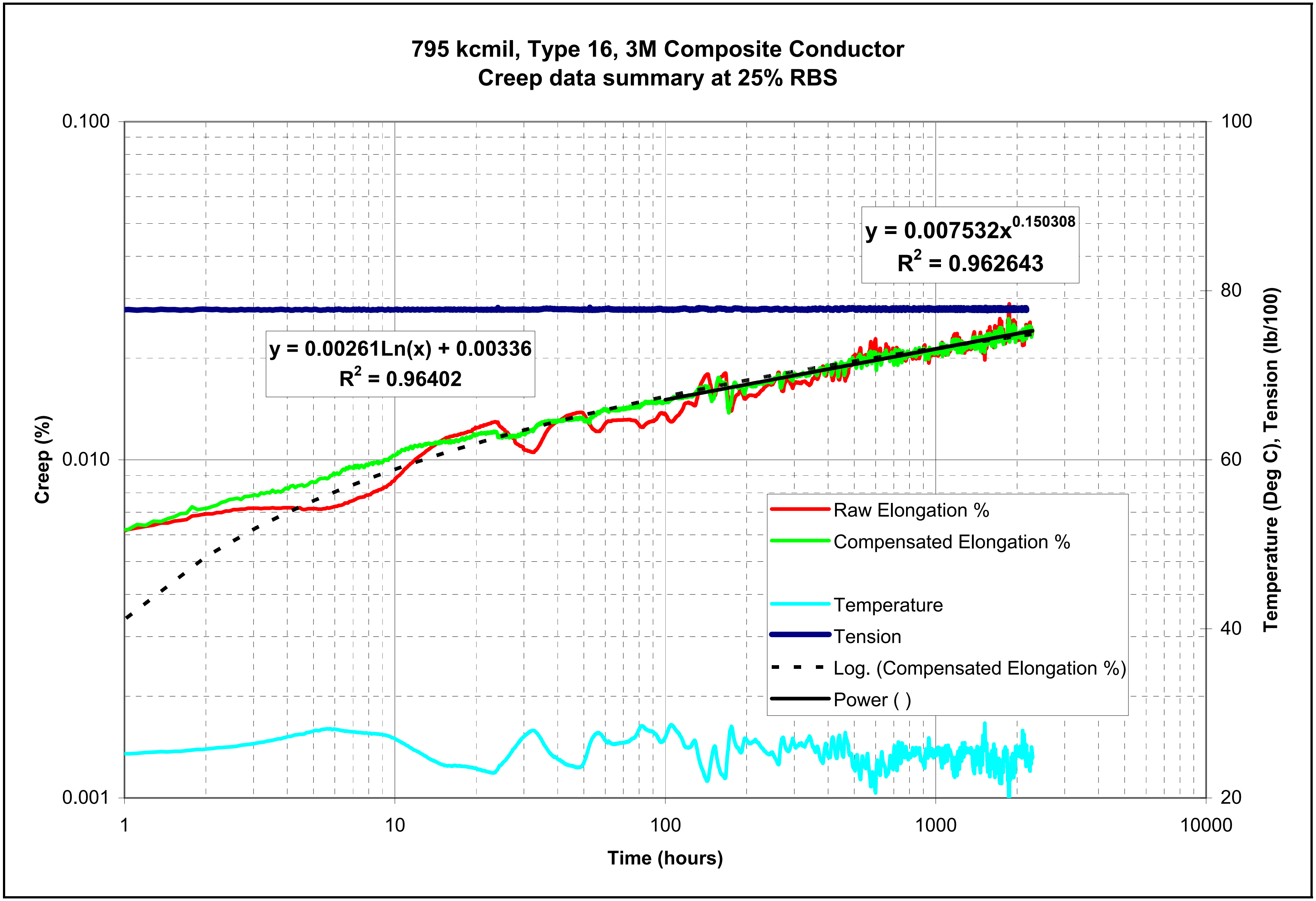

Figure 5, Room Temperature 25% RBS Raw Creep Data, Compensated Data, Tension, Temperature, and Fit Curve

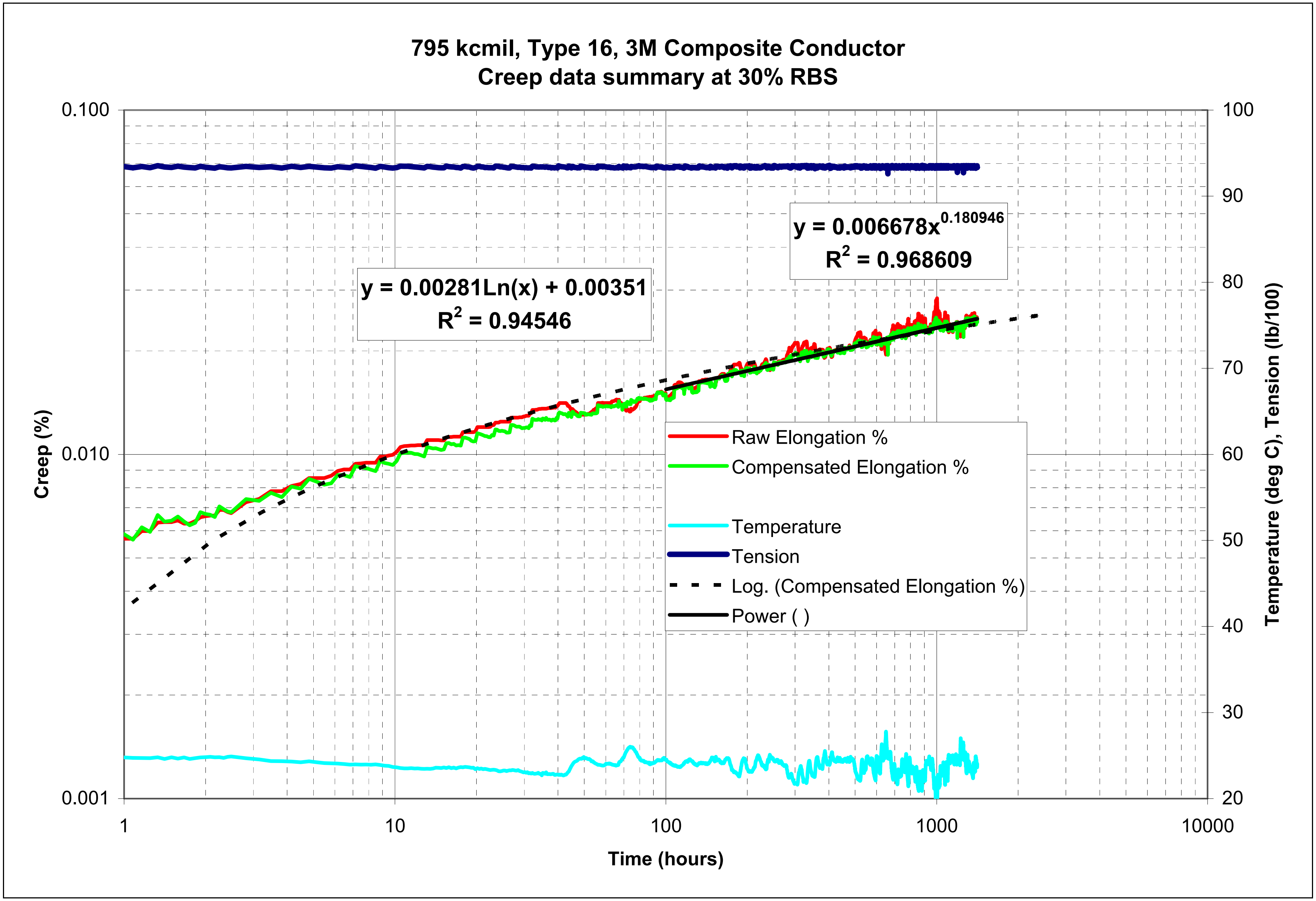

Figure 6, Room Temperature 30% RBS Raw Creep Data, Compensated Data, Tension, Temperature, and Fit Curve