477 kcmil, 3M Brand Composite Conductor
Mechanical Properties, Volume 2
Room-temperature Creep

Minnesota Mining and Manufacturing (3M) Company
Purchase Order 0000227040

NEETRAC Project Number: 01-121

March, 2002

National Electric Energy Testing, Research & Applications Center

A Center of
The Georgia Institute of Technology

ISO 9001

Requested by: Mr. Colin McCullough
3M

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Paul Springer III, P.E.

Reviewed by: ____________________
Dale Callaway

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Summary:

3M contracted with NEETRAC for a series of tests designed to characterize the mechanical behavior of 477 kcmil 26/7 metal matrix composite (MMC) core aluminum conductor composite reinforced (ACCR). This report provides the test data summary and conductor property coefficients for room temperature creep tests performed in accordance with Aluminum Association guidelines.

Samples:

1) Conductor reel containing approximately sixty (60) meters of 477 kcmil, type 16, 3M Composite conductor

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 0000227040
4) Conductor reel containing approximately sixty (60) meters of 477 kcmil 477 kcmil, type 16, 3M Composite conductor.
5) E-mail dated 6/7/01 from Colin McCullough with details on conductor and core strand properties.
6) PRJ 01-121, 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
8) High current AC test set, Control # CN 3007

Procedure:

Testing was conducted in accordance with a NEETRAC procedure entitled “PRJ0121, CONFIDENTIAL – MMC Conductor Evaluation”. The procedure controls all technical and quality management details for the project.

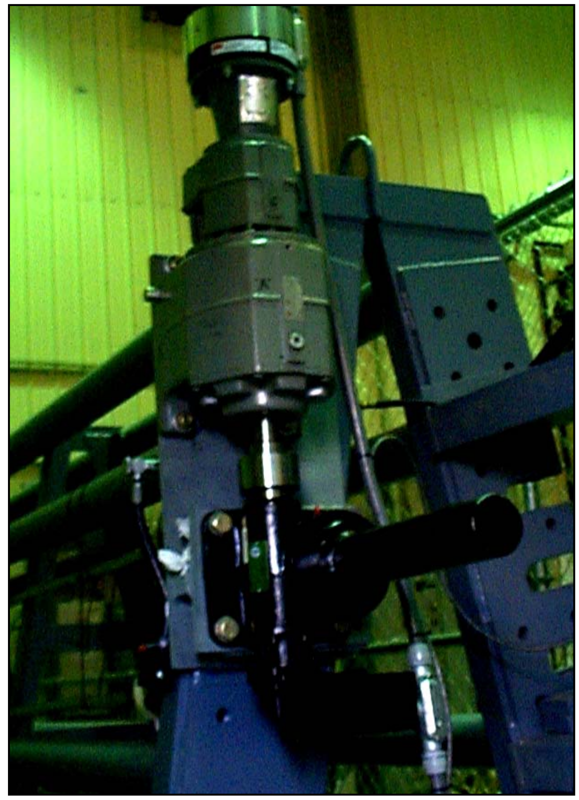
Creep Tests:

Creep tests are 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.

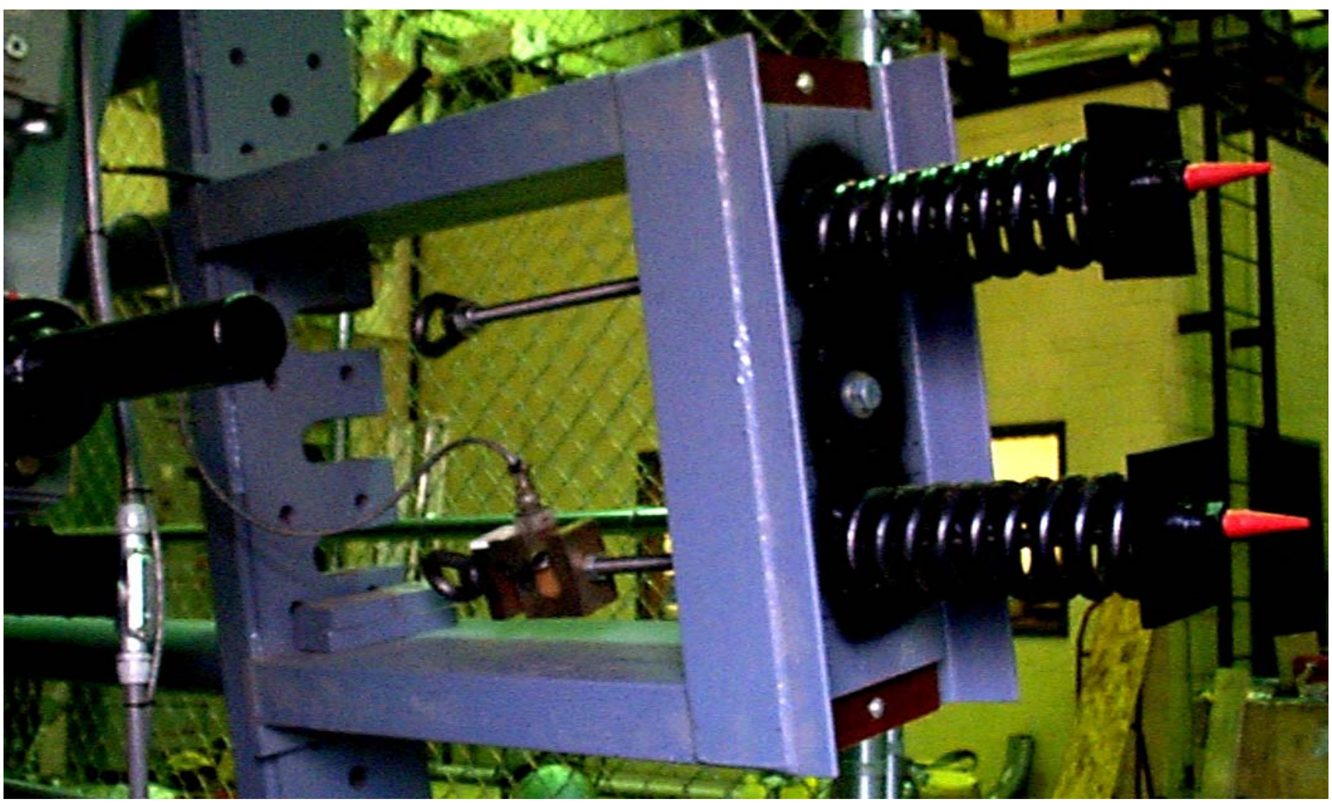
Creep test data are extremely temperature sensitive. The test equipment is designed to be somewhat self-compensating. This is accomplished by making the gage reference of the same material as the sample – typically aluminum. Low thermal expansion of MMC caused thermal effects on the gage rod to appear in the test data. Consider that the total creep during the 15% RBS test is less than 100 PPM. The thermal coefficient for aluminum is 23 PPM/^{o} C. Even a 2 degree temperature swing causes thermal change close to 50% of the total measurement range. Correction factors are developed to compensate elongation data for tension, sample temperature, and gage rod temperature. Data compensation is discussed in Appendix 1. All graphs of test data show both the compensated and the raw test data. Compensated data was used for all trend calculations.

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 6
Long View of Creep Frame



Photograph 7
Lead Screw, Motor, and Gearbox



Photograph 8
Compression Springs and Load Cell

Results:

Data files containing test data were processed using Microsoft® Excel Spreadsheet with Business Graphics and Database 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 and power equations fit both matched the data up to 1000 hours reasonably well. The best fit was found when the power fit equation was matched to the last 900 hours of creep data. Omitting the first 100 hours from the fit curve results in a good match at the end of 1000 hours. There was no significant degradation even as low as one hour resulting from this method. The "power" fit is shown on the creep graphs, and the projections to 10 years creep. The log fit was beginning to undershoot the creep curve at 1000 hours, and is an extremely poor fit for early creep. Therefore, a log fit was not used.

The following formulas describe the creep properties of the conductor, where t is time in hours, stress is in psi, strain is in percent:

Creep at 15% RBS:	Creep (%) = $0.001600(\text{hours})^{0.192092}$
Creep at 20% RBS	Creep (%) = $0.003217(\text{hours})^{0.202529}$
Creep at 25% RBS:	Creep (%) = $0.004163(\text{hours})^{0.196377}$
Creep at 30% RBS:	Creep (%) = $0.004772(\text{hours})^{0.197411}$
6 month creep added to stress strain curve:	Stress (psi) = 87,584 * Strain (%)
1 year creep added to stress strain curve:	Stress (psi) = 85,595 * Strain (%)
10 year creep added to stress strain curve:	Stress (psi) = 77,643 * Strain (%)

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%.

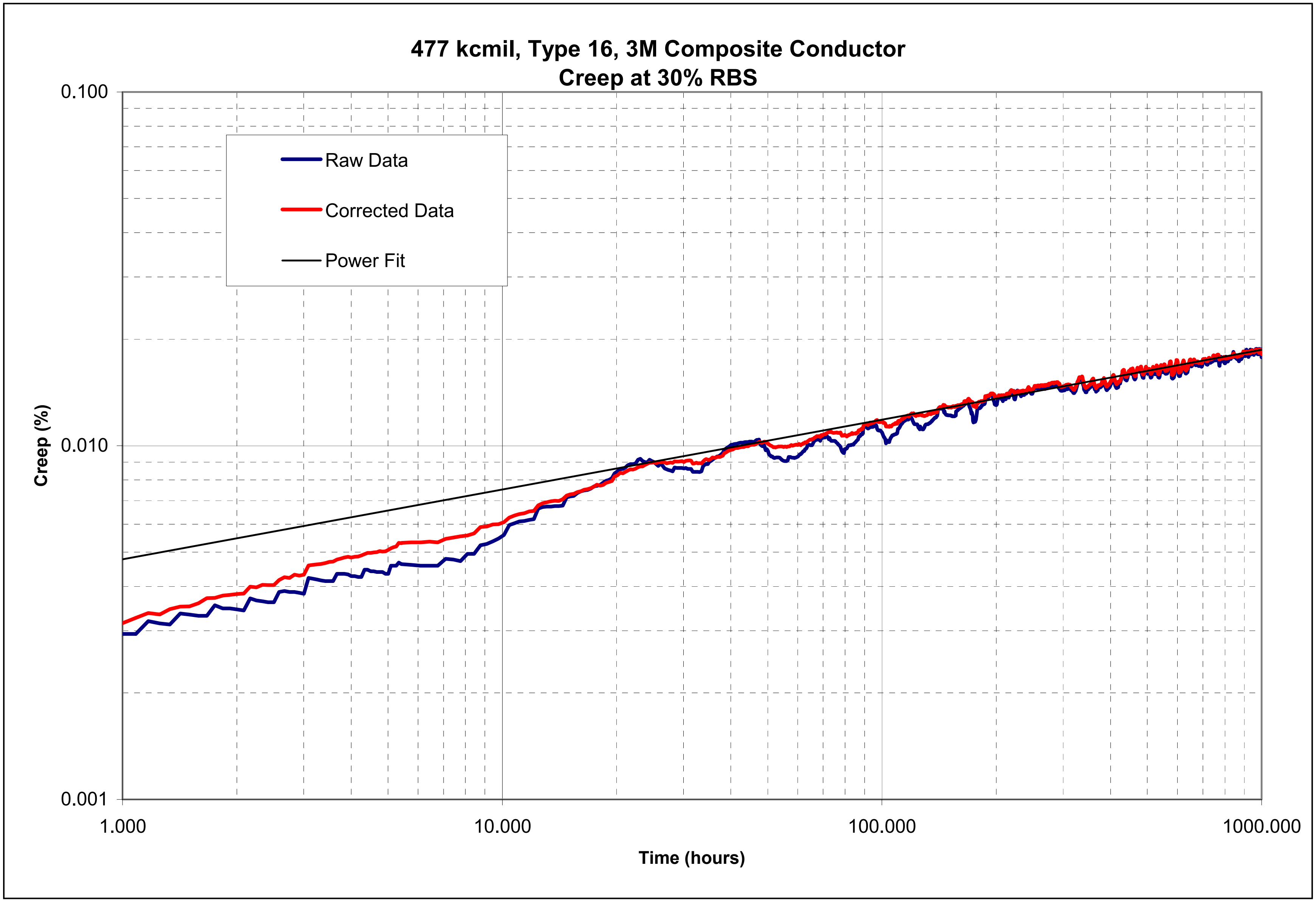
Creep (Elongation):

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:

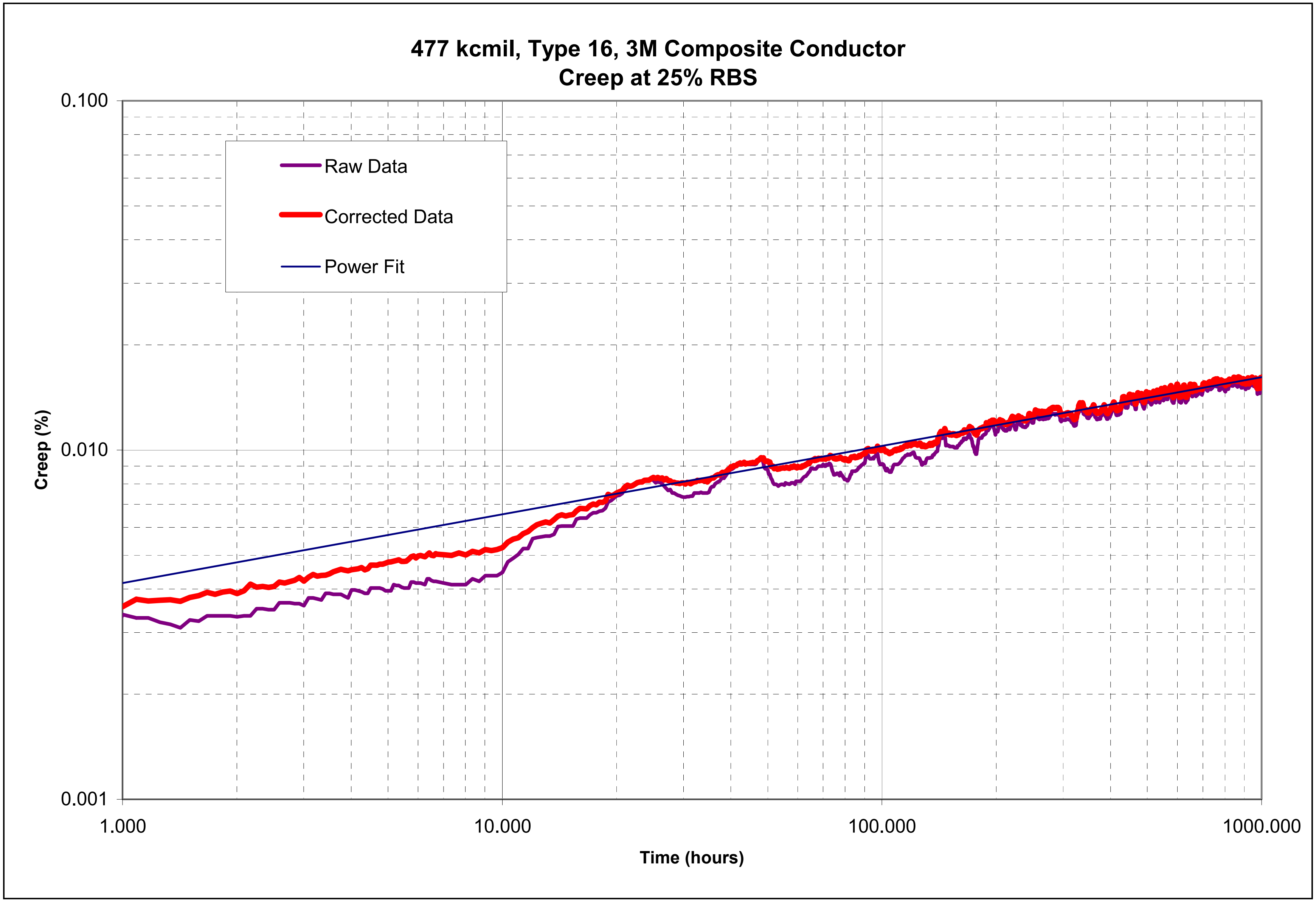
> <u>Effect of load measurement errors:</u> linear (0.5% of reading)
>
> <u>Effect of mechanical deflections of the gage rod:</u> The gage rod is a 2" x 6" x 1/8" x 19' aluminum box beam, which is extremely stiff. The only bending force is friction in the guide bearings for the displacement sensor. The error is less than 1.0 PPM.
>
> <u>Effect of thermal expansion of the sample and gage rod:</u> 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 16 PPM/ ^{o}C. This means that thermal elongation of the gage rod affects the data with an error of approximately 7 PPM/ ^{o}C. Temperature in the creep room is controlled, but even small changes appear in the creep data. Temperature compensation was clearly needed for the creep data. Use of nominal coefficients did not significantly smooth the temperature cycles, which means that more than simple thermal expansion of the gage rod was affecting the data. A value of 40 PPM ^{o}C was found to smooth the temperature oscillations reasonable well on all the creep graphs. The apparent coefficient is larger than the nominal value for aluminum. This is due either to thermal effects on the instrument mounting hardware, or due to slight bowing of the gage rod as the temperature changes.
>
> <u>Effect of starting gage length:</u>
> 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).

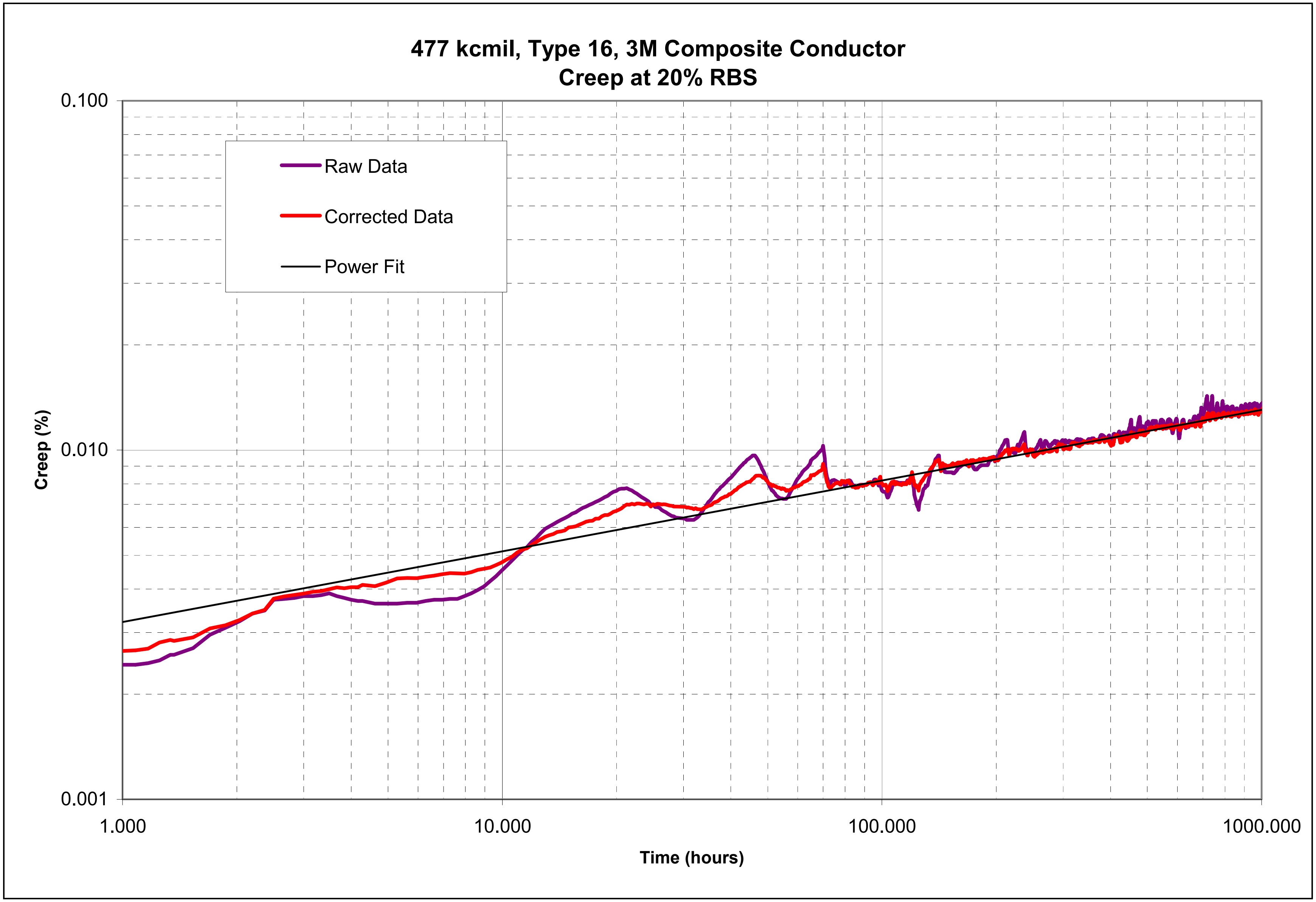
Appendix 2
Creep Graphs



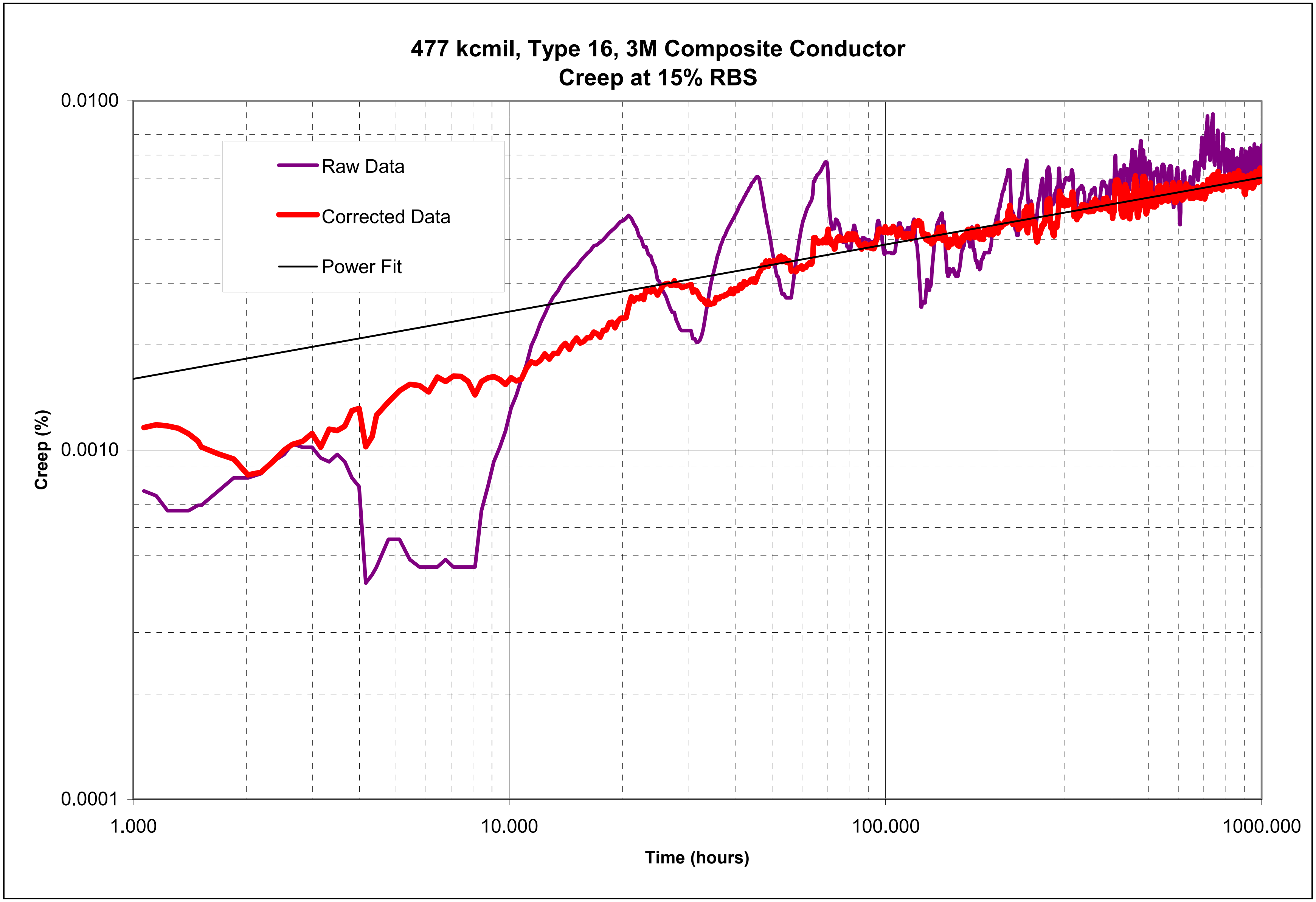
Room Temperature, 30% RBS, Raw Data, Corrected Data, and Trend



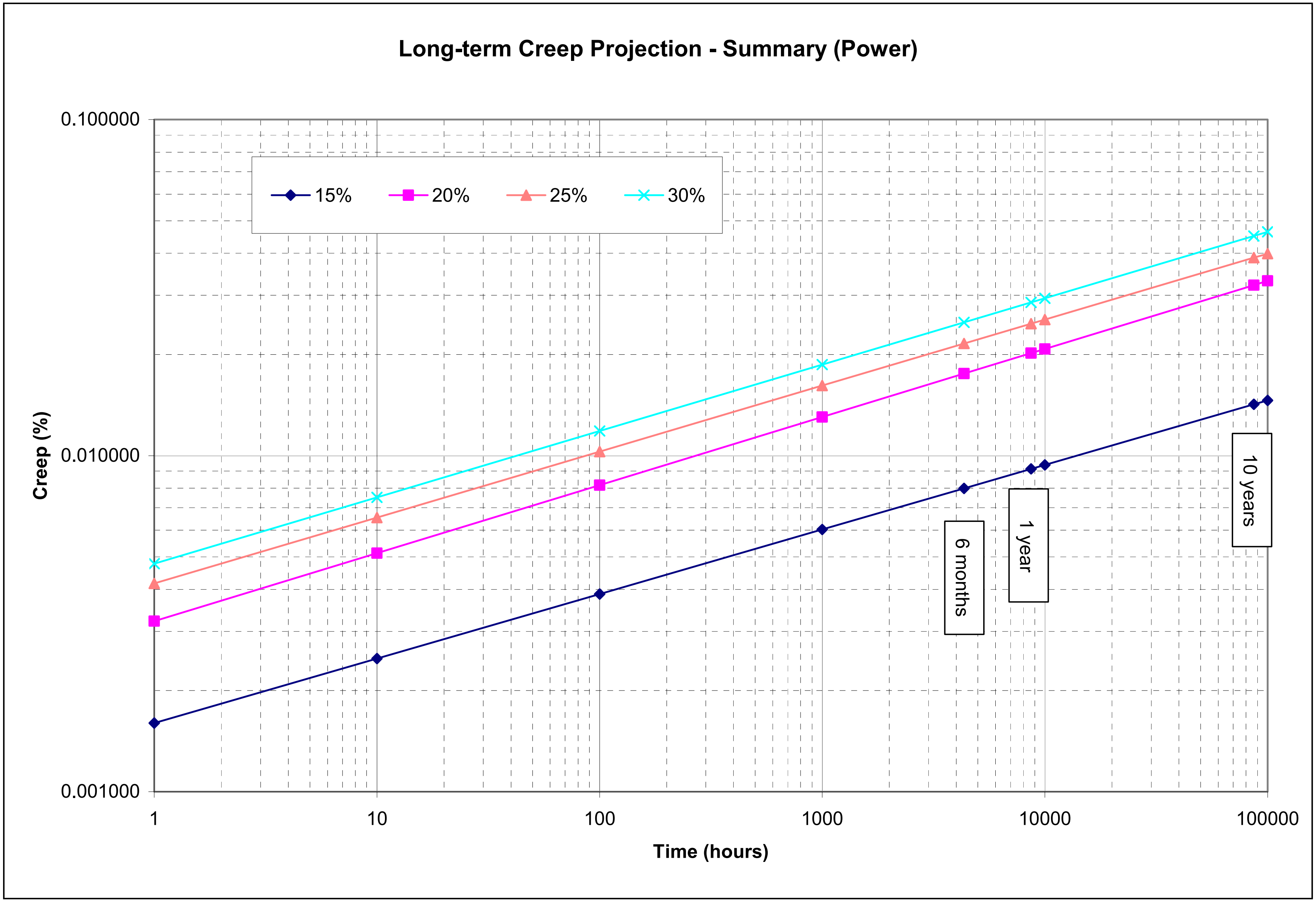
Room Temperature, 25% RBS, Raw Data, Corrected Data, and Trend



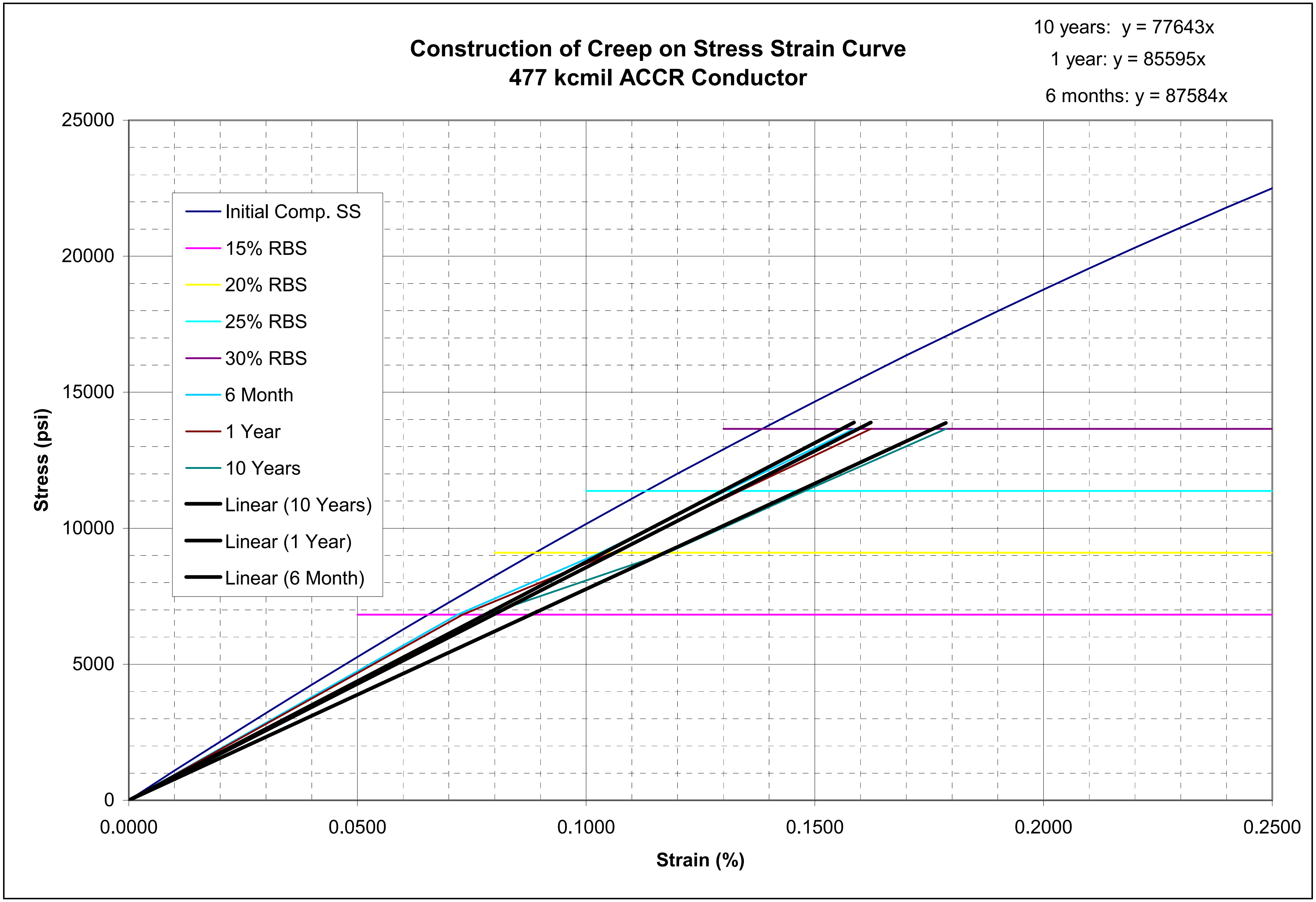
Room Temperature, 20% RBS, Raw Data, Corrected Data, and Trend



Room Temperature, 15% RBS, , Raw Data, Corrected Data, and Trend



Summary of Fit Curves to Creep Test Data



Construction of Long Time Creep Curves on Stress Strain Curve
(In Accordance Appendix 2.2 of Aluminum Association Guide