795-kcmil, 3M Brand Composite Conductor
Room Temperature Stress-Strain Tests

3M Company
Purchase Order 0000523450

NEETRAC Project Number: 02-133

August, 2002
Revised December 2003

A Center of
The Georgia Institute of Technology

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Summary:

3M contracted with NEETRAC for measurement of conductor stress-strain properties in accordance with an Aluminum Association guide dated 1999. The guide was adapted for the special properties of the MMC core material.

Samples:

1) Conductor reel containing approximately twenty (20) meters of 795-kcmil, 3M Brand 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 0000523450
4) 3M data file dated June 27, 2002 containing conductor technical specifications
5) PRJ 02-133, NEETRAC Project Plan

Equipment Used:

1) MTS Servo-hydraulic tensile machine, Control # CQ 0195 (load and crosshead data)
2) Dynamics Research Corporation (DRC)/NEETRAC cable extensometer, Control # CQ 3002 (strain data).
3) Yokogawa DC100 data acquisition system, Control # CN 3022 (temperature data)

Procedure:

Composite Conductor Stress-Strain Test:

Samples were terminated with resin fittings, and mounted in the MTS hydraulic tensile machine. The free-span conductor length is 19 feet. The active gage section between knife-edges on the cable extensometer is 18 feet, +/- 1/16". Tension is controlled automatically. Load, crosshead position, elongation, and temperature data were saved to a computer file. The file was processed to produce the stress-strain charts. See Appendix 1 for an error analysis for the test system. The stress-strain plots are in Appendix 2. The modulus data are in "Results" section of this report. Photograph 1 shows the long view of the test apparatus. Photograph 2 is a close-up of the resin socket and extensometer attachment. All details in the photographs are in accordance with the test performed, except that the conductor is 477 kcmil 3M Brand Composite Conductor from Project 01-121.

Placing a support at 1/2 span minimizes conductor slack. This ensures the conductor is nearly straight, prevents slack from showing up as elongation in the stress-strain data. The test profile is in accordance with the Aluminum Association guide, as follows:

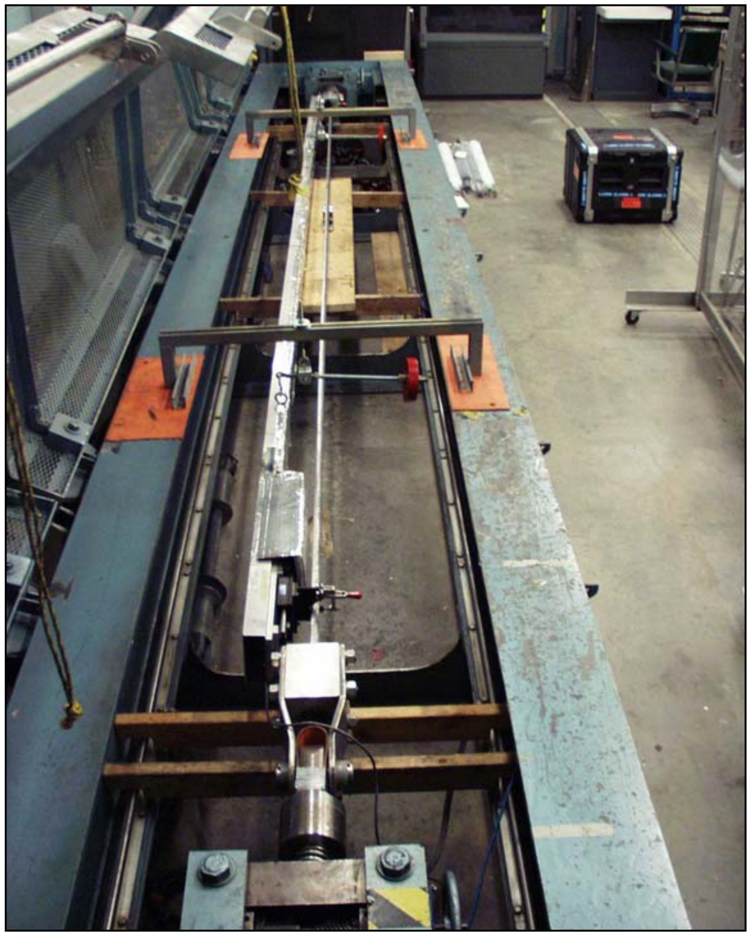
Composite conductor:

1) Apply load of 1,000 lbs. Remove sag with a mid-span support.
2) Install extensometer, and set to zero.
3) Pull to 30% of RBS (9,340 lbs)
4) Hold for 30 minutes.
5) Relax load to 1,000 lbs.
6) Pull to 50% RBS (15,570 lbs). Hold for one hour.
7) Relax load to 1,000 lbs.
8) Pull to 70% RBS (21,790 lbs). Hold for one hour.
9) Relax load to 1,000 lbs.
10) Pull to 75% (23,350 lbs). RBS.
11) Relax load to 1,000 lbs, and remove the extensometer (for its own protection).
12) Pull to destruction.

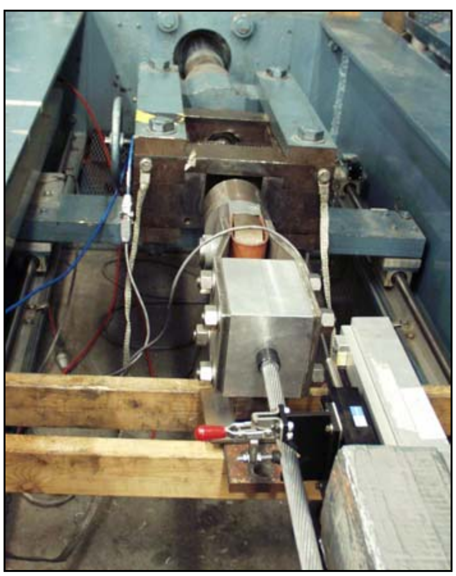
There was a discrepancy during the 50% load hold period. The computer key that commands a new load setpoint was accidentally pressed when the operator intended to press the key that commands a data recording. The load was reduced, and then immediately restored to the correct value when the error was detected. This was a momentary event, and the load was reduced from the nominal setting for only a few seconds. Therefore, it is not likely that the modulus or other stress-strain coefficients are affected. There is an extra line in the stress-strain graphs showing the discrepancy. There was no attempt to edit the data for display in this report. Corrective action has been implemented to prevent this type of error in future tests.

Core strands:

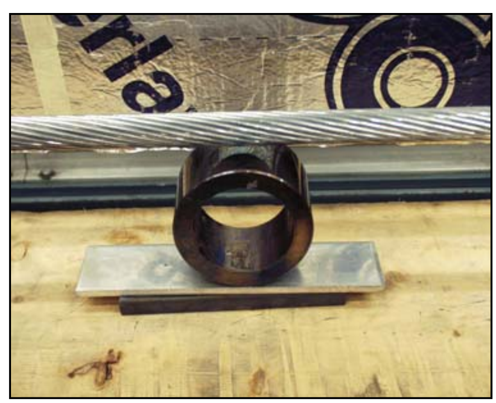
1) Pull to calculated initial tension (in this case, 437 lbs)
2) Install extensometer, and set to zero.
3) Pull to same strain as conductor at start of 30% of RBS test (0.11616%). Hold for 30 minutes.
4) Relax load to 437 lbs.
5) Pull to same strain as conductor at start of 50% of RBS test (0.21051%). Hold for one hour.
6) Relax load to 437 lbs.
7) Pull to same strain as conductor at start of 70% of RBS test (0.33051%). Hold for one hour. Relax load to 437 lbs.
8) Pull to 75% of the core RBS (13,920 lbs)
9) Relax load to 437 lbs, and remove the extensometer (for its own protection).
10) Pull to destruction.



Photograph 1, Long View of Stress-Strain Test



Photograph 2
Load Actuator and Extensometer



Photograph 3
Mid-span Support to Remove Sag

Results:

Data files containing test data were processed using Microsoft Excel® software to obtain engineering values and graphical presentation. Temperature during testing was 21.5^{o} C. Graphs showing data for each test are shown in Appendix 2.

Composite Conductor Properties:

Initial Modulus for Stress Strain Curve:	Stress (psi) = $-61955*(Strain\%)^2 + 104284*(Strain\%)$
Final Modulus for Stress Strain Curve:	Stress (psi) = 122238*(Strain%) – 14,322
Tensile Test, Stress Strain Sample:	31870 lbs (102% RBS)

Core Properties:

Initial Modulus for Stress Strain Curve:	Stress (psi) = $-68763*(Strain\%)^2 + 360329*(Strain\%)$
Final Modulus for Stress Strain Curve:	Stress (psi) = 343705*(Strain%) - 392
Tensile Test, Core Stress Strain Sample:	18600 lbs (100% RBS)

Aluminum Properties:

Initial Modulus for Stress Strain Curve:	Stress (psi) = -60864*(Strain%)2 + 63251*(Strain%)
Final Modulus for Stress Strain Curve:	Stress (psi) = 86746*(Strain%) – 16163

Note: Second order fits will not extrapolate properly beyond the limits of the data. Therefore, the conductor properties are valid up to a strain of 0.36%, the strain reached during the 70% RBS load. A higher order polynomial may be used to improve the extrapolation. A non-polynomial fit may also provide more reasonable extrapolations to the test data.

Acknowledgement:

This material is based upon work supported by the U.S. Department of Energy under Award No. DE-FC02-02CH11111.

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.

Appendix 1, Calibration and Error Analysis for Stress-Strain Tests

Mechanical load (stress):

Measurement equipment is certified to exceed requirements of ASTM E4-1998 (+/-1%). MTS Tensile Machine "as-found" calibration data show accuracy is typically better than 0.5%. Stress is calculated based on the nominal (as opposed to measured) conductor dimensions.

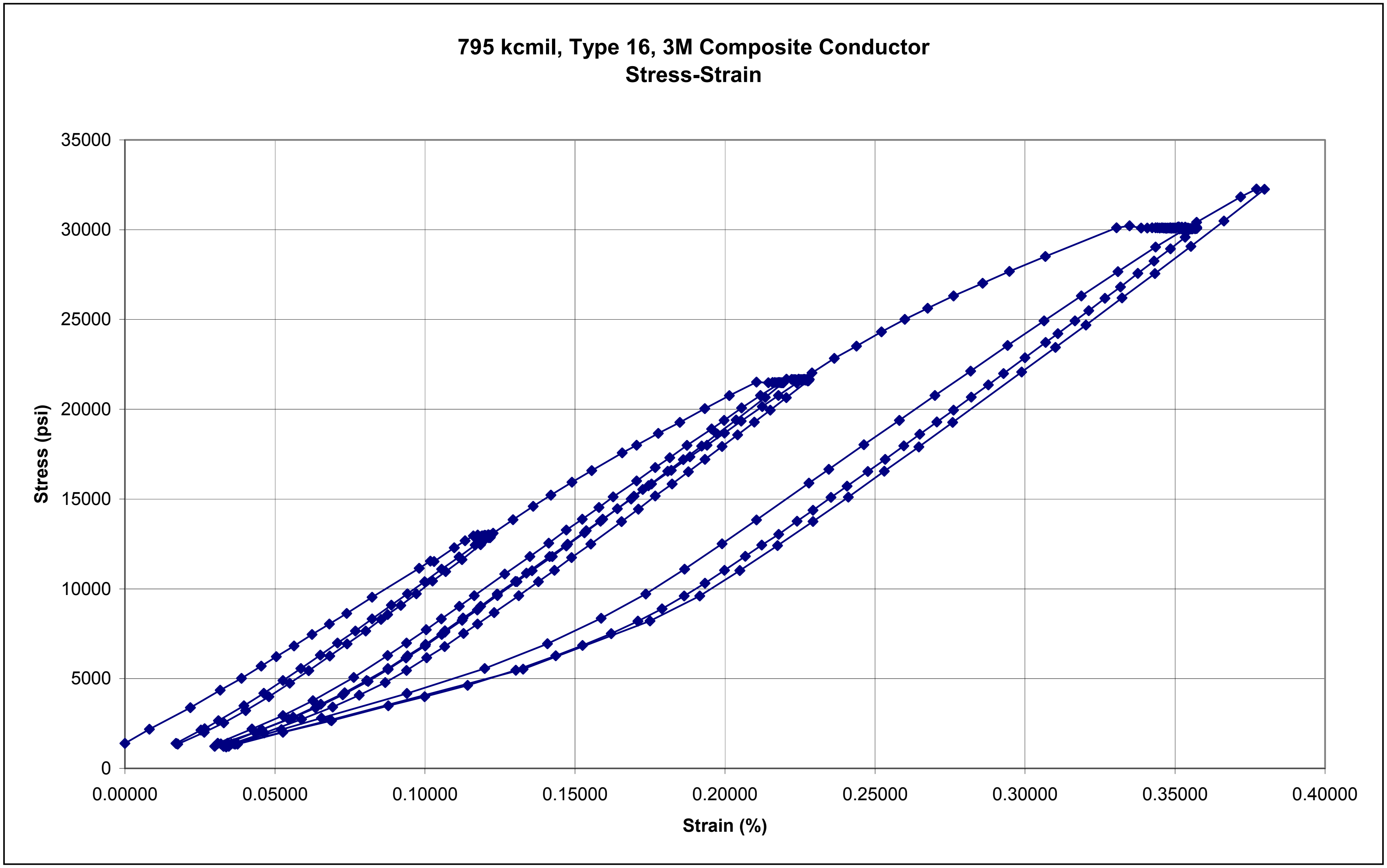
Conductor Elongation (strain):

The DRC displacement transducer resolution is +/- 0.0001". For the 18 ft. gage section, resolution is 0.0001"/216", or 0.000046% (0.46 PPM). Sensor accuracy is +/- 0.0002", or 0.92 PPM. This is a digital measurement made with a laser diode reading an etched titanium silicate (glass) rod. The material has near-zero thermal coefficient. Data are transmitted via digital communication with an interface board in a PC data acquisition system. Therefore, there is no calibration drift or 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:

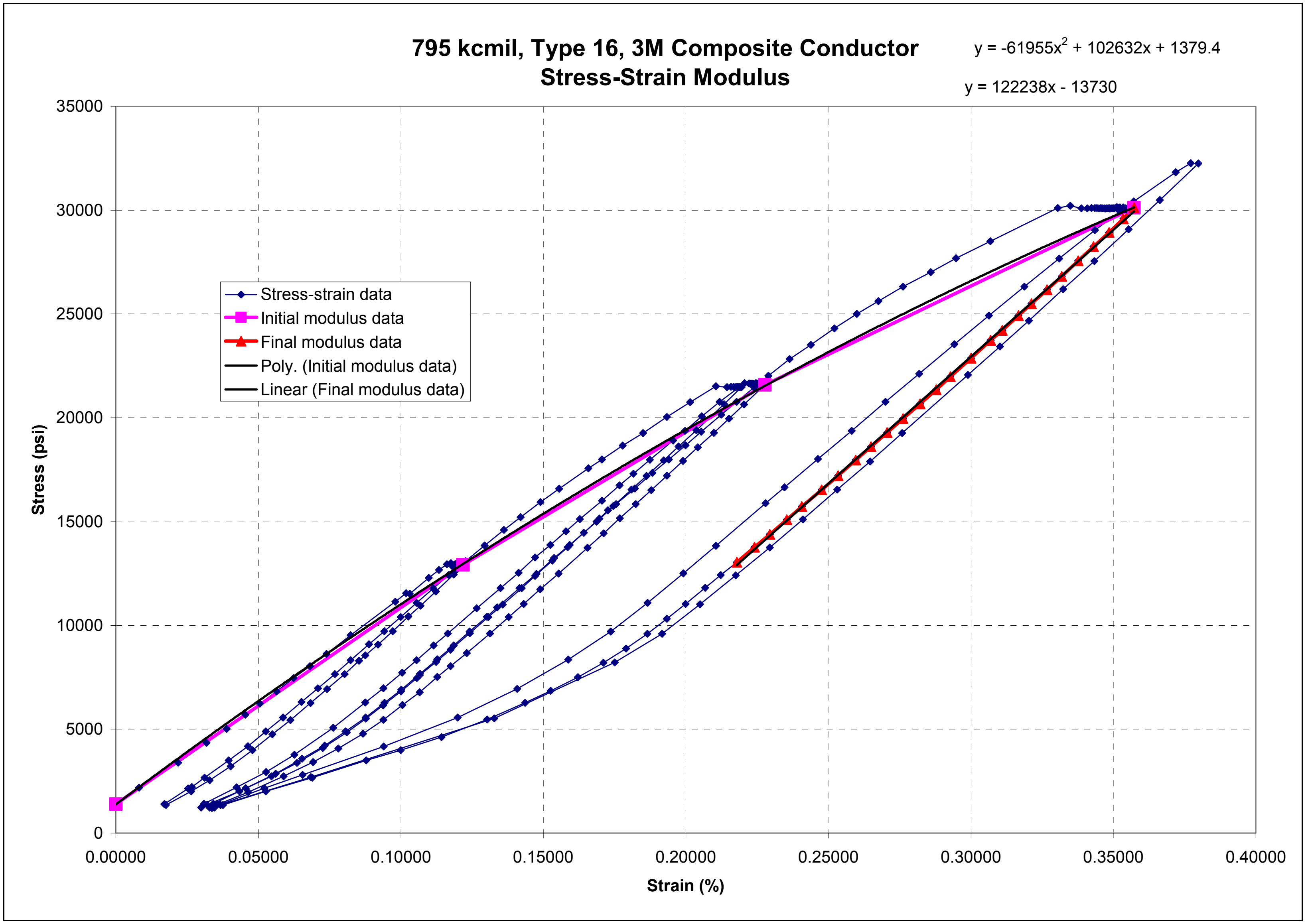
> Effect of load measurement errors: strain error is linear wrt load error. Error is 0.5% of reading.
>
> Effect of mechanical deflections of the gage rod: The gage rod is a 2" x 6" x 1/8" x 19 ft aluminum box beam, which is extremely stiff. The only bending force is friction in the guide bearings and wiper seals for the displacement sensor. Starting and running friction were measured as 0.3 lbs, and 0.2 lbs respectively. The error is less than 0.5 PPM.
>
> Effect of thermal expansion of the sample and gage rod: Lab temperature changed 0.2^{o}C from beginning of the test to the end. Temperature change is partly compensated using a gage reference of the same material as the sample. In this case, the gage rod is aluminum (23 PPM/ ^{o} C), while the sample thermal elongation is estimated to be 16 PPM/ ^{o}C. Error in the strain measurement is, therefore, 7 PPM/ ^{o}C. For the 0.2 ^{o}C temperature variation, the error is 1.4 PPM. The error does not affect the modulus values, because load is changed rapidly relative to rate of temperature change. Thermal affects could affect measurement of short-term creep during load hold periods. However, 1.4 PPM is small relative to measured creep (over 600 PPM during the 30% RBS load hold). Therefore, this error is about 0.2% of reading, and is therefore neglected. No mathematical temperature compensation was used for any of the stress-strain tests.
>
> Effect of starting gage length:
> An error of +/- 1/16" is possible. The maximum error affects the strain measurement by 0.02% of reading.

Overall accuracy is calculated based on root-mean squared error estimation. Given the assumptions above, the elongation measurement is considered accurate within 1% of reading, plus or minus 2 parts per million. 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 0.46 PPM (0.0001 inches in 18 ft).

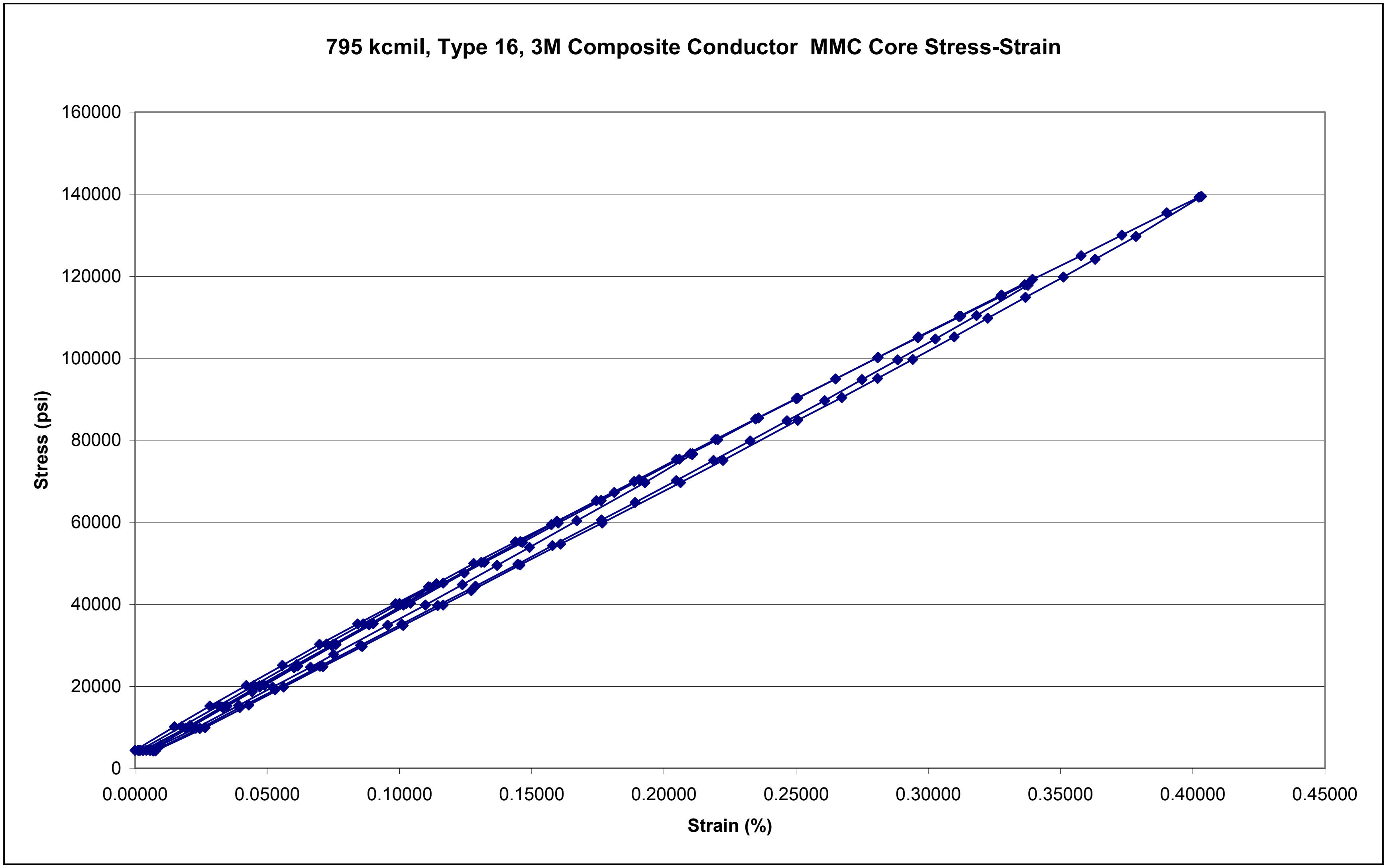
Appendix 2
Stress-Strain Graphs



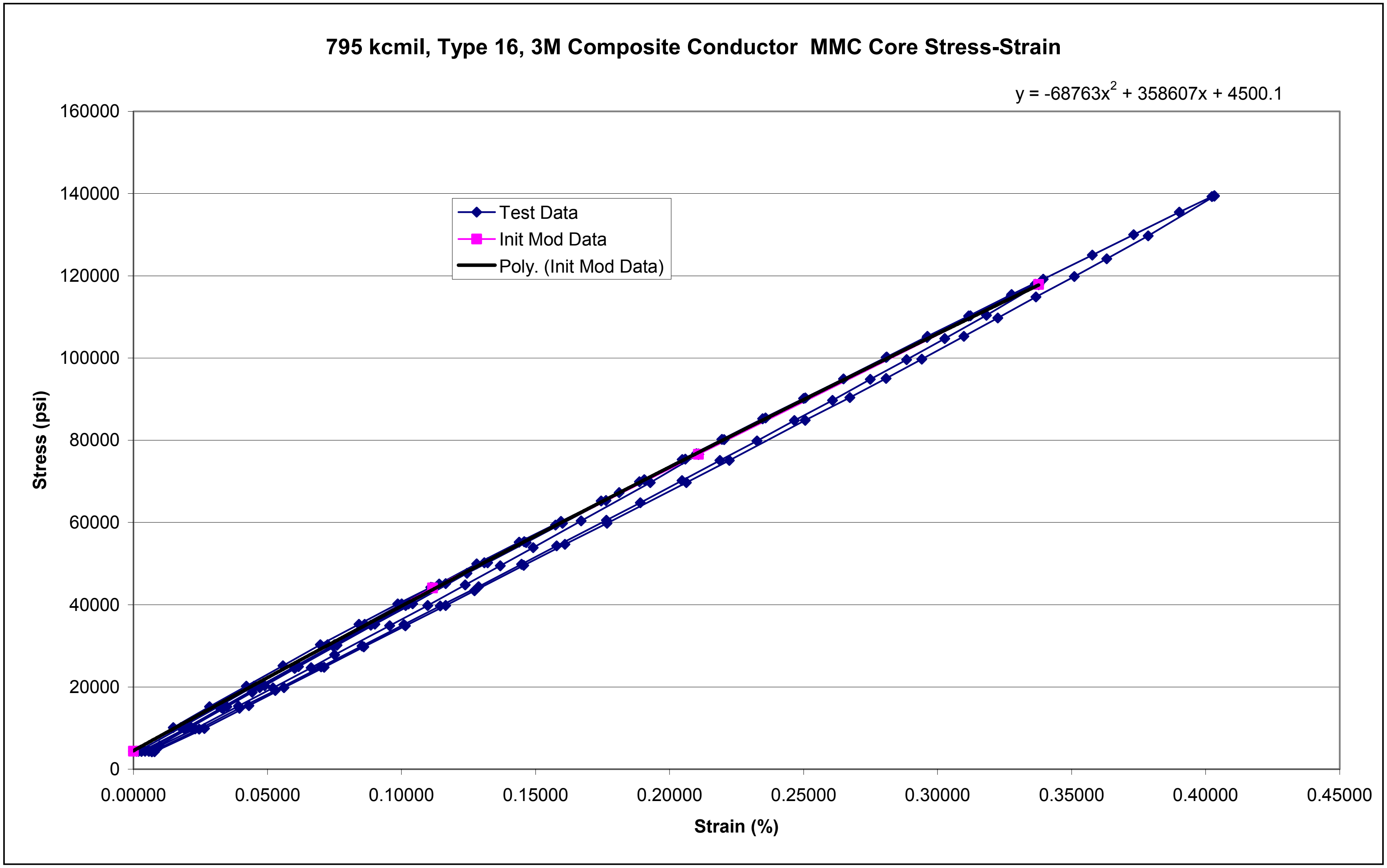
Composite Stress-Strain Plot in Accordance with Aluminum Association Guide



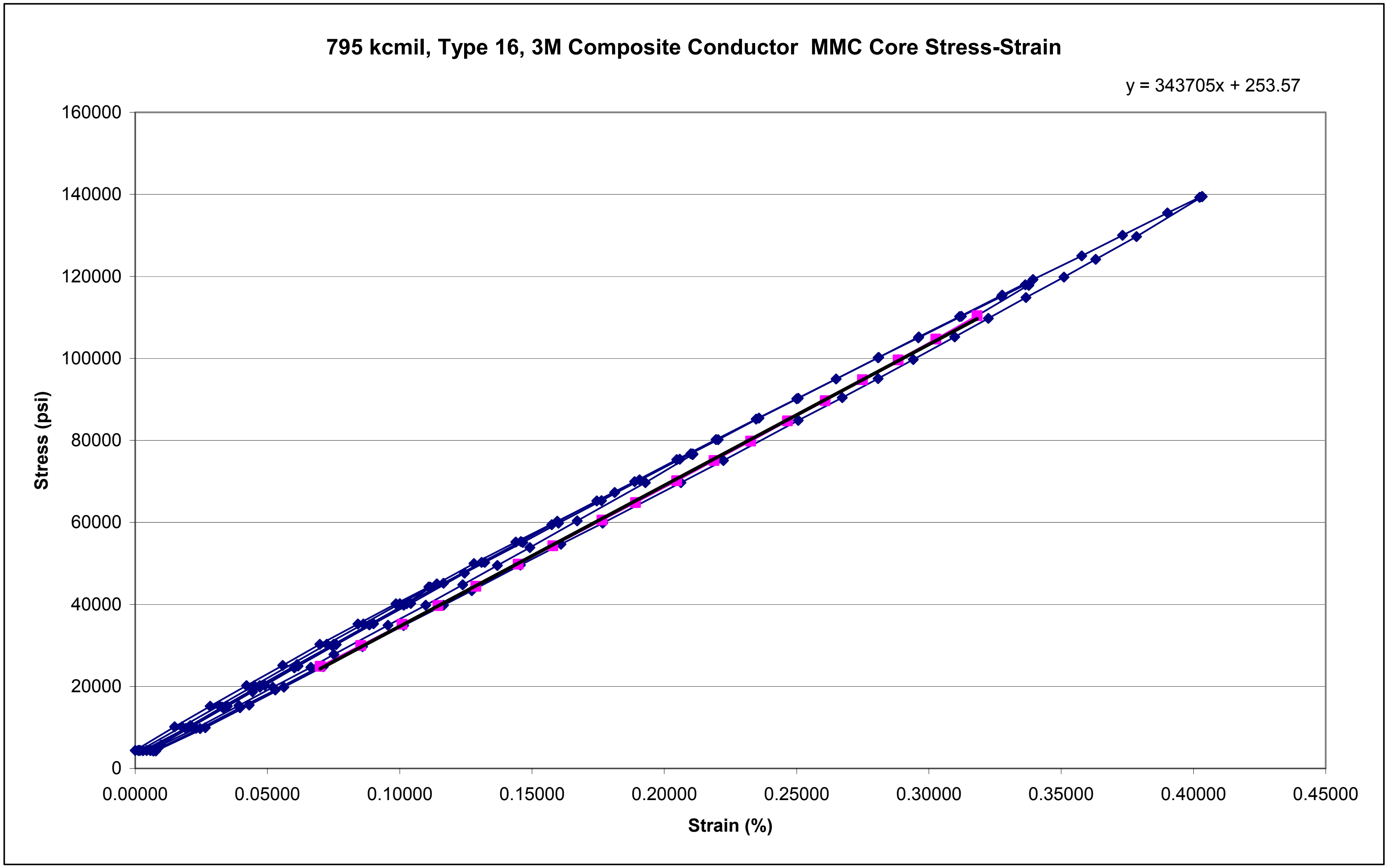
Composite Stress-Strain Plot with Data Fit for Initial and Final Modulus



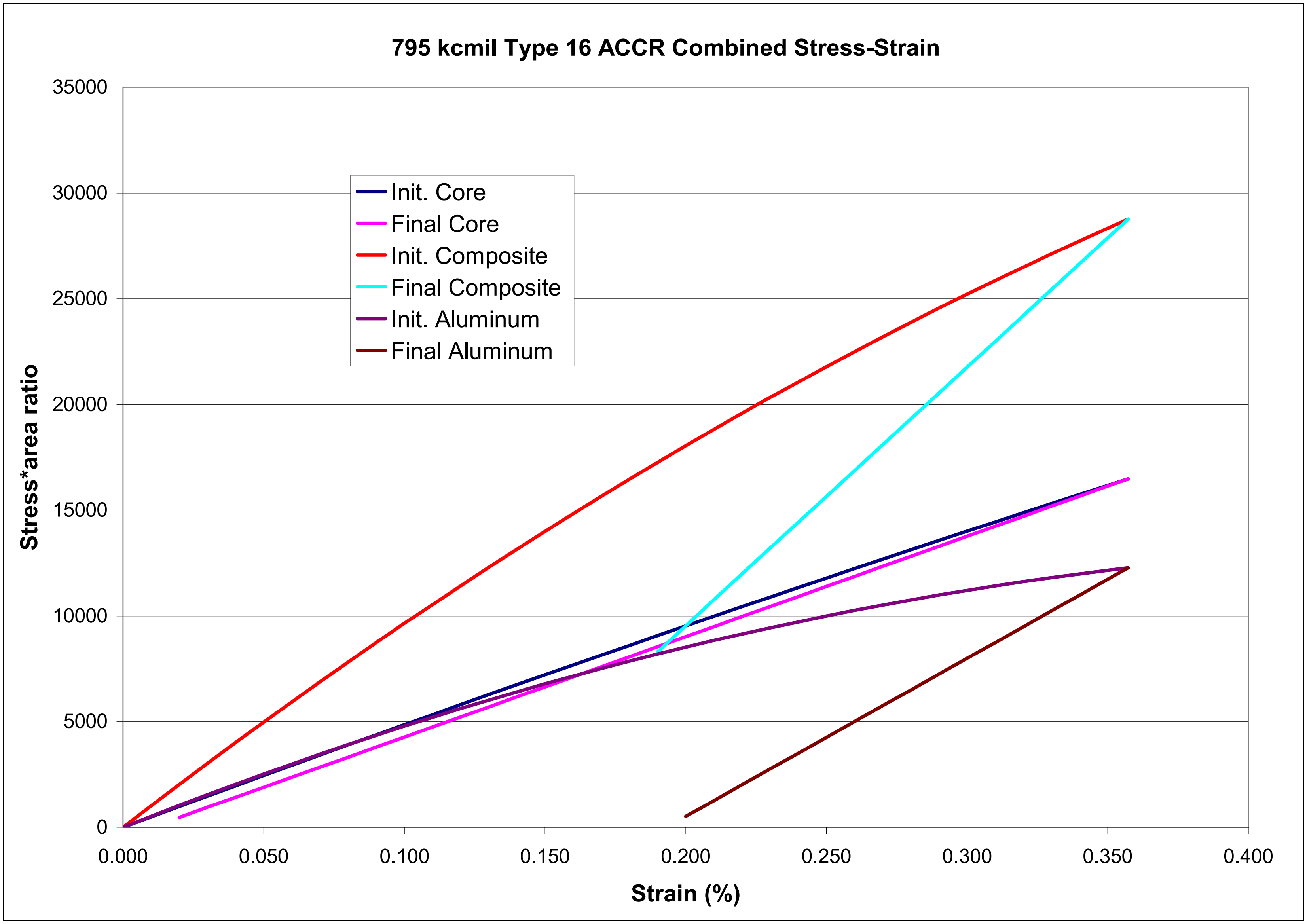
Core Stress Strain per Aluminum Association Guide



Core Initial Modulus Data



Core Final Modulus Data



Summary Graph – 795 3M Composite Conductor