

**“Merrimack” and “Suwannee”
ACSS/TW/HS285 Conductor
Stress-Strain Tests**

Southwire Company

NEETRAC Project Number: 05-204

November, 2005



Requested by: Mr. Kiran Manchiraju
Southwire Company

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SUMMARY:

Mr. Kiran Manchiraju of Southwire Company requested that NEETRAC measure the stress-strain properties for Merrimack and Suwannee ACSS/TW/HS285 conductors. This report outlines the test procedures and results of each test.

SAMPLES:

- 1) Hand coil containing approximately 100 feet of 1433.6 kcmil Type-13 “Merrimack” ACSS/TW/HS285
- 2) Hand coil containing approximately 100 feet of 959.6 kcmil Type-16 “Suwannee” ACSS/TW/HS285

PROCEDURE AND RESULTS:

“Merrimack” Conductor:

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 presented later in this section of the report. Photograph 1 shows the long view of the test apparatus for a typical test sample. Photograph 2 is a close-up of a resin socket and the extensometer attachment.

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:

“Merrimack” 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 (14,520 lbs)
- 4) Hold for 30 minutes.
- 5) Relax load to 1,000 lbs.
- 6) Pull to 50% RBS (24,200 lbs). Hold for one hour.
- 7) Relax load to 1,000 lbs.
- 8) Pull to 70% RBS (33,880 lbs). Hold for one hour.
- 9) Relax load to 1,000 lbs.
- 10) Pull to 75% RBS (36,300 lbs).
- 11) Relax load to 1,000 lbs, and remove the extensometer (for its own protection).
- 12) Pull to destruction.

“Merrimack” Core strands:

- 1) Pull to calculated initial tension (in this case, 550 lbs)
- 2) Install extensometer, and set to zero.
- 3) Pull to same strain as conductor at start of 30% of RBS test (0.2128%). Hold for 30 minutes.
- 4) Relax load to 550 lbs.
- 5) Pull to same strain as conductor at start of 50% of RBS test (0.4110%). Hold for one hour.
- 6) Relax load to 550 lbs.
- 7) Pull to same strain as conductor at start of 70% of RBS test (0.6497%). Hold for one hour.
Relax load to 550 lbs.
- 8) Pull to 75% of the core rating (29,440 lbs)
- 9) Relax load to 550 lbs, and remove the extensometer (for its own protection).
- 10) Pull to destruction.



Figure 1, Long View of Typical Stress-Strain Test



Figure 2, Typical Resin Socket and Extensometer

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

“Merrimack” Composite Conductor Properties:

Initial Modulus for Stress Strain Curve: $\text{Stress (psi)} = -19,053 * (\text{Strain}\%)^2 + 51,611 * (\text{Strain}\%)$
Final Modulus for Stress Strain Curve: $\text{Stress (psi)} = 104,311 * (\text{Strain}\%) - 48,818$
Tensile Test, Stress Strain Sample: 48,980 lbs (101% RBS)

“Merrimack” Core Properties:

Initial Modulus for Stress Strain Curve: $\text{Stress (psi)} = 635 * (\text{Strain}\%)^2 + 266,728 * (\text{Strain}\%)$
Final Modulus for Stress Strain Curve: $\text{Stress (psi)} = 285,097 * (\text{Strain}\%) - 12,300$
Tensile Test, Core Stress Strain Sample: 39,110 lbs (99% Nominal Rating) **

** Sample did not fail. The resin sockets were crushed in the test fixture prior to failure of the strands.

“Merrimack” Aluminum Properties:

Initial Modulus for Stress Strain Curve: $\text{Stress (psi)} = -21,550 * (\text{Strain}\%)^2 + 24,325 * (\text{Strain}\%)$
Final Modulus for Stress Strain Curve: $\text{Stress (psi)} = 81,379 * (\text{Strain}\%) - 53,347$

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 0.73%, 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.

“Suwannee” Conductor:

Composite Conductor Stress-Strain Test:

Test set-up was identical to the “Merrimack” sample. 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 30.6% of RBS (11,800 lbs)*
- 4) Hold for 30 minutes.
- 5) Relax load to 1,000 lbs.
- 6) Pull to 51% RBS (19,660 lbs)*. Hold for one hour.
- 7) Relax load to 1,000 lbs.
- 8) Pull to 71% RBS (27,530 lbs)*. Hold for one hour.
- 9) Relax load to 1,000 lbs.
- 10) Pull to 76.4% RBS (29,490 lbs)*.
- 11) Relax load to 1,000 lbs, and remove the extensometer (for its own protection).
- 12) Pull to destruction.

Core strands:

- 1) Pull to calculated initial tension (in this case, 222 lbs)
- 2) Install extensometer, and set to zero.
- 3) Pull to same strain as conductor at start of 30% of RBS test (0.1645%). Hold for 30 minutes.
- 4) Relax load to 222 lbs.
- 5) Pull to same strain as conductor at start of 50% of RBS test (0.3125%). Hold for one hour.
- 6) Relax load to 222 lbs.
- 7) Pull to same strain as conductor at start of 70% of RBS test (0.5058%). Hold for one hour.
Relax load to 222 lbs.
- 8) Pull to 75.3% of the core rating (24,450 lbs)*
- 9) Relax load to 222 lbs, and remove the extensometer (for its own protection).
- 10) Pull to destruction.

*Note: There is a very slight discrepancy in the % of RBS used for the test as compared to the Aluminum Association standard. The value was based upon reported RBS of 39,324 lbs for the composite conductor and 32,595 lbs for the steel core, while the actual required RBS was 38,600 lbs and 32,475 lbs, respectively. The difference resulted in slightly higher percentages of load used for the tests.

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

“Suwannee” Composite Conductor Properties:

Initial Modulus for Stress Strain Curve: $\text{Stress (psi)} = -38,208 * (\text{Strain}\%)^2 + 78,030 * (\text{Strain}\%)$
Final Modulus for Stress Strain Curve: $\text{Stress (psi)} = 113,182 * (\text{Strain}\%) - 32,962$
Tensile Test, Stress Strain Sample: 44,270 lbs (115% RBS)

“Suwannee” Core Properties:

Initial Modulus for Stress Strain Curve: $\text{Stress (psi)} = -1,675 * (\text{Strain}\%)^2 + 282,873 * (\text{Strain}\%)$
Final Modulus for Stress Strain Curve: $\text{Stress (psi)} = 292,846 * (\text{Strain}\%) - 881$
Tensile Test, Core Stress Strain Sample: 33,010 lbs (102% Nominal Rating)

“Suwannee” Aluminum Properties:

Initial Modulus for Stress Strain Curve: $\text{Stress (psi)} = -44,146 * (\text{Strain}\%)^2 + 44,737 * (\text{Strain}\%)$
Final Modulus for Stress Strain Curve: $\text{Stress (psi)} = 83,981 * (\text{Strain}\%) - 37,295$

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 0.57%, 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.

REFERENCES:

- 1) 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”
- 2) Southwire “Overhead Conductor Manual”

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)

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

Mechanical load (stress):

Measurement equipment is certified to exceed requirements of ASTM E4-2003 (+/-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.

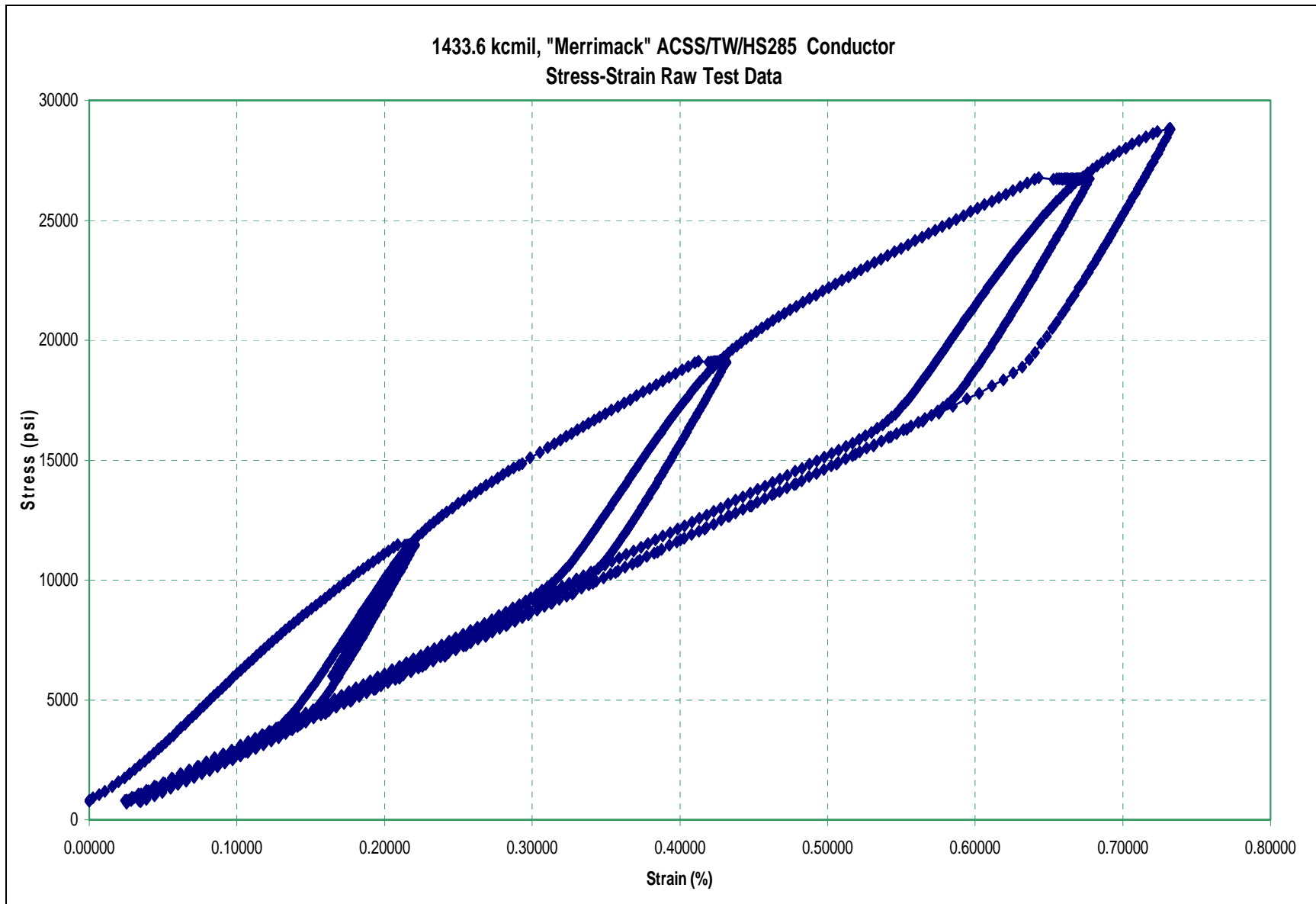
Effect of mechanical deflections of the gage rod: The gage rod is a 2” x 6” x 1/8” x 19 ft aluminum box beam, which is extremely stiff. The only bending force is friction in the guide bearings and wiper seals for the displacement sensor. Starting and running friction were measured as 0.3 lbs, and 0.2 lbs respectively. The error is less than 0.5 PPM.

Effect of thermal expansion of the sample and gage rod: Lab temperature changed 0.4 °C and 0.6 °C from beginning of the test to the end for the Merrimack and Suwannee tests, respectively. 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/°C), while the sample thermal elongation is estimated to be 16 PPM/°C. Error in the strain measurement is, therefore, 7 PPM/°C. For the 0.4 °C temperature variation, the error is 2.8 PPM. For the 0.6 °C temperature variation, the error is 4.2 PPM. The error does not affect the modulus values, because load is changed rapidly relative to rate of temperature change. Thermal effects could affect measurement of short-term creep during load hold periods. Thus, mathematical temperature compensation was used for both stress-strain tests.

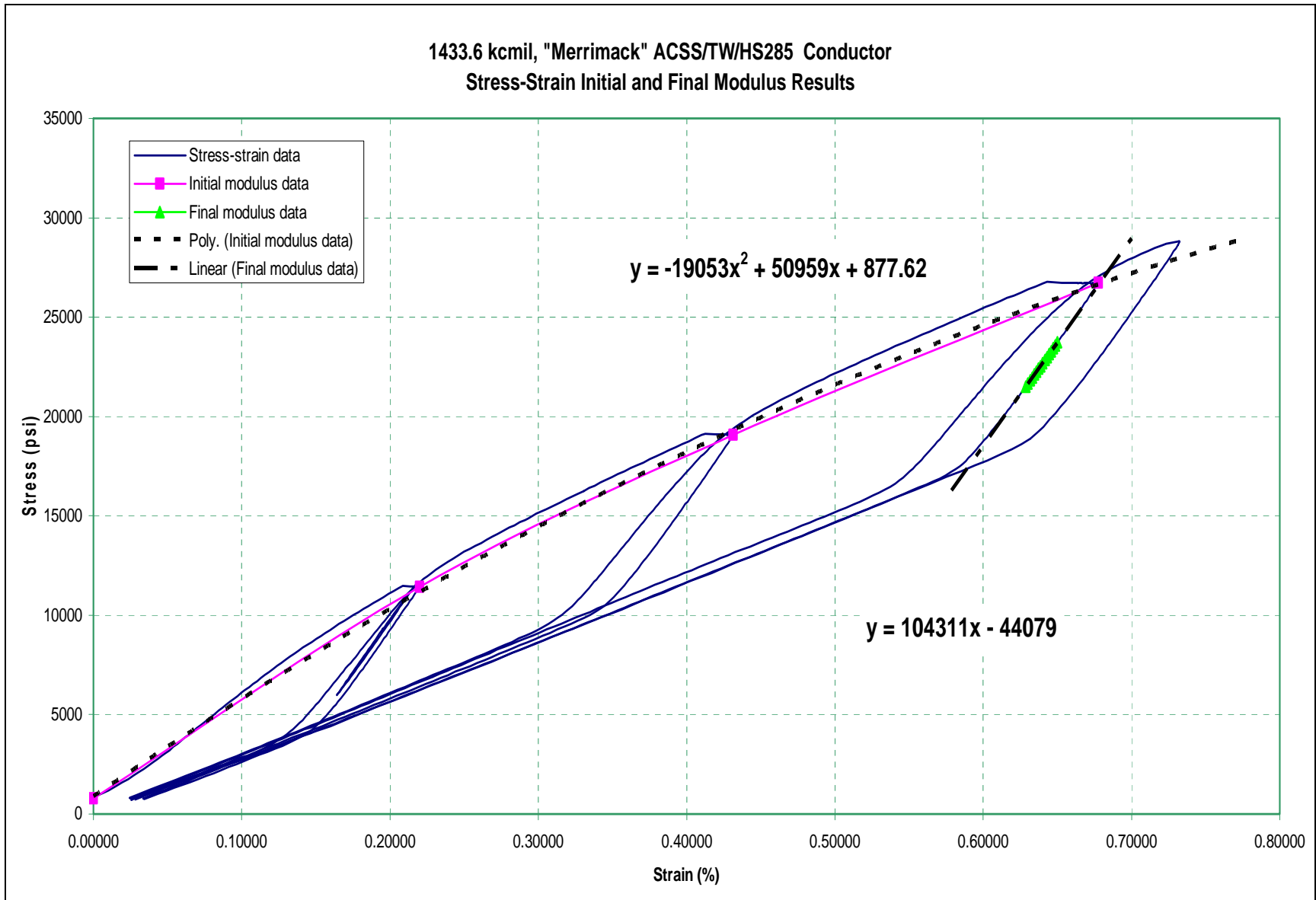
Effect of starting gage length: An error of +/- 1/16” is possible. The maximum error affects the strain measurement by 0.02% of reading.

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 3 parts per million (Merrimack) or 4 parts per million (Suwannee). 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).

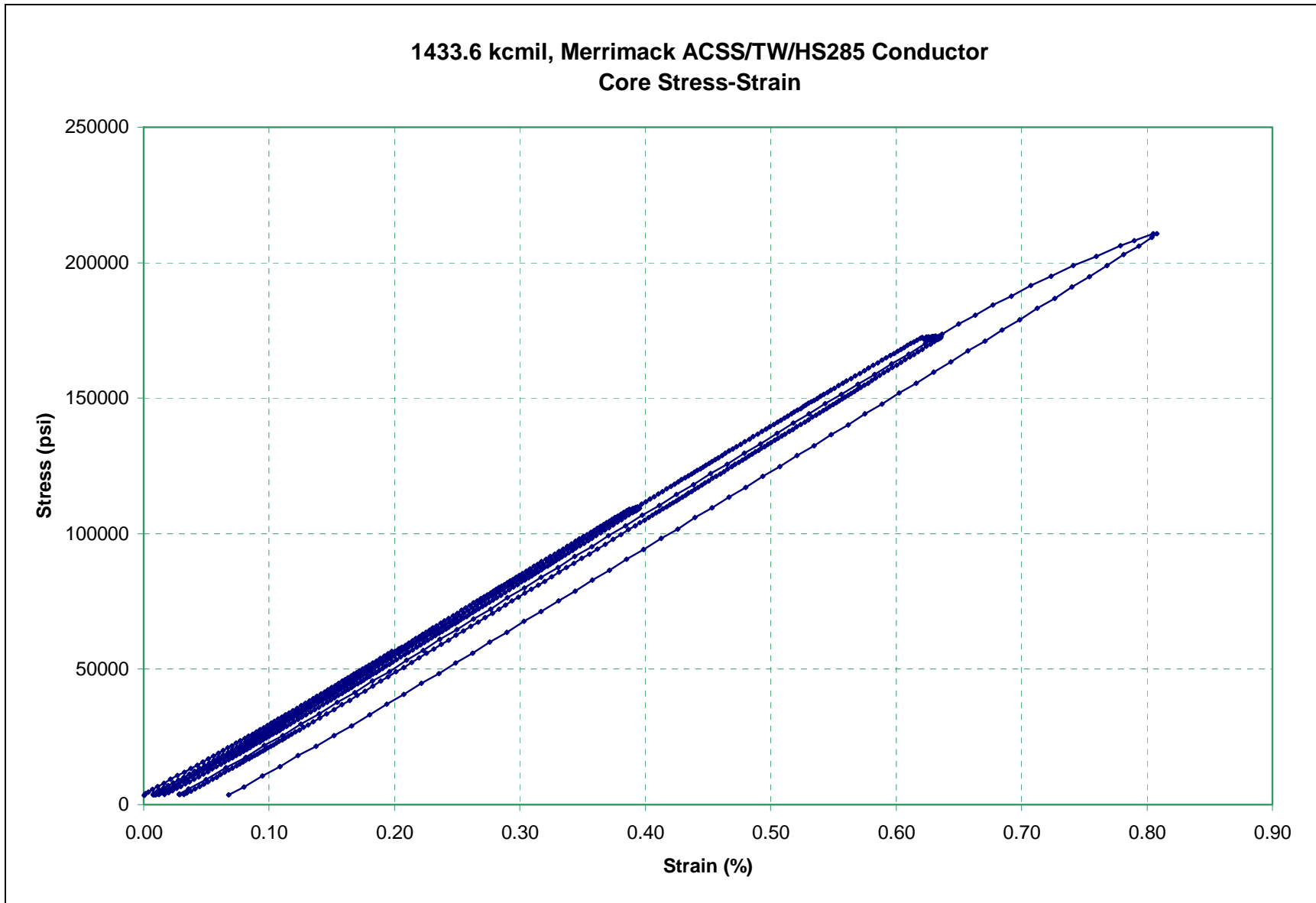
Appendix 2
Stress-Strain Graphs
“Merrimack” ACSS/TW/HS285



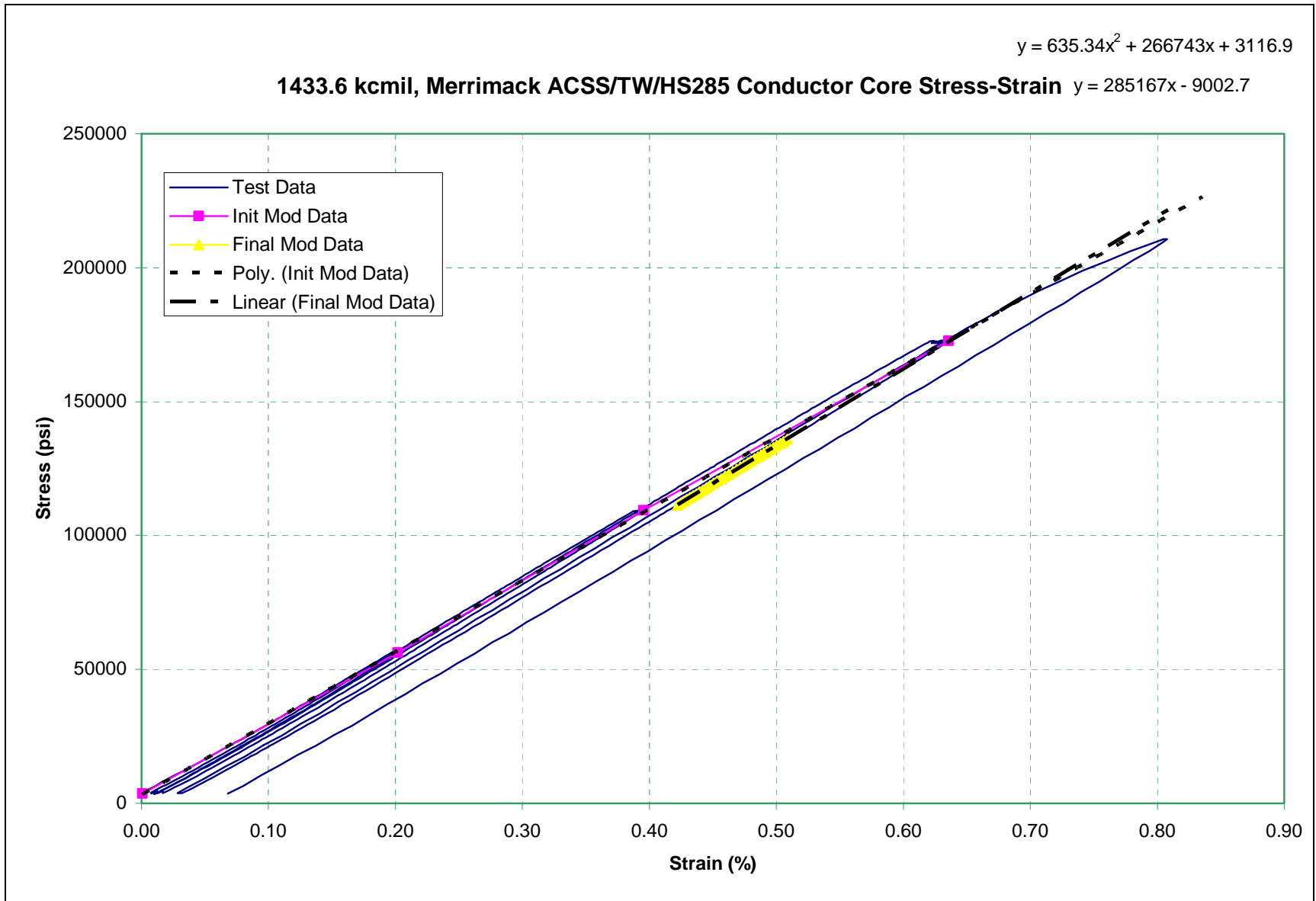
Composite Stress-Strain Plot in Accordance with Aluminum Association Guide



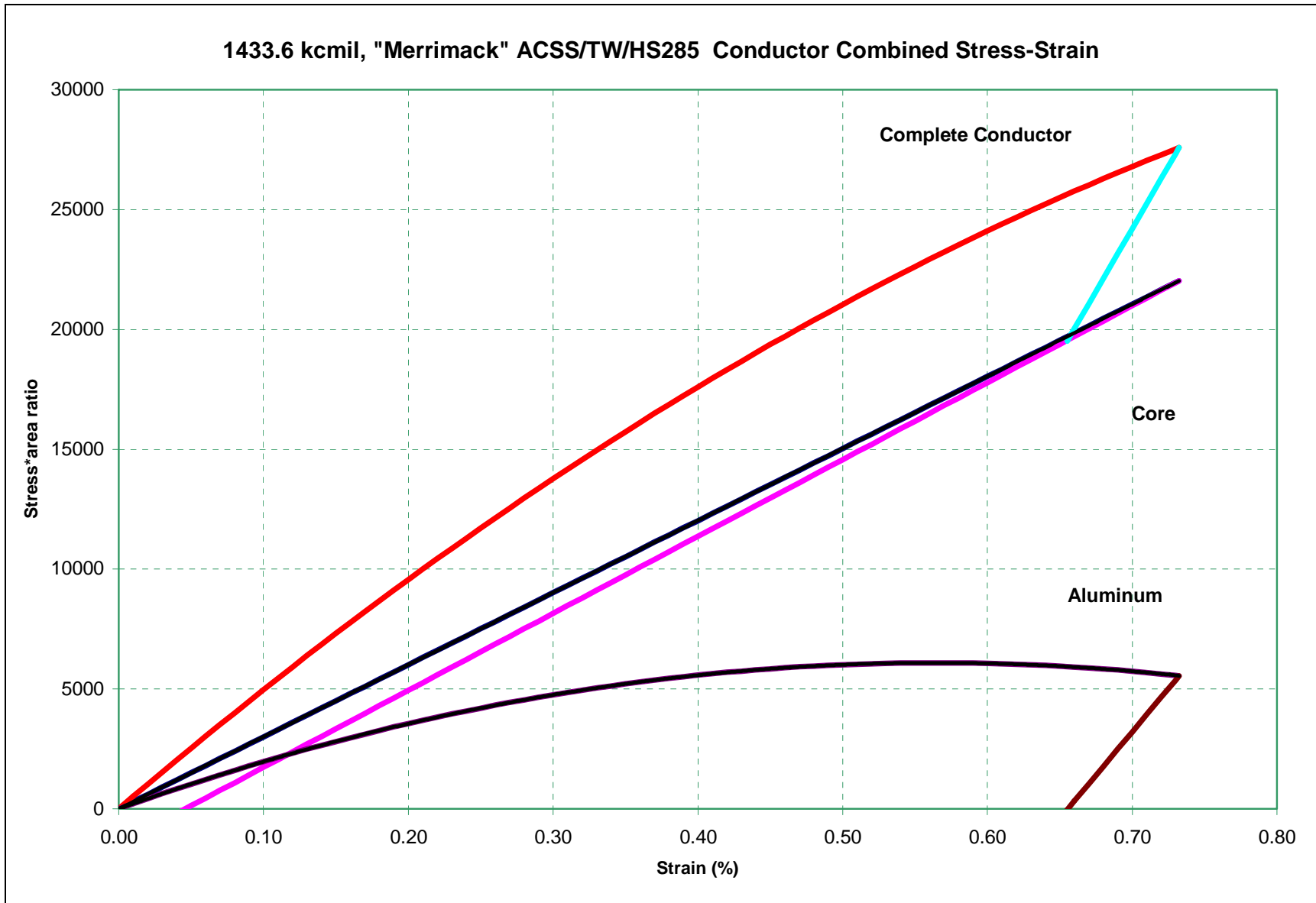
Composite Stress-Strain Plot with Data Fit for Initial and Final Modulus



Core Stress Strain per Aluminum Association Guide

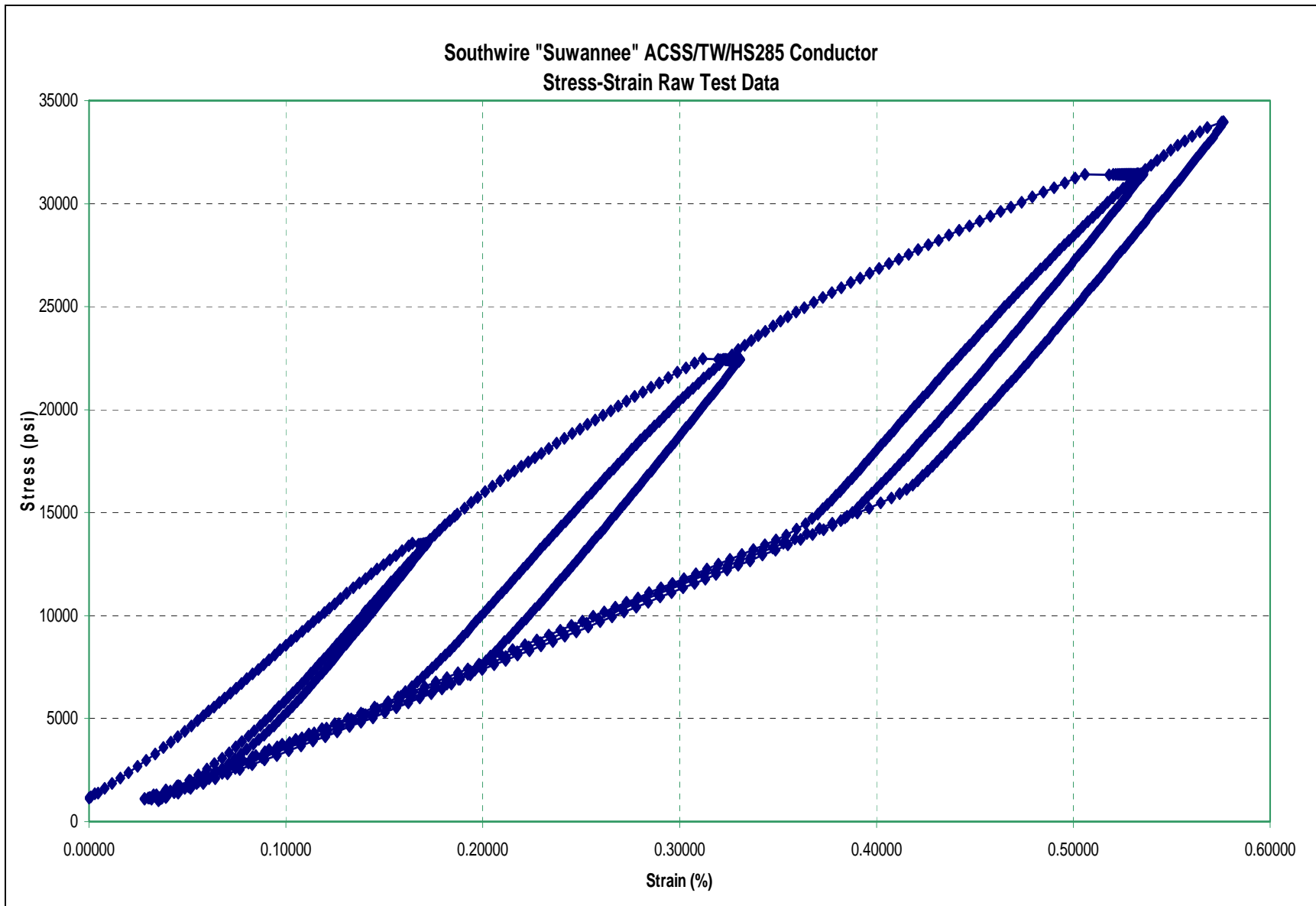


Core Initial Modulus and Final Modulus Data

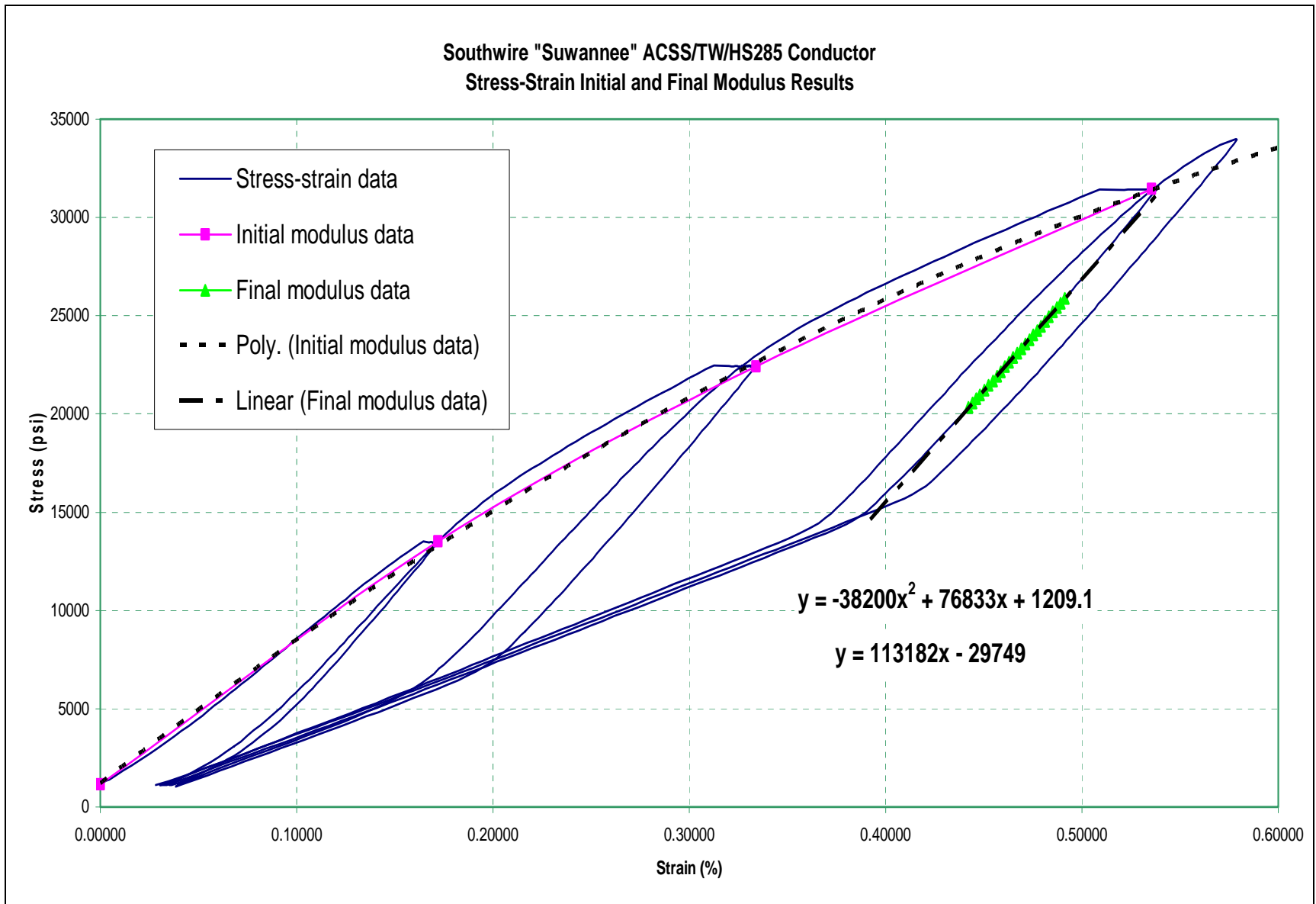


Summary Graph – Merrimack ACSS/TW/HS285 Conductor

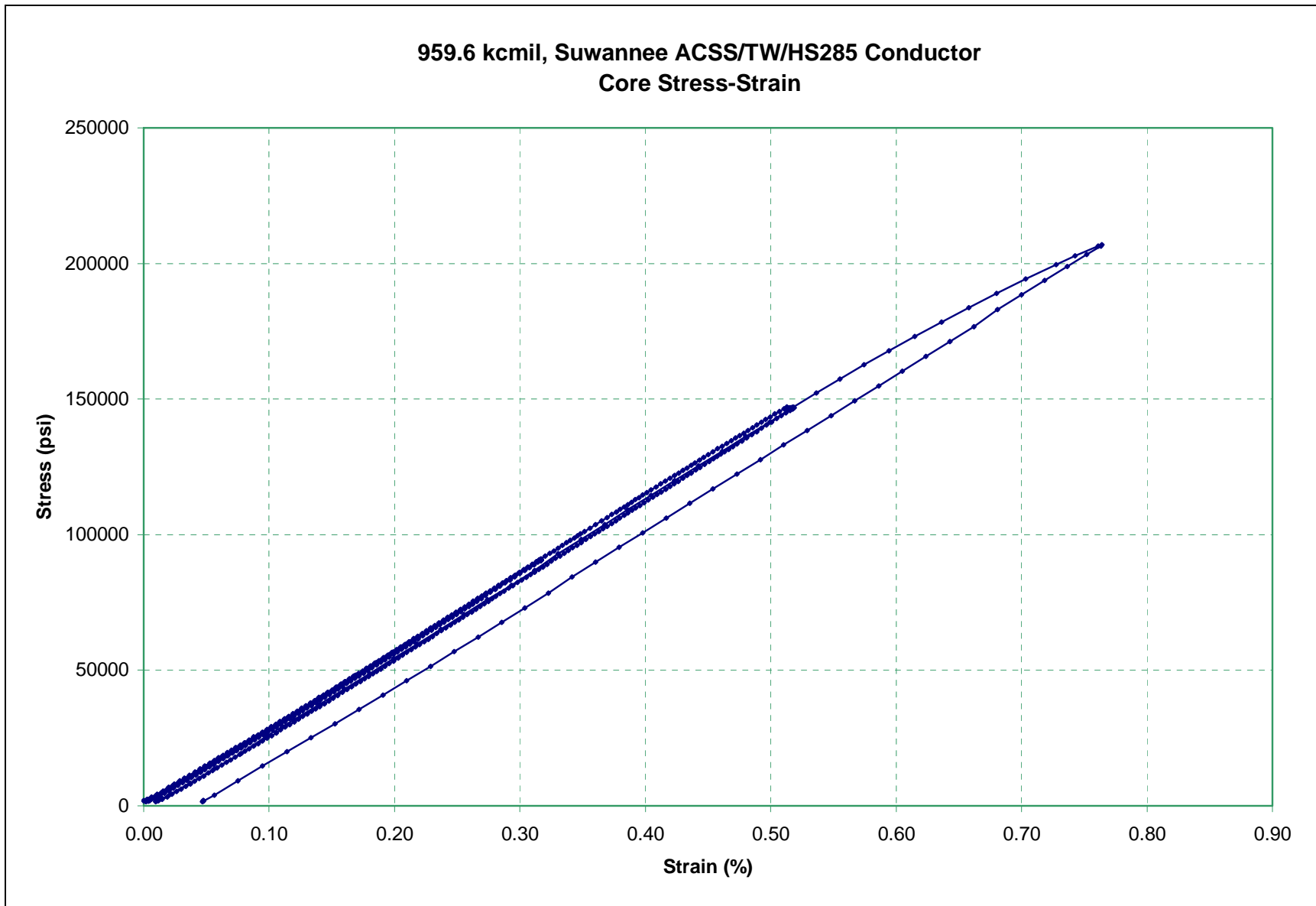
Appendix 3
Stress-Strain Graphs
“Suwannee” ACSS/TW/HS285



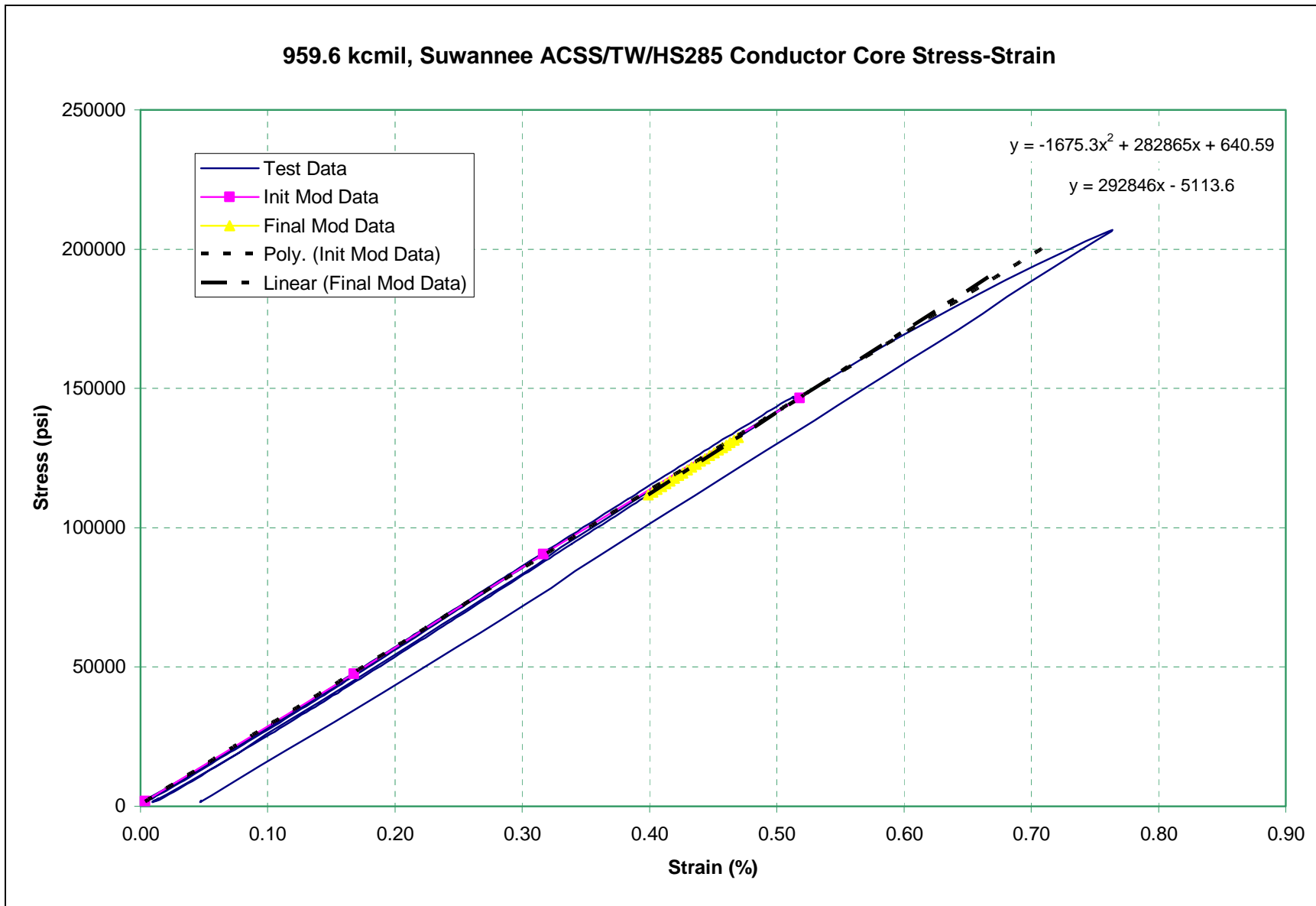
Composite Stress-Strain Plot in Accordance with Aluminum Association Guide



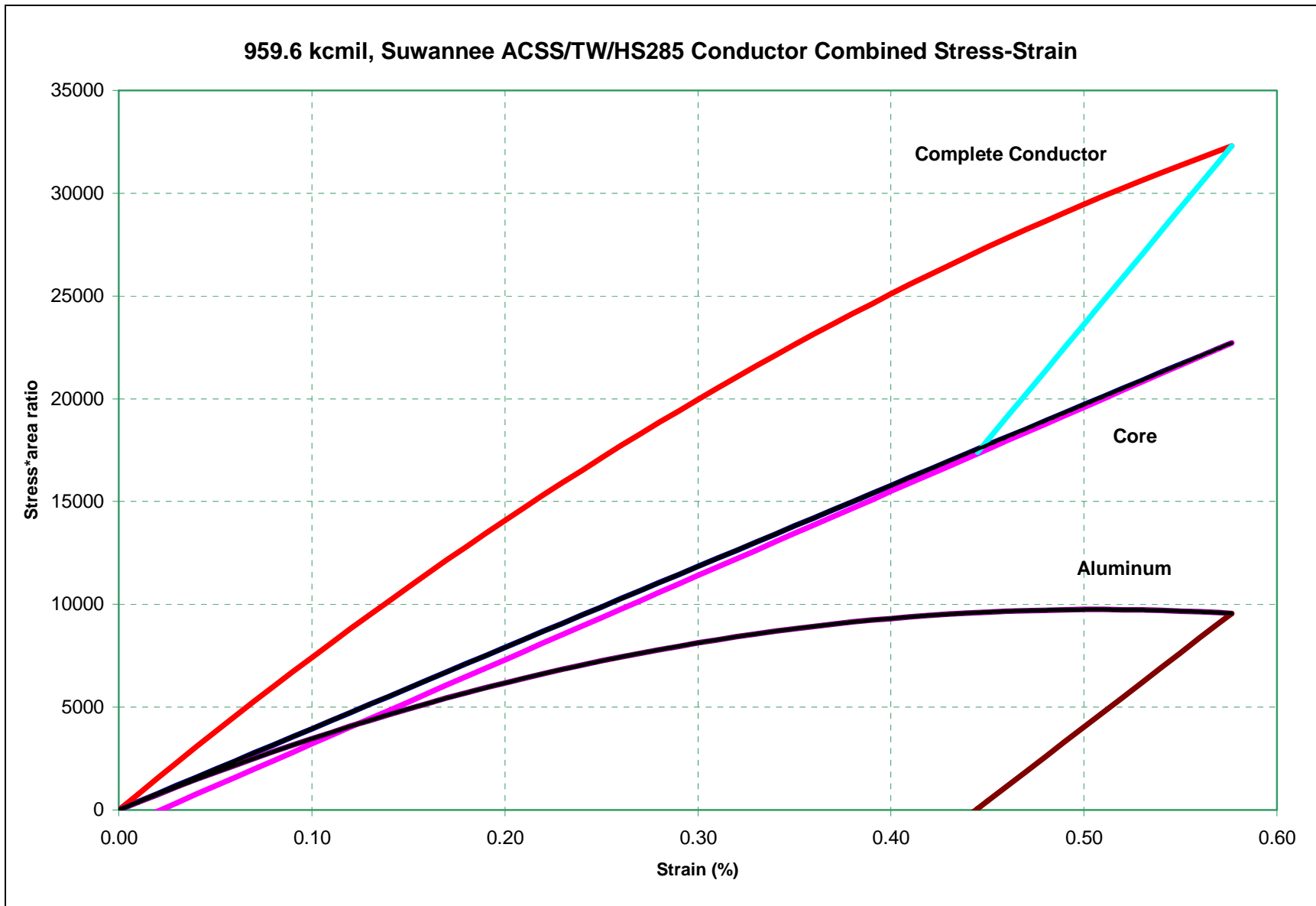
Composite Stress-Strain Plot with Data Fit for Initial and Final Modulus



Core Stress Strain per Aluminum Association Guide



Core Initial Modulus and Final Modulus Data



Summary Graph – Suwannee ACSS/TW/HS285 Conductor