675/TW-kcmil, Type 11, 3M Brand Composite Conductor
Tensile and Stress-Strain Tests

3M Company
Purchase Order 0001111355

NEETRAC Project Number: 03-211

January, 2004

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

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Summary:

3M contracted with NEETRAC for a series of tests to measure the mechanical characteristics of 675/TW 3M Brand Composite Conductor. This conductor can also be referred to as 675 ACCR/TW (where ACCR is Aluminum Conductor Composite Reinforced). Conductor stress-strain properties were measured in accordance with an Aluminum Association guide dated 1999. The guide was adapted for the special properties of the MMC core material. All test results conform to 3M's published nominal values.

Samples:

1) Conductor reel received 10/28/2003, identified as "Oak Ridge 675 kcmil ACCR/TW"

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 0001111355
4) 3M data file "3M Composite Conductor Specification – 675/TW, dated October 14, 2003, containing conductor technical specifications
5) PRJ 03-211, 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)
4) HBM linear position indicator for crosshead displacement (for reference only)

Procedure:

Tensile Tests:

Three samples, each 20 feet long were terminated with cast resin fittings designed to preserve the "as manufactured" conductor properties during testing. Samples were loaded in the MTS horizontal tensile machine, and pulled to destruction at a loading rate of 10,000 lb/min. Figure 1 shows the load versus crosshead displacement for the three pulls. Also shown are results of tensile tests on the stress-strain samples after completion of that test. Maximum loads were:

Sample	Max load (lbs)	% RBS	Failure mode
1	24460	109	All strands failed, mid gage section
2	24910	111	All strands failed, mid gage section
3	24660	110	All strands failed, mouth of socket
Stress-strain conductor	25470	113	All strands failed, mid gage section
Stress-strain core	12860	111	All strands failed, mid gage section

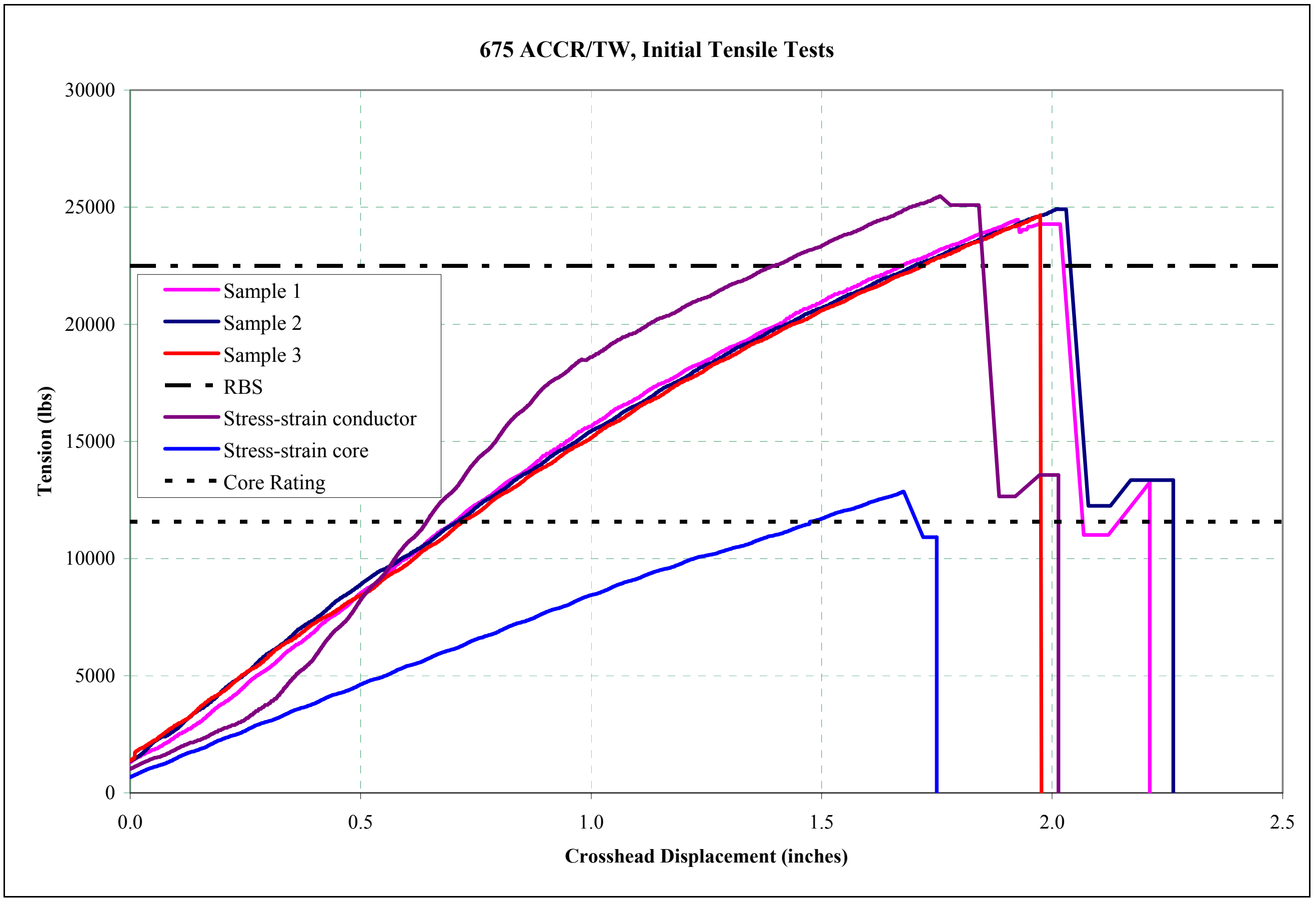


Figure 1, Load and Crosshead Position Data for Tensile Tests

Conductor Stress-Strain Test:

One sample each of the conductor and the core 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.

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:

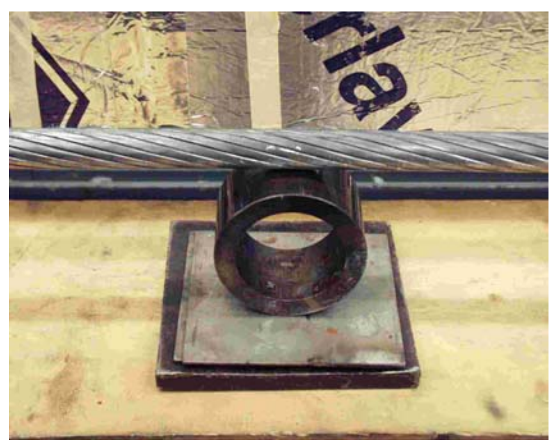
1) Apply load of 1,000 lbs. Remove sag with a mid-span support
2) Install extensometer, and set to zero.
3) Pull to 30% of RBS (6,750 lbs)
4) Hold for 30 minutes.
5) Relax load to 1,000 lbs.
6) Pull to 50% RBS (11,240 lbs)
7) Hold for one hour
8) Relax load to 1,000 lb
9) Pull to 70% RBS (15,740 lb)
10) Hold for one hour.
11) Relax load to 1,000 lbs.
12) Pull to 75% RBS (16,870 lbs).
13) Relax load to 1,000 lbs, and remove the extensometer (for its own protection).
14) Pull sample to destruction.

Core strands:

1) Pull to calculated initial tension (in this case, 399 lbs). Remove sag with a mid-span support
2) Install extensometer, and set to zero
3) Pull to same strain as conductor at start of 30% of RBS test (0.12324%)
4) Hold for 30 minutes.
5) Relax load to 399 lbs.
6) Pull to same strain as conductor at start of 50% of RBS test (0.21796%)
7) Hold for one hour.
8) Relax load to 399 lbs.
9) Pull to same strain as conductor at start of 70% of RBS test (0.33403%)
10) Hold for one hour
11) Relax load to 399 lbs.
12) Pull to 75% of the core RBS (8,670 lbs)
13) Relax load to 399 lbs, and remove the extensometer (for its own protection).
14) Pull sample to destruction.

Long View of Stress-strain Test on 675/TW Conductor

Photograph 2
Load Actuator and Extensometer
(Core strand is under test)



Photograph 3
Mid-span Support to Remove Sag
(675/TW Under test)

Results:

Data files containing test data were processed using Microsoft Excel® to obtain engineering values and graphical presentation. Ambient temperature during testing changed by less than 0.3° C. No temperature compensation was applied to the test data. Graphs showing data for each test are shown in Appendix 2. Figures 8 and 9 show the construction used to adjust the test data so that zero strain corresponds to zero stress (it is not practical to hold zero stress in a test frame). Figure 8 also shows a curve derived from the crosshead data during the tensile test. The strain instrument is delicate, and must be removed at high loads. The crosshead instrument is rugged, but does not measure true strain, because end effects and elastic effects in the frame are included in the measurement. However, the crosshead data can be scaled to closely match the strain instrument during the stress-strain test. It is reasonable to assume that strain values can be estimated at extreme loads using the scaled crosshead data. The crosshead data shows that the stress-strain fit curve is reasonable even at loads above the safe level for the strain instrument.

Composite Conductor Properties, direct test values:

Initial Modulus for Stress Strain Curve:	Stress (psi) = -30776*(Strain%)^2+79610*(Strain%)+1695
Final Modulus for Stress Strain Curve:	Stress (psi) = 108935*(Strain%) – 13364
Tensile Test, Stress Strain Sample:	25470 lb (113% RBS)

Composite Conductor, data shifted along strain axis to provide correct zero strain reference:

Initial Modulus for Stress Strain Curve:	Stress (psi) = -30776*(Strain%)^2 + 80910*(Strain%)
Final Modulus for Stress Strain Curve:	Stress (psi) = 108935*(Strain%) – 15665

Core Strand Properties, direct test values:

Initial Modulus for Stress Strain Curve	Stress (psi) = -39619*(Strain%)^2+327809*(Strain%)+6611
Final Modulus for Stress Strain Curve:	Stress (psi) = 327961*(Strain%) – 364
Tensile Test, Stress Strain Sample:	12860 lb (111% of nominal rating)

Core Properties, data shifted along strain axis to provide correct zero strain reference:

Initial Modulus for Stress Strain Curve:	Stress (psi) = -39619*(Strain%)2 + 329403*(Strain%)
Final Modulus for Stress Strain Curve:	Stress (psi) = 327961*(Strain%) - 6962

Aluminum Properties (computed, direct measurement is not possible):

Initial Modulus for Stress Strain Curve:	Stress (psi) = -29767*(Strain%)^2+52545*Strain
Final Modulus for Stress Strain Curve:	Stress (psi) = = 83934*Strain -16479

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 E4-2001 (+/-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, strain resolution is 0.0001"/216", or 0.000046% (0.46 PPM). Sensor accuracy specification is +/- 0.0002", or 0.92 PPM. The measurement technique is digital from the sensor to the recording device. Noise and temperature drift are negligible. 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> strain error is linear wrt load error. Error is 0.5% of reading.

<u>Effect of mechanical deflections of the gage rod:</u> The gage rod is a 2" x 5" 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.

<u>Effect of thermal expansion of the sample and gage rod:</u> Because the gage rod has different thermal elongation than the sample, errors are introduced if ambient temperature changes occur during the test. The lab is climate controlled, but the test requires 4 hours to complete and temperature effects can introduce test errors. The test is somewhat self-compensating, because both the instrument and the sample have similar positive temperature coefficients. Temperature is monitored. Temperature compensation is employed if the temperature changes cause significant test errors. In this case, ambient temperature changed less than 0.3^{o}C during the composite test, and less than 0.5 ^{o}C during the core test. Because temperature was stable, errors are small (less than 0.1%). No temperature compensation was needed (raw test data are shown in the graphs in the appendix).

<u>Effect of starting gage length:</u>
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

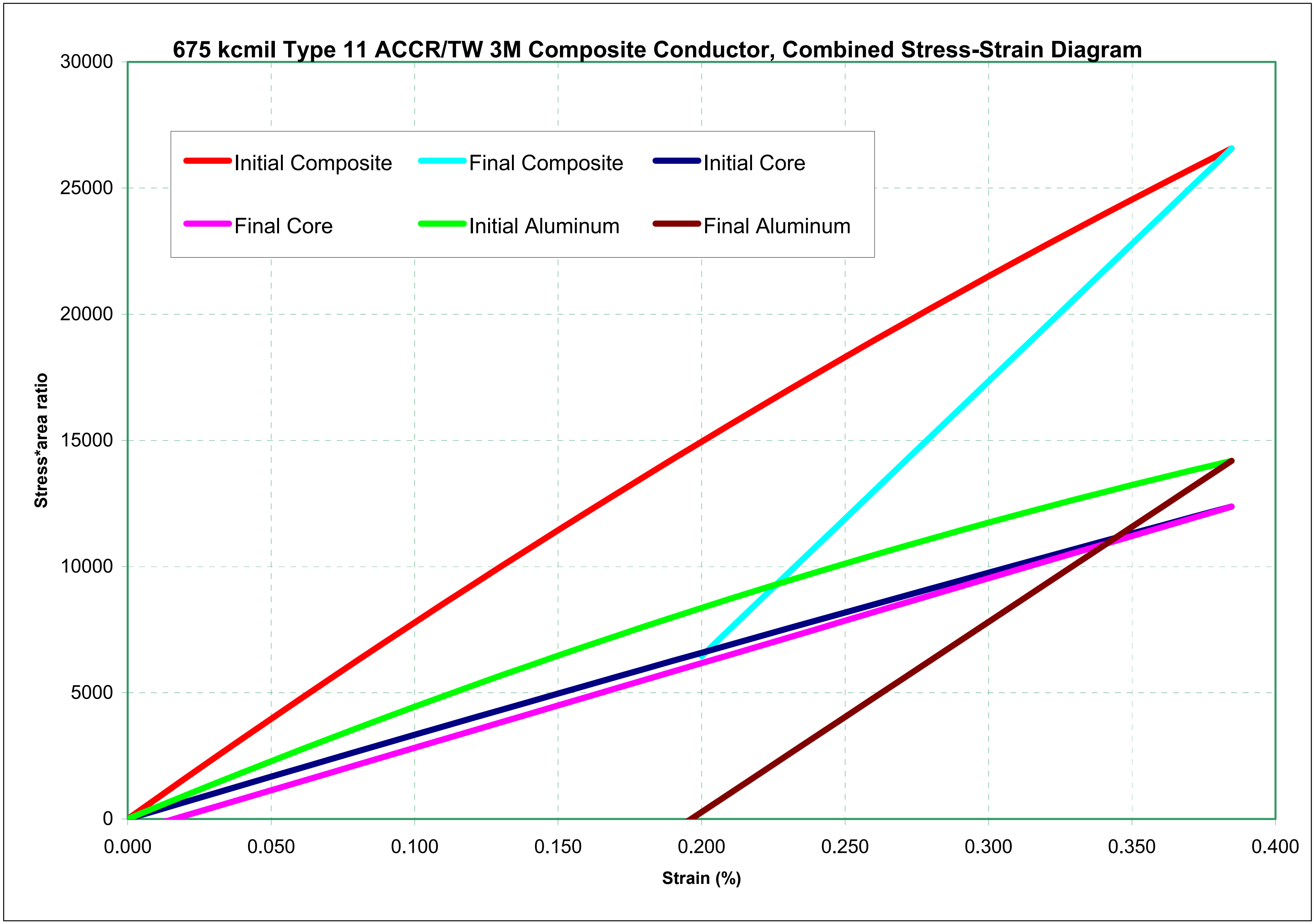


Figure 2, Summary Stress-Strain Plot (all values normalized to area ratio)

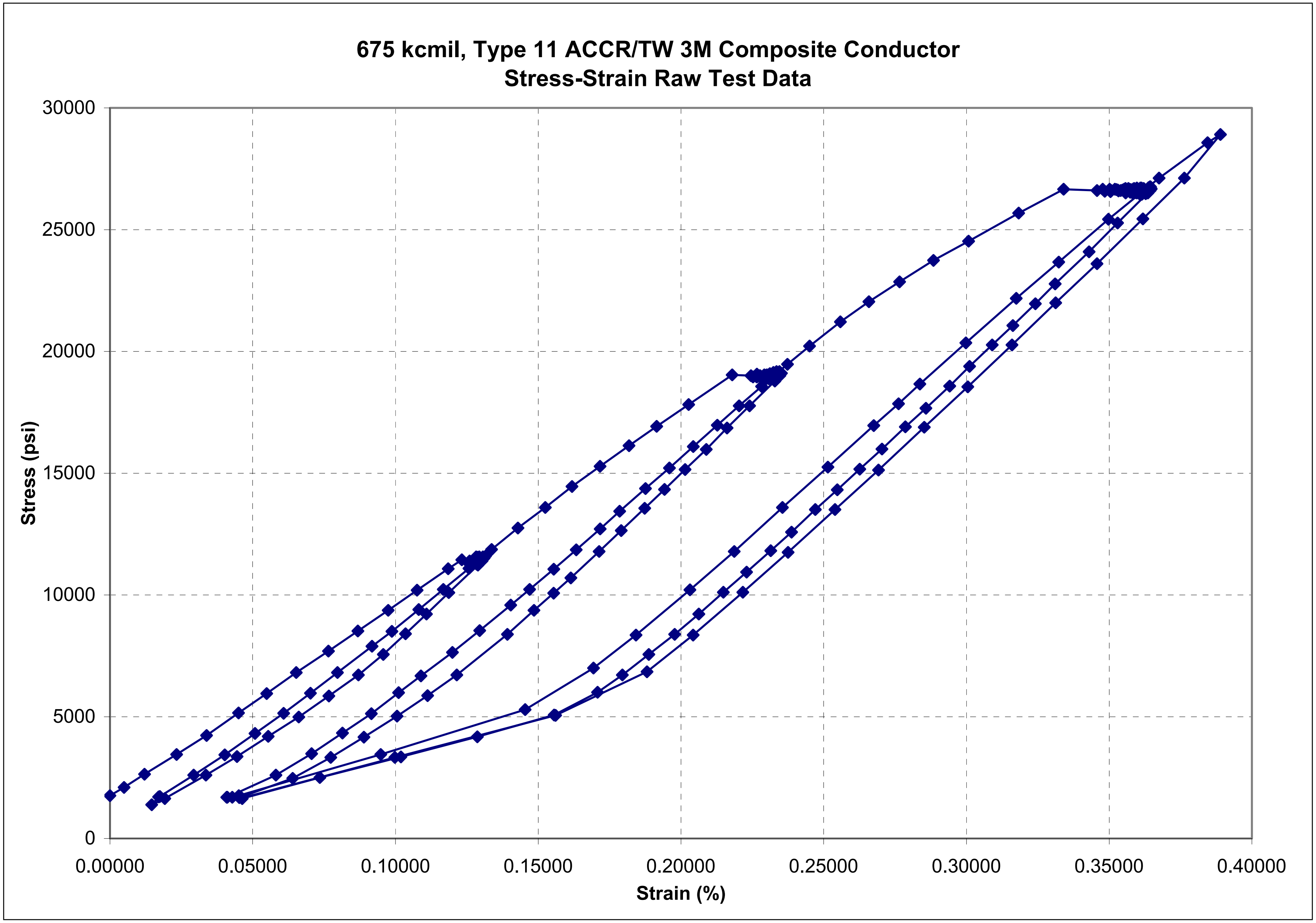


Figure 3, Conductor Stress-Strain Data

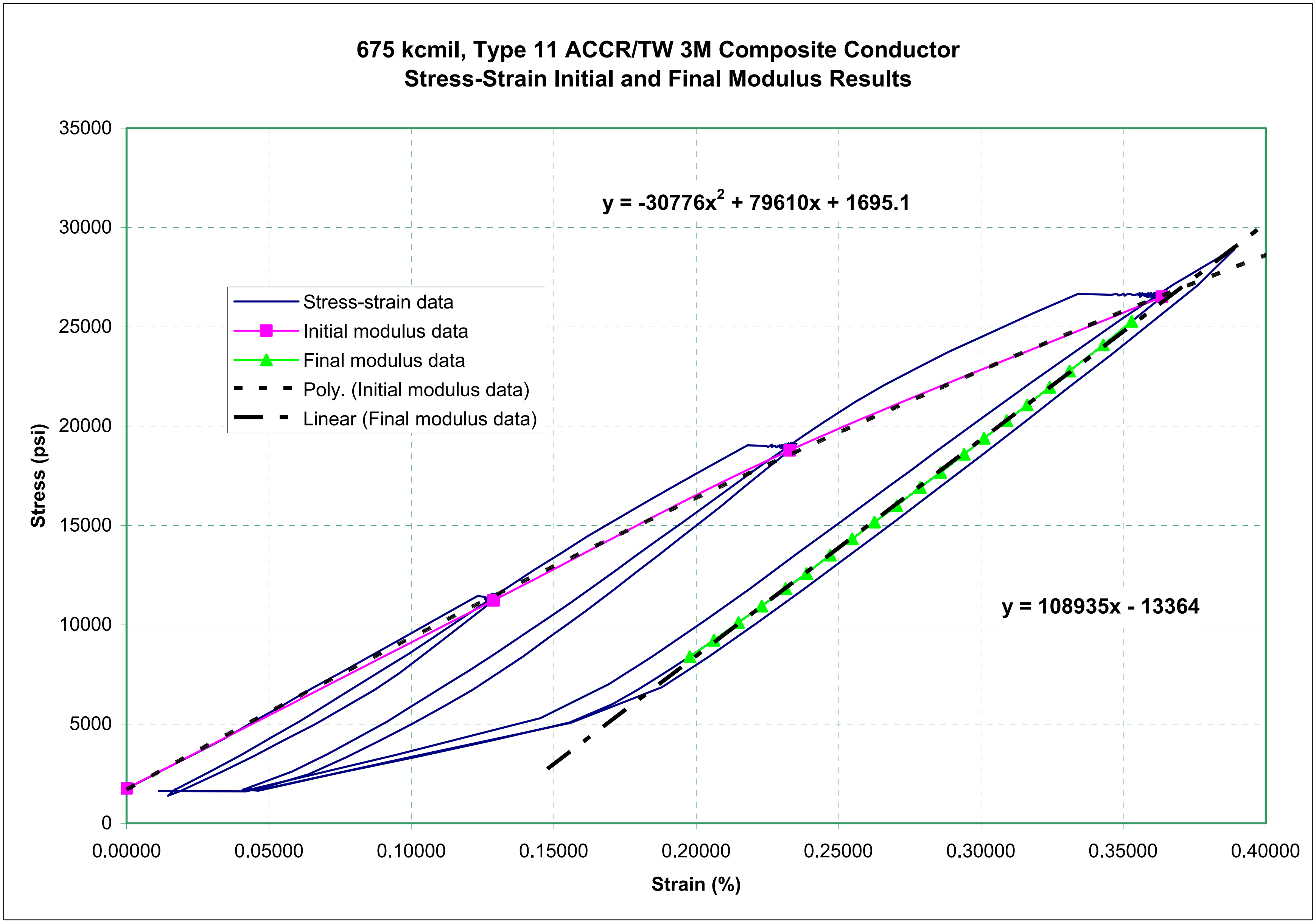


Figure 4, Composite Stress-Strain Plot with Data Fits for Initial and Final Modulus

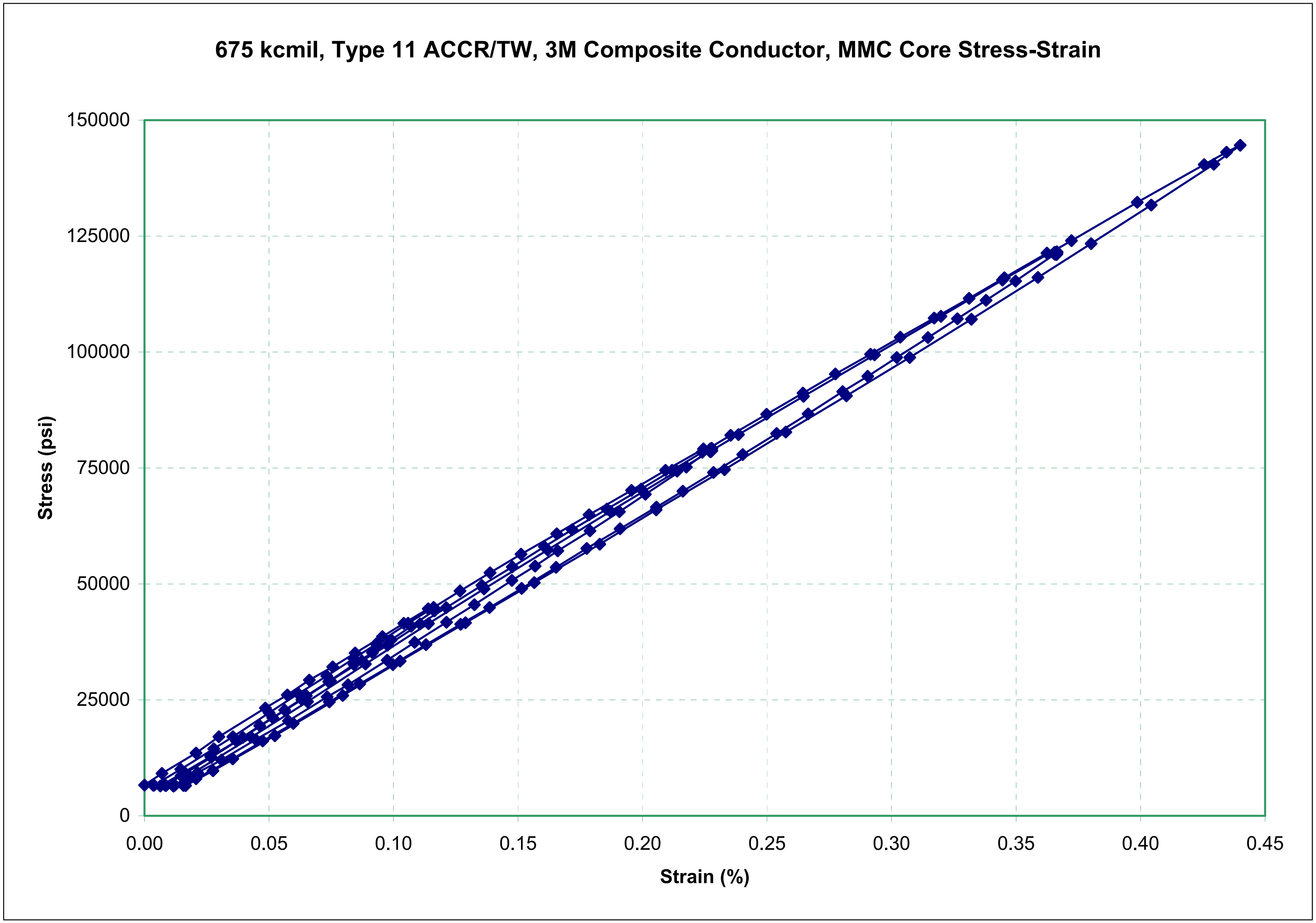


Figure 5, Core Stress-Strain per Aluminum Association Guide

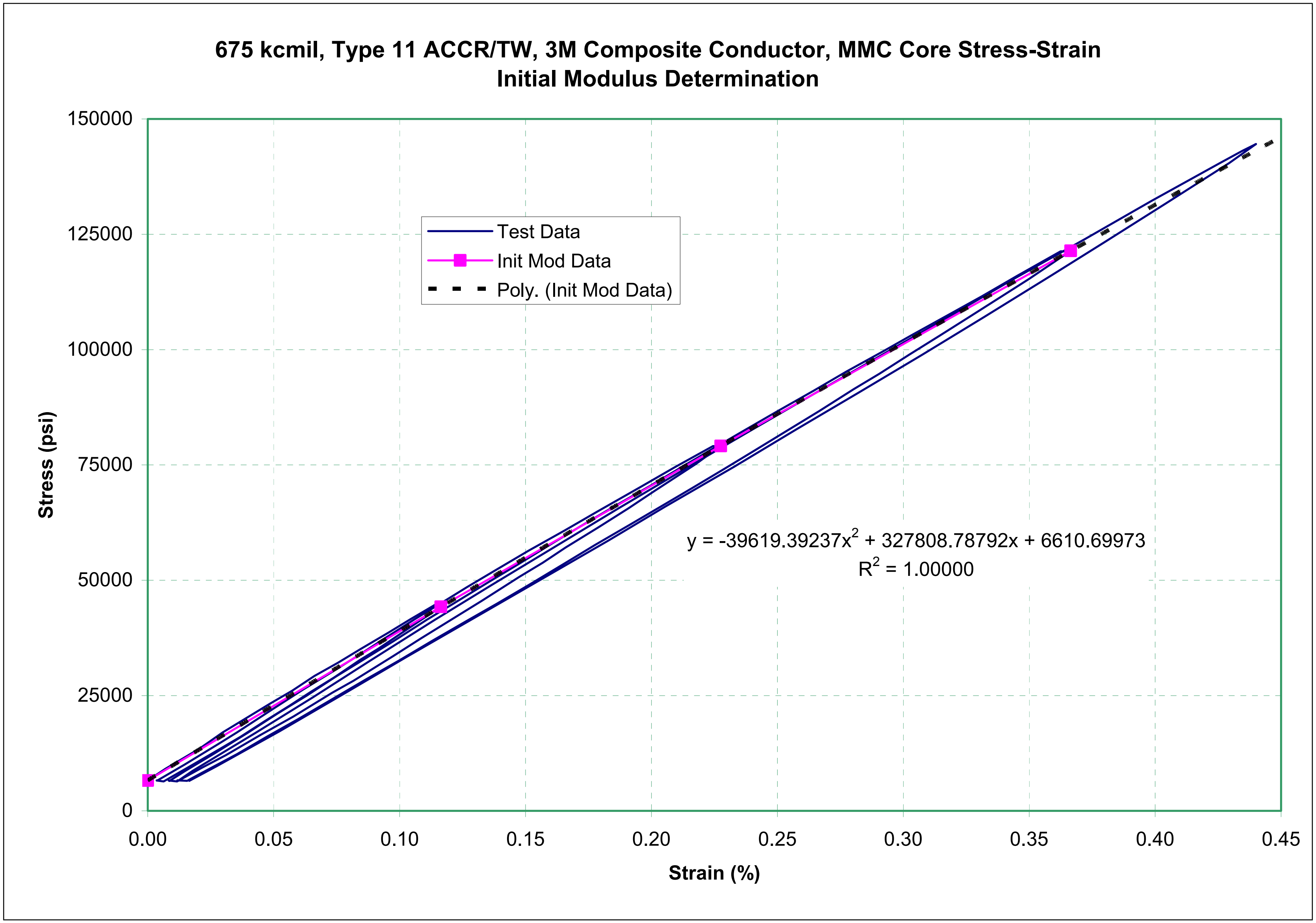


Figure 6, Core Graph with Initial Modulus Data

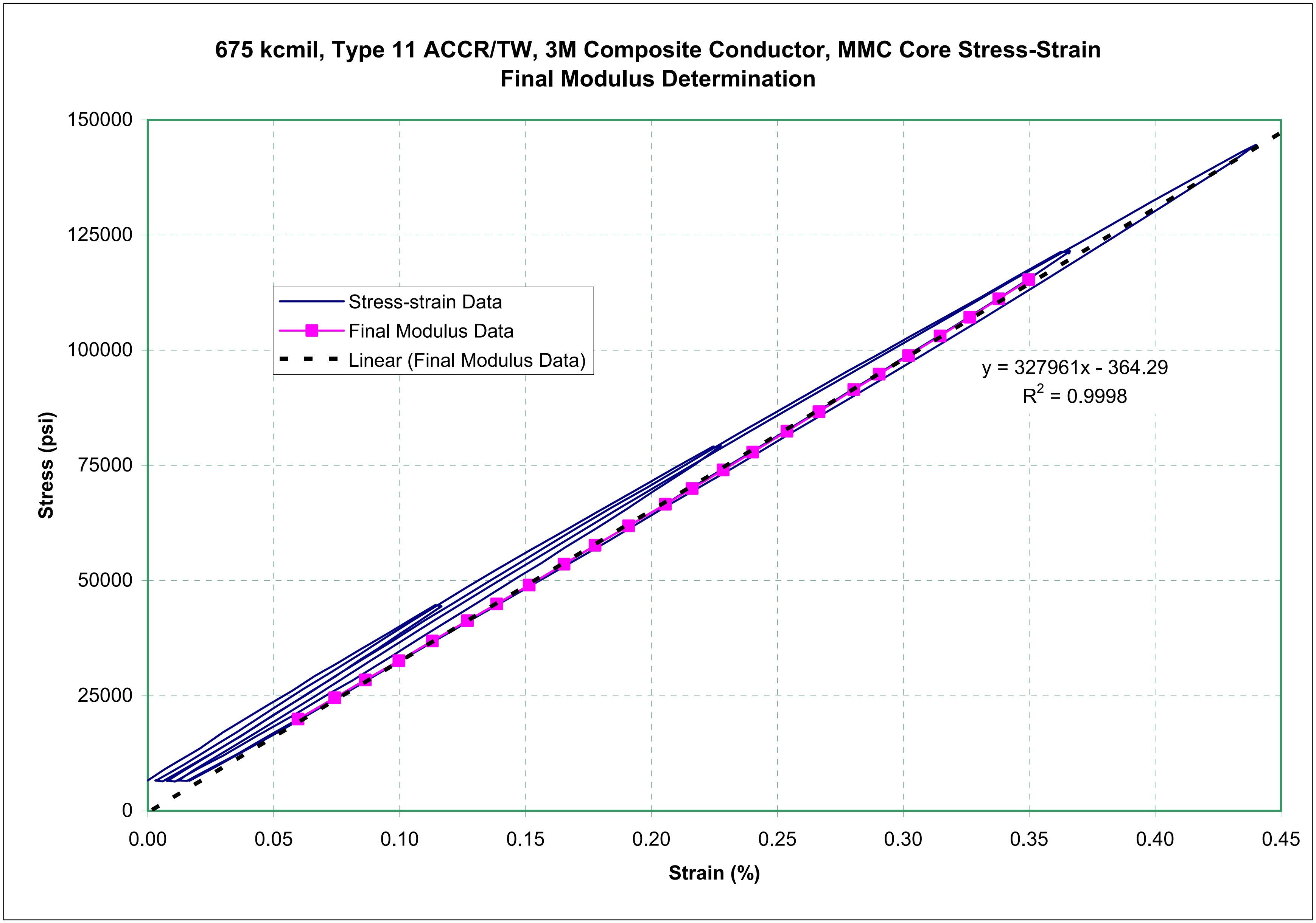


Figure 7, Core Graph with Final Modulus Data

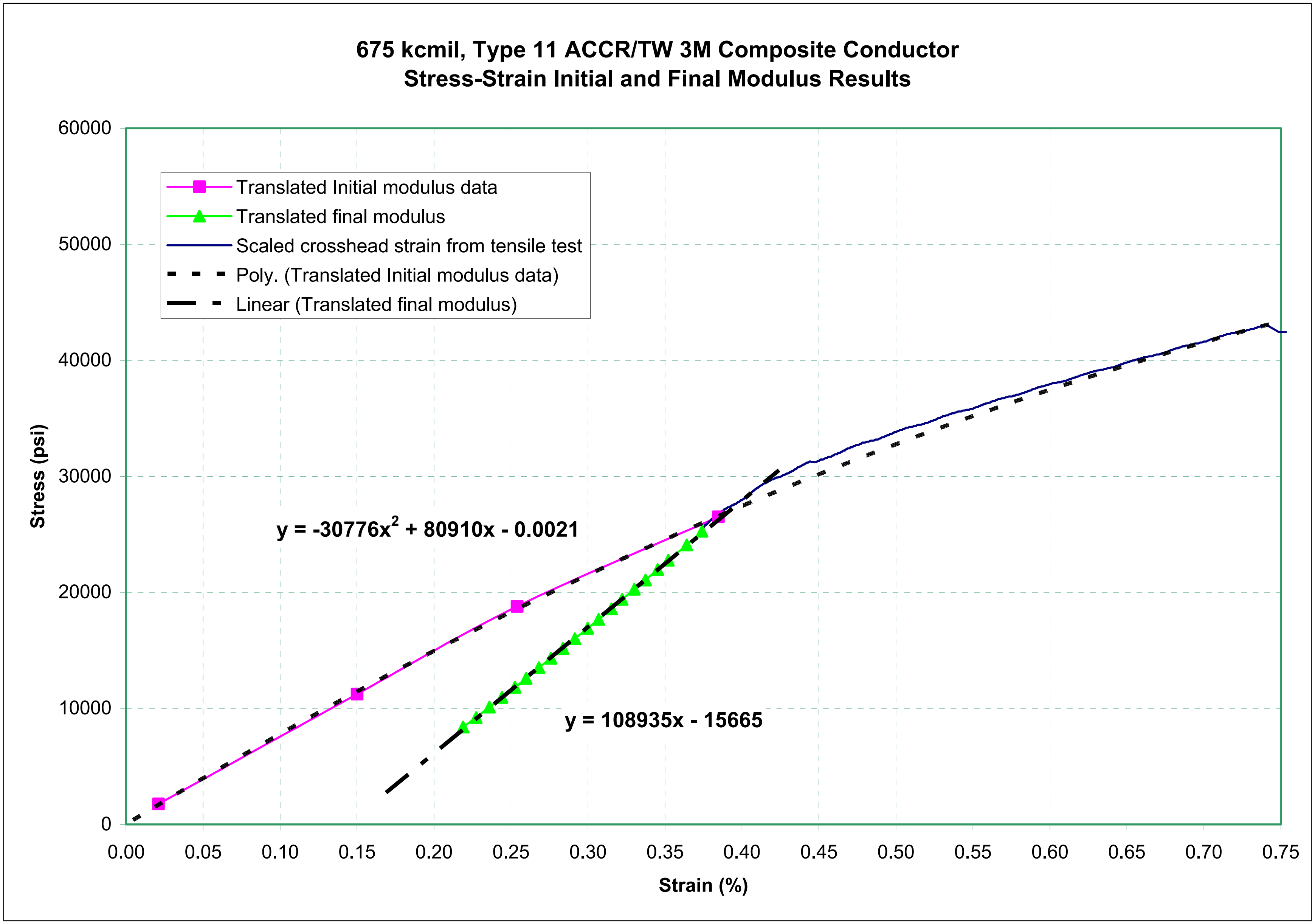


Figure 8, Composite conductor data with shifted curves and extended curve based on crosshead position data

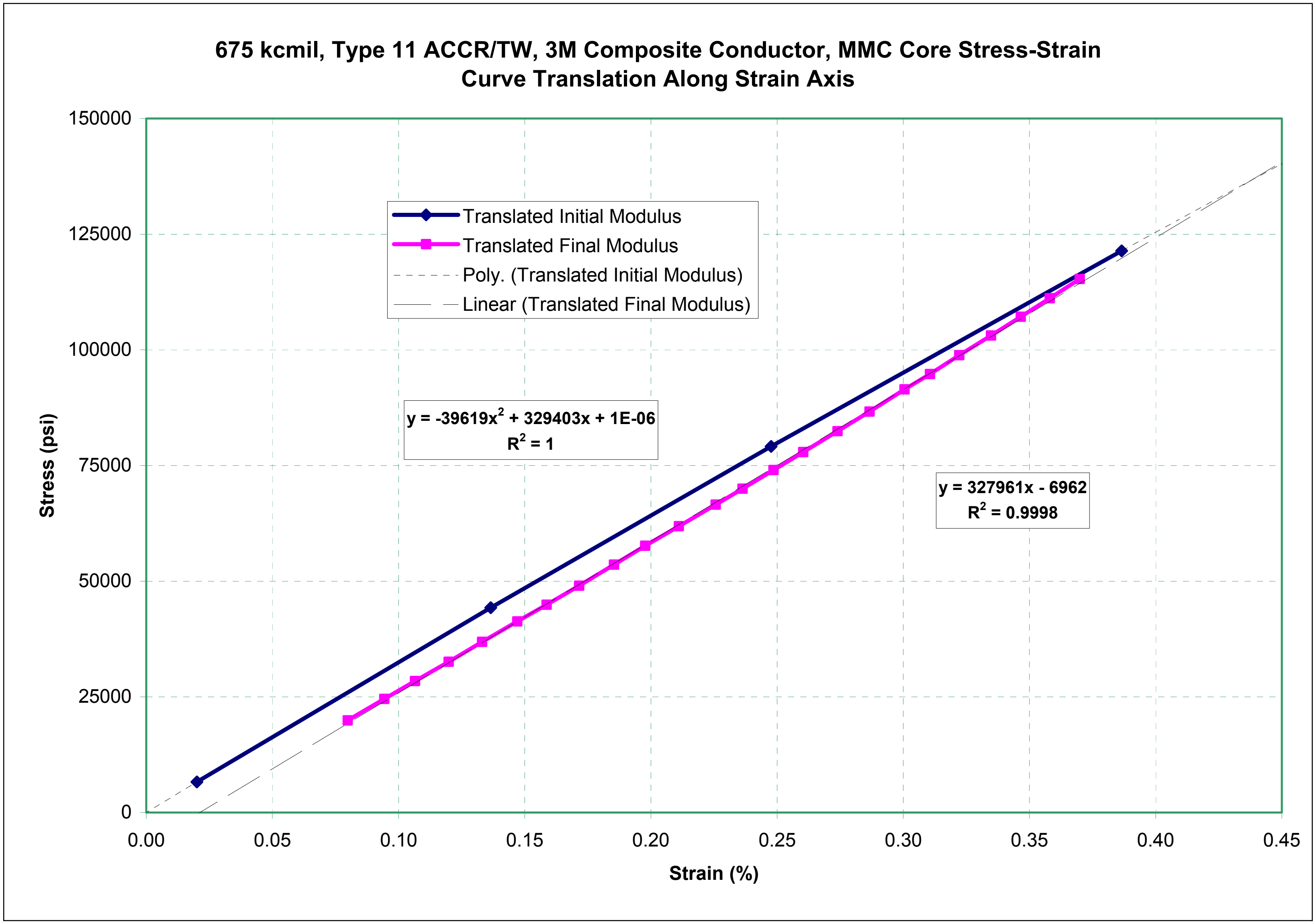


Figure 9, Core data shifted to adjust for correct zero crossing