774-kcmil, Type 53, 3M Brand Composite Conductor

Tensile and Stress-Strain Tests

3M Company
Purchase Order 0001325106

NEETRAC Project Number: 04-107a

July, 2005

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

Requested by: Mr. Colin McCullough
3M

Principal Investigator: Paul Springer III, P.E.

Reviewed by: Dale Callaway

774-kcmil, Type 53, 3M Brand Composite Conductor

Tensile and Stress-Strain Tests

3M Company
Purchase Order 0001325106

NEETRAC Project Number: 04-107a

July, 2005

Summary:

3M contracted with NEETRAC for mechanical testing for 774-kcmil ACCR 3M Brand Composite Conductor. Tests performed are stress-strain in accordance with the 1999 Aluminum Association guideline, and tensile tests on conductor. The core was also tensile tested independently after completion of the core stress-strain test.

Samples:

1) 200-ft conductor on reel received 06/02/2004

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 0001325106
4) 3M data file "3M ACCR 774-T53 River-X Cable Spec.xls", dated May 18, 2004, containing conductor technical specifications
5) PRJ 04-107, 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 and Results:

Conductor Tensile Tests:

Determination of the tensile strength for conductor requires cast-resin terminations to ensure all strands are properly loaded. In this case, the high strength of the MMC core caused problems with the laboratory termination. The resin moulds were deformed before the conductor reached rated breaking strength (RBS). Using the next largest size termination corrected the overload problem, but created another problem because the conductor was too small for the fitting. Therefore, the tensile results are less than optimal, and one sample failed at 99% of RBS.

Three samples, each 20 feet long were tested. Samples were loaded in the MTS horizontal tensile machine, and pulled to destruction at a loading rate of 50% of RBS/min (35,500 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	70050	99	All strands failed at resin plug
2	72030	101	All strands failed at resin plug
Stress-strain sample:	72220	102	All strands failed at resin plug
Stress-strain core	43410	100	All strands failed at resin plug

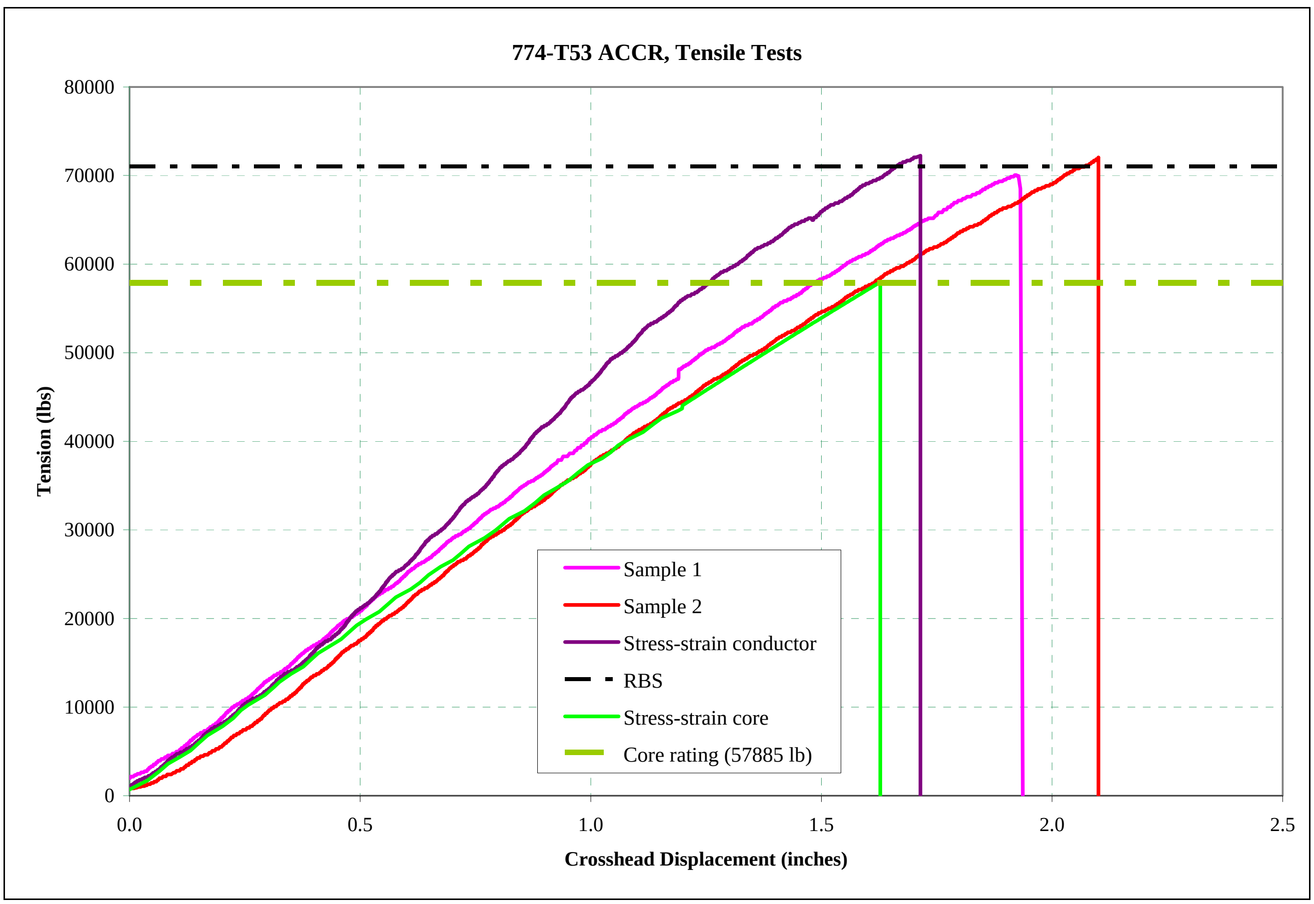

Figure 1, Load and Crosshead Position Data for Tensile Tests

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 (21,300 lbs).
4) Hold for 30 minutes.
5) Relax load to 1,000 lbs.
6) Pull to 50% RBS (35,510 lbs).
7) Hold for one hour.
8) Relax load to 1,000 lb.
9) Pull to 70% RBS (49,710 lb).
10) Hold for one hour.
11) Relax load to 1,000 lbs.
12) Pull to 75% RBS (53,260 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, 710 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 (0.14282%).
4) Hold for 30 minutes.
5) Relax load to 710 lbs.
6) Pull to same strain as conductor at start of 50% of RBS test (0.24898%).
7) Hold for one hour.
8) Relax load to 710 lbs.
9) Pull to same strain as conductor at start of 70% of RBS test (0.36907%).
10) Hold for one hour.
11) Relax load to 710 lbs.
12) Pull to 75% of the core rating (43,410 lbs).
13) Relax load to 710 lbs, and remove the extensometer (for its own protection).
14) Pull sample to destruction.

Photograph 1, long view of stress-strain test

Data files containing test data were processed using Microsoft Excel® Software to obtain engineering values and graphical presentation. Ambient temperature during testing ranged from 21.4° C to 21.9°C. Thermal strains are sufficiently small that temperature compensation was not applied to the test data. Graphs showing measured data and properties based on the data are shown in Appendix 2.

Composite Conductor Properties, direct test values:

Initial Modulus for Stress Strain Curve: Stress (psi) = -52688*(Strain%)^2+157920*(Strain%)+1052
Final Modulus for Stress Strain Curve: Stress (psi) = 173642*(Strain%) – 12945
Tensile Test, Stress Strain Sample: 72220 lb (102% RBS)

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

Initial Modulus for Stress Strain Curve: Stress (psi) = -52688*(Strain%)^2 + 158620*(Strain%)
Final Modulus for Stress Strain Curve: Stress (psi) = 173642*(Strain%) – 14098

Core Strand Properties, direct test values:

Initial Modulus for Stress Strain Curve: Stress (psi) = -27549*(Strain%)^2+327571*(Strain%)+2233
Final Modulus for Stress Strain Curve: Stress (psi) = 340319*(Strain%) – 7150
Tensile Test, Stress Strain Sample: 43410 lb (100% of nominal rating)

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

Initial Modulus for Stress Strain Curve: Stress (psi) = -27549*(Strain%)^2 + 327946*(Strain%)
Final Modulus for Stress Strain Curve: Stress (psi) = 340319*(Strain%) - 9469

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

Initial Modulus for Stress Strain Curve: Stress (psi) = -65937*(Strain%)^2+69364*Strain
Final Modulus for Stress Strain Curve: Stress (psi) = 85792*(Strain%) -15836

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:

> 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 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.
>
> Effect of thermal expansion of the sample and gage rod: 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 0.5^{o}C during the composite test, and less than 0.9^{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).
>
> 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

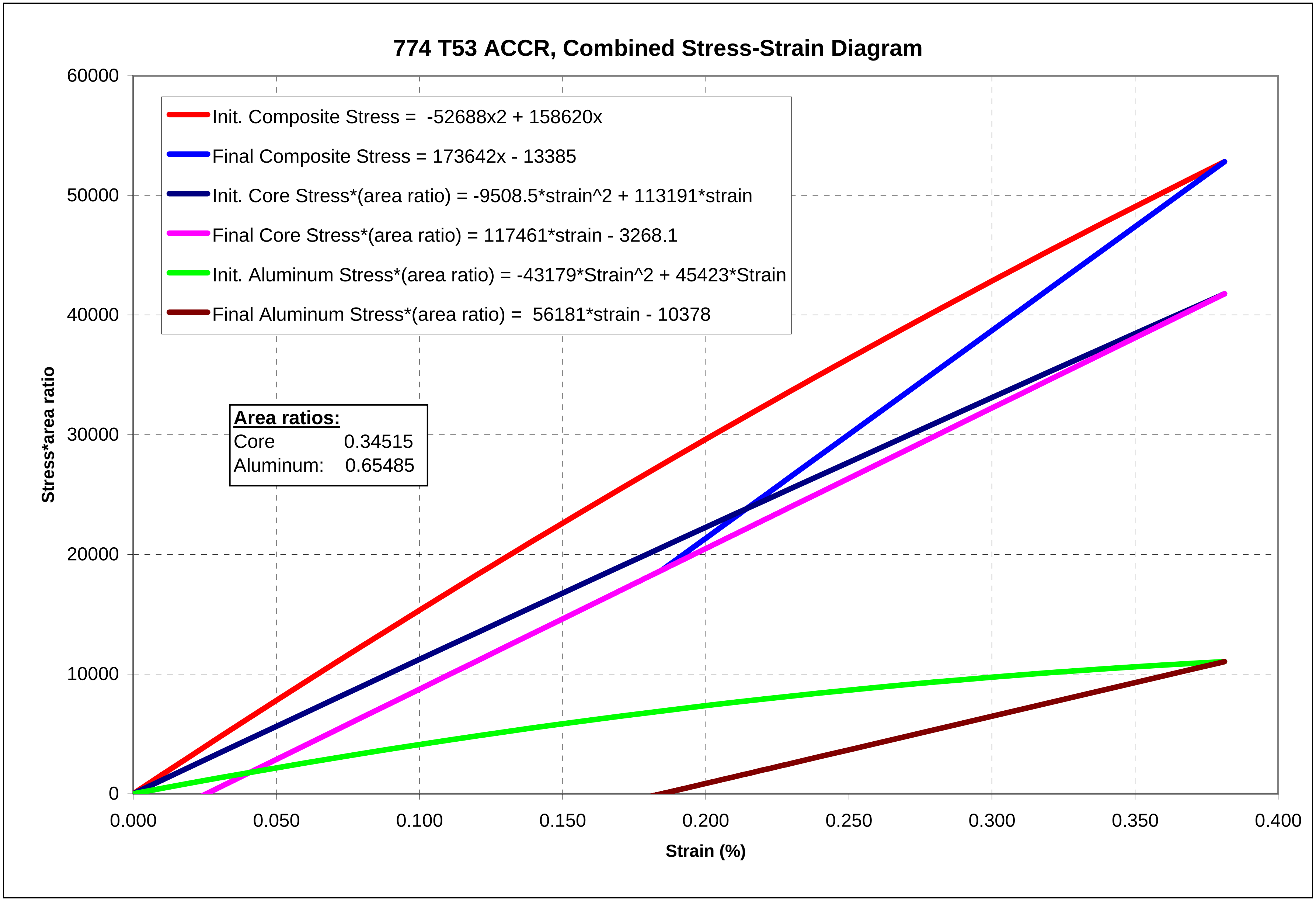

Figure 2, Summary Stress-Strain Plot (all values normalized to area ratio)

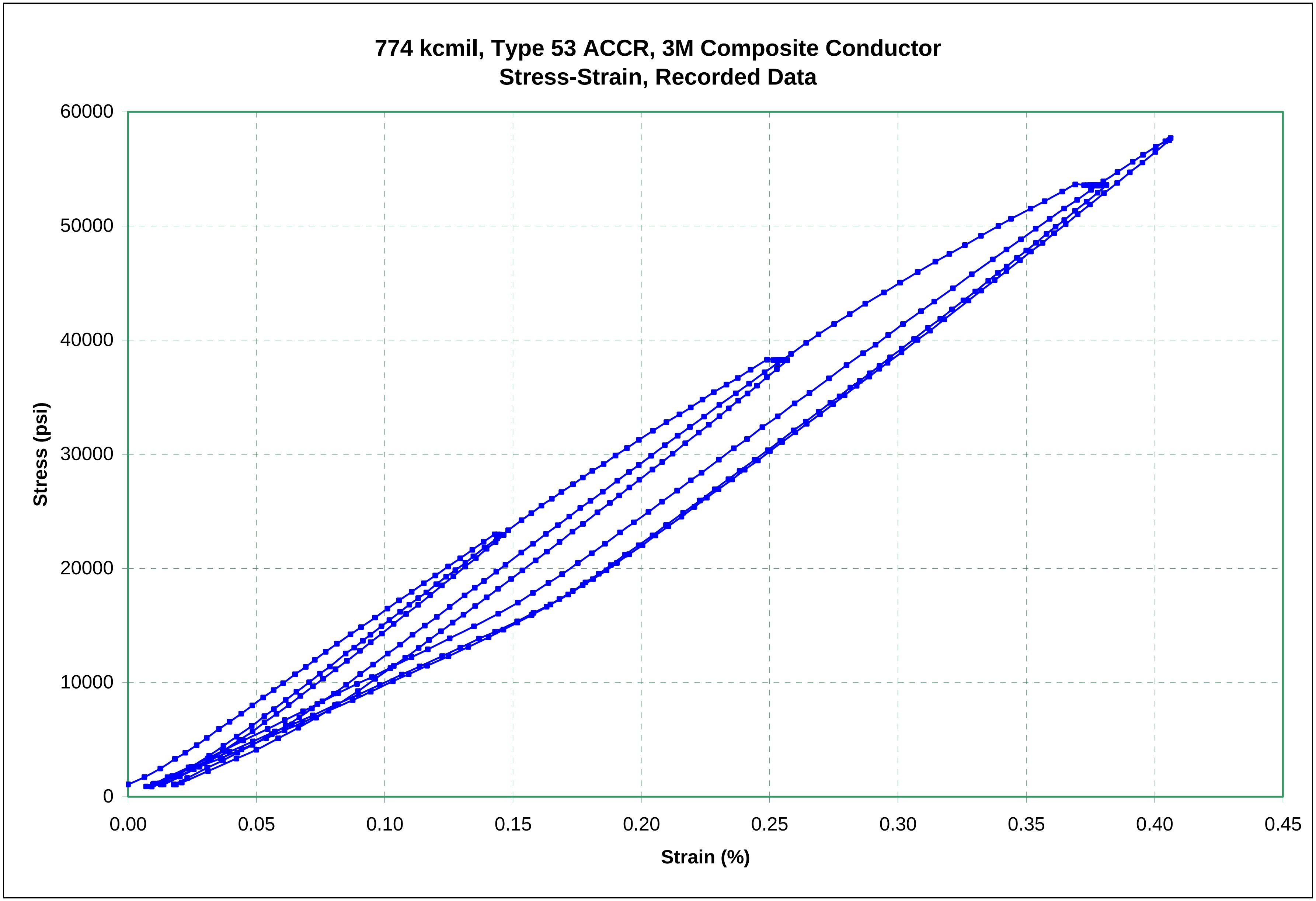

Figure 3, Conductor Stress-Strain Data

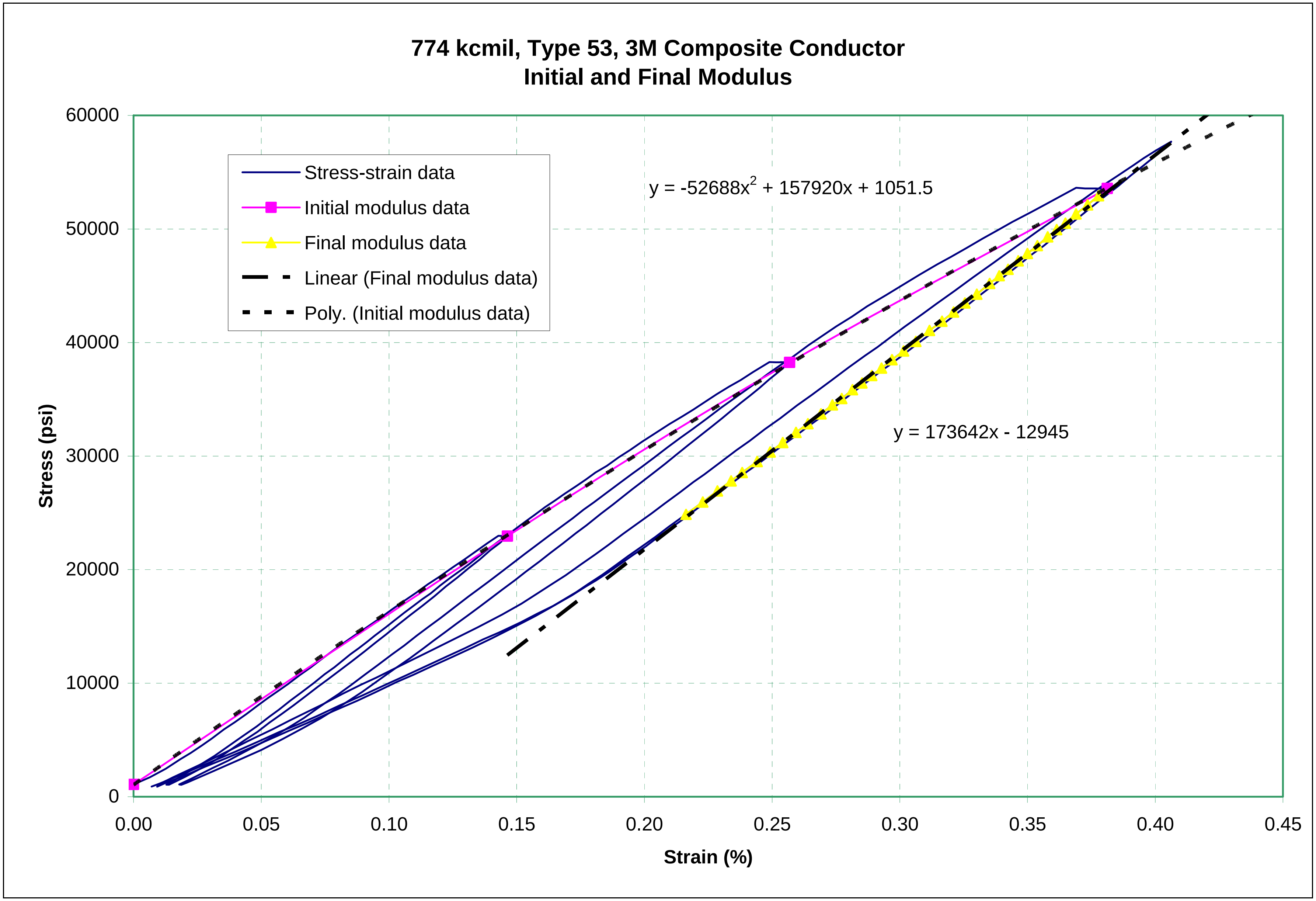

Figure 4, Composite Stress-Strain Plot with Data Fits for Initial and Final Modulus

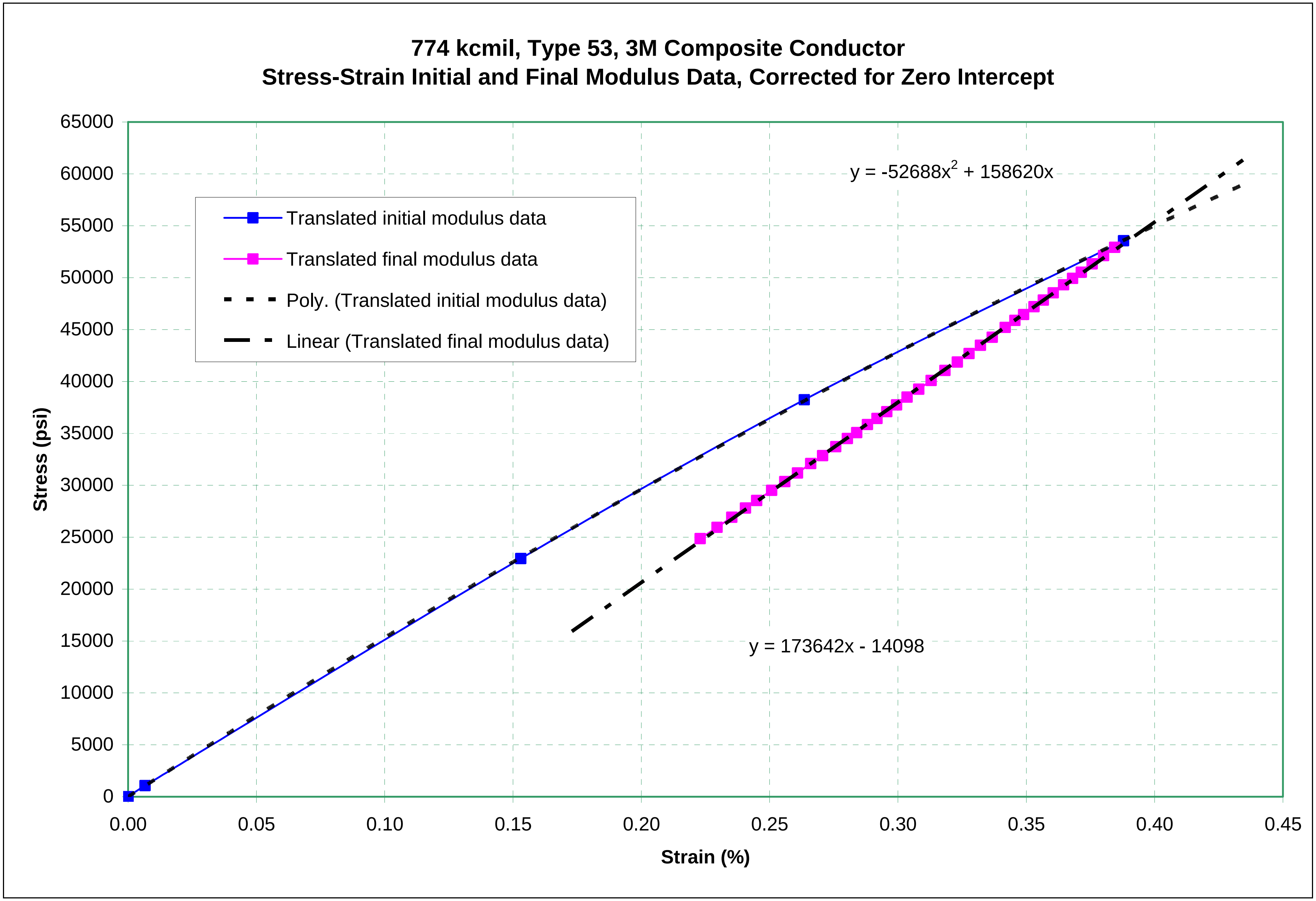

Figure 5, Conductor stress-strain data shifted to adjust for correct zero crossing

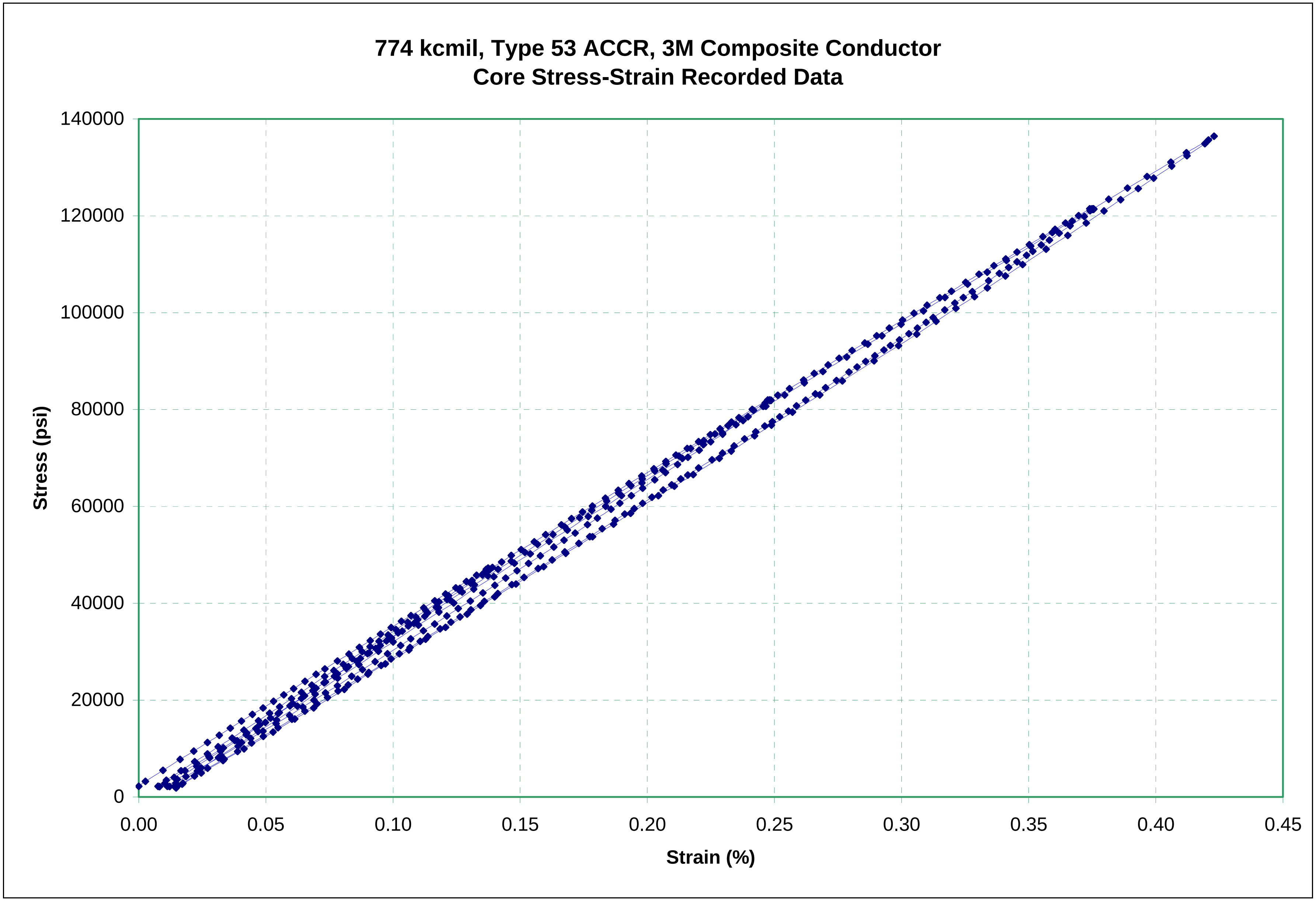

Figure 6, Core Stress-Strain per Aluminum Association Guide

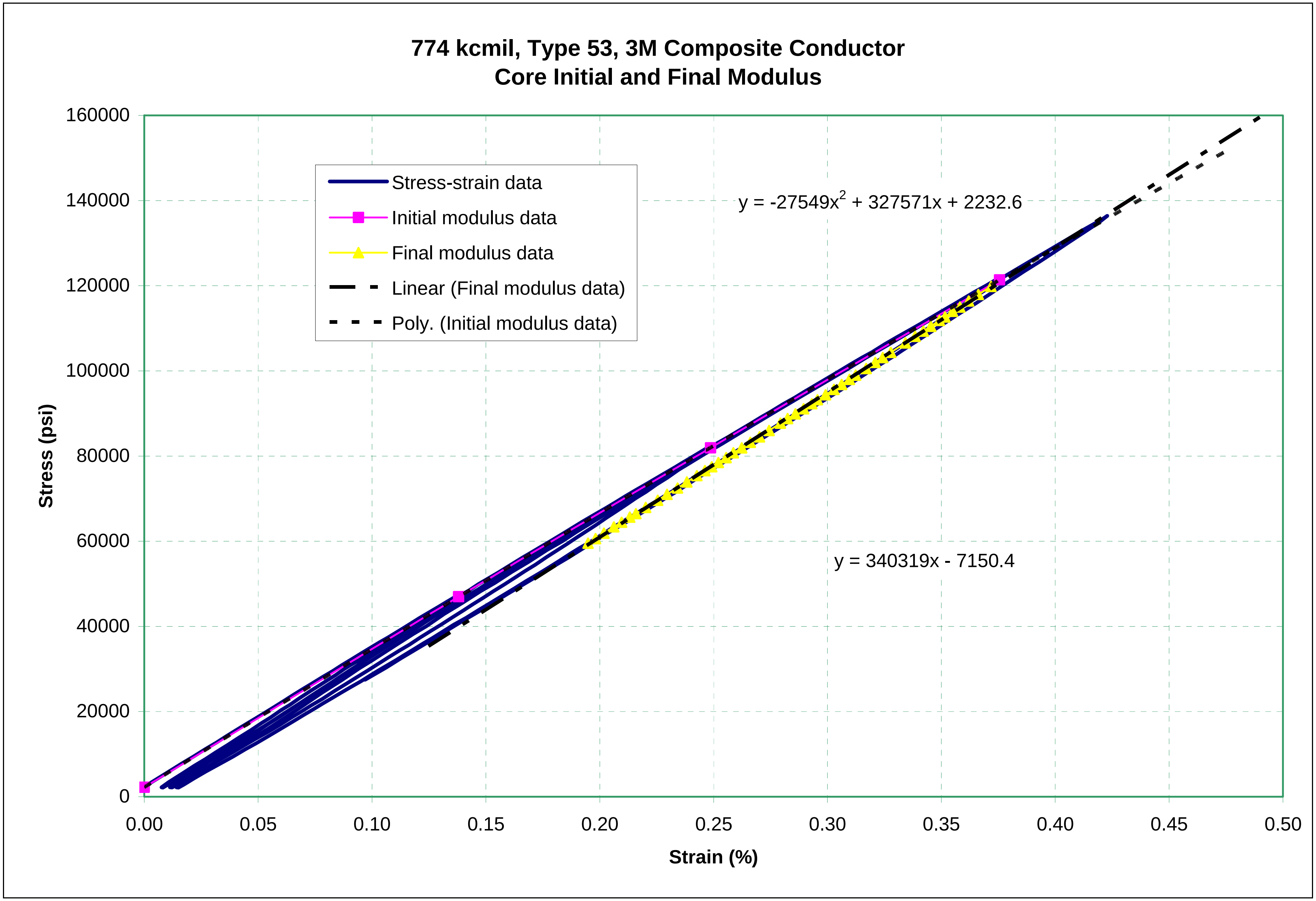

Figure 7, Core Graph with Initial Modulus Data

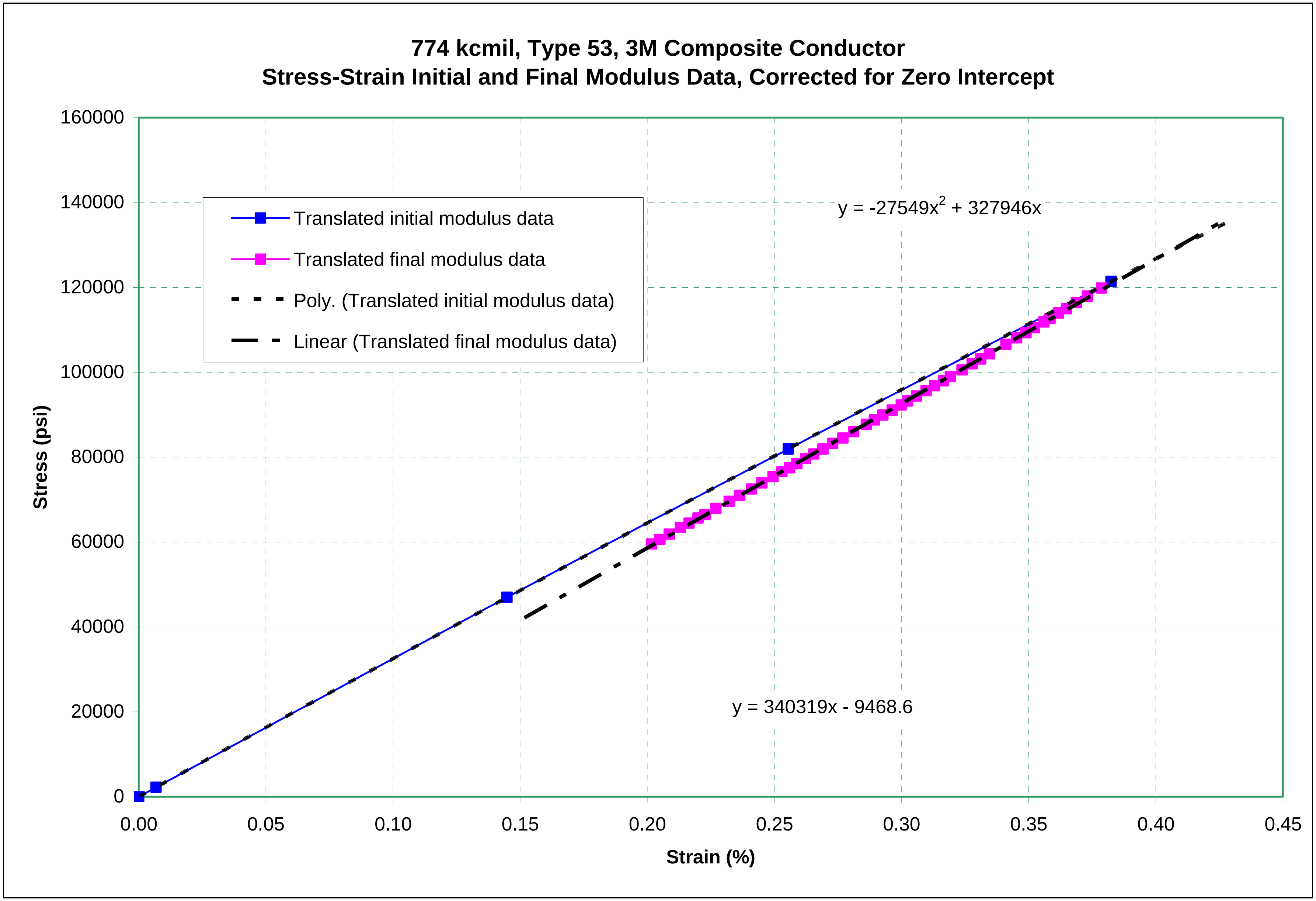

Figure 8, Core data shifted to adjust for correct zero crossing