1272 kcmil, 3M Brand Composite Conductor
Tensile Tests
Stress-Strain Tests

3M Company
Purchase Order 0000738926

NEETRAC Project Number: 02-327

February, 2003, Revised March, 2003

A Center of
The Georgia Institute of Technology

Requested by: Mr. Colin McCullough
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Principal Investigator: ______________________
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Reviewed by: ______________________
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Summary:

3M contracted with NEETRAC for 1272 kcmil ACCR tensile tests, and 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.

This report was revised in March 2003 at 3M request. The only change is a modification in the method used to adjust the off-set of the initial modulus curve to obtain the modulus equations. The February report translated the offset on the stress (Y) axis. For this report, the curves are translated on the strain (X) axis. The final modulus curves also needed offset corrected to meet the new location for the initial modulus curves.

Samples:

1) Conductor reel received 12/02/2002, identified as "Type A" 1272 kcmil ACCR

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 0000738926
4) 3M data file dated June 27, 2002 containing conductor technical specifications
5) PRJ 02-327, 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 20,000 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	46500	106	All strands failed, mid gage section
2	47090	108	All strands failed, mid gage section
3	46610	107	All strands failed, 2 ft from end
Stress-strain conductor	47890	110	All strands failed, mid gage section
Stress-strain core	23420	99	All strands failed, at knife edge damage

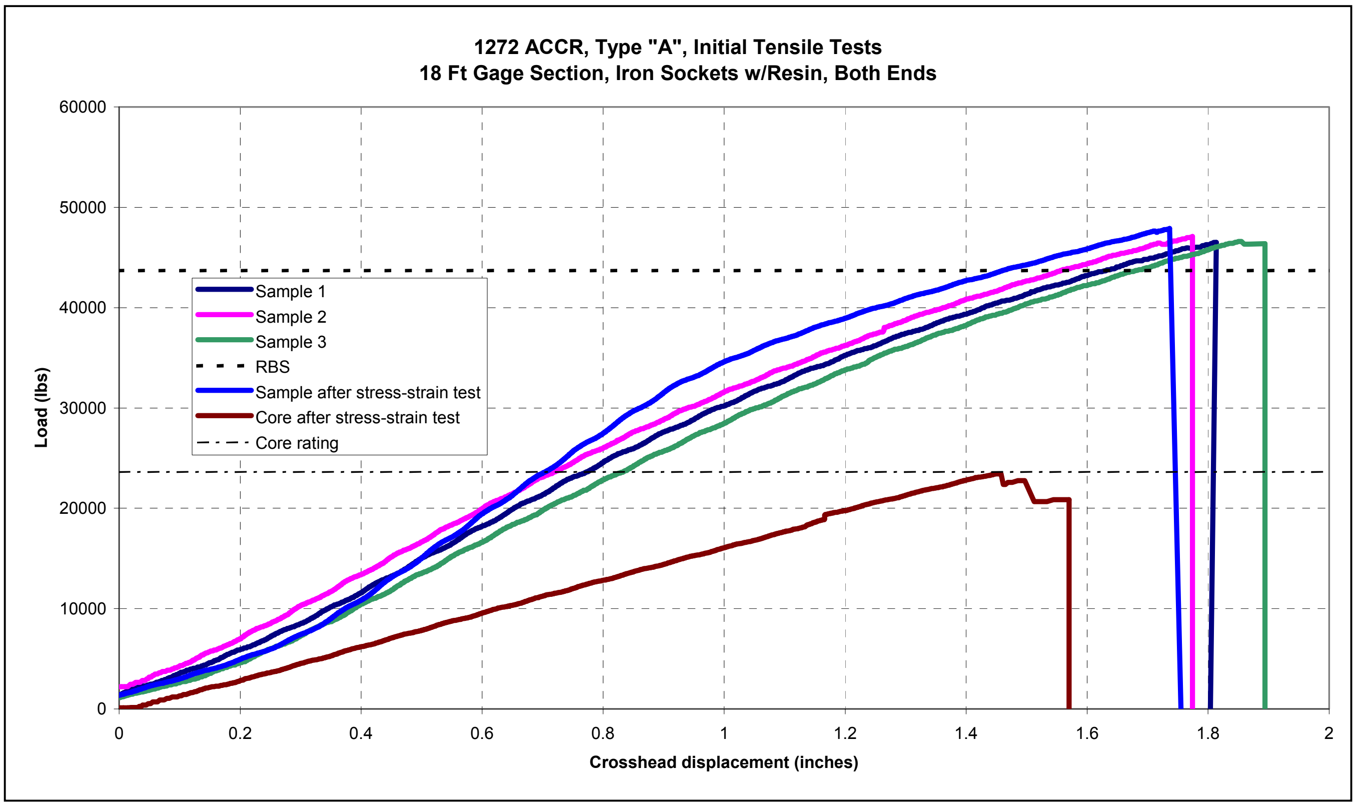


Figure 1, Load and Crosshead Position Data for Tensile Tests

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.

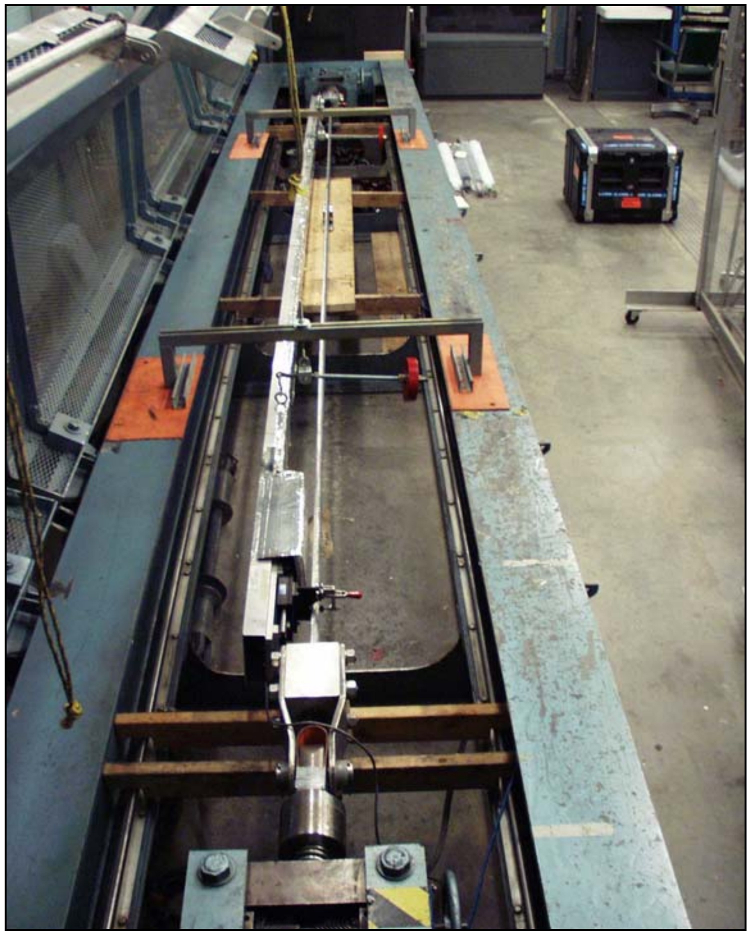
Placing a support at 1/2 span minimizes conductor slack. This ensures the conductor is nearly straight, prevents slack from showing up as elongation in the stress-strain data. The test profile is in accordance with the Aluminum Association guide, as follows:

Composite conductor:

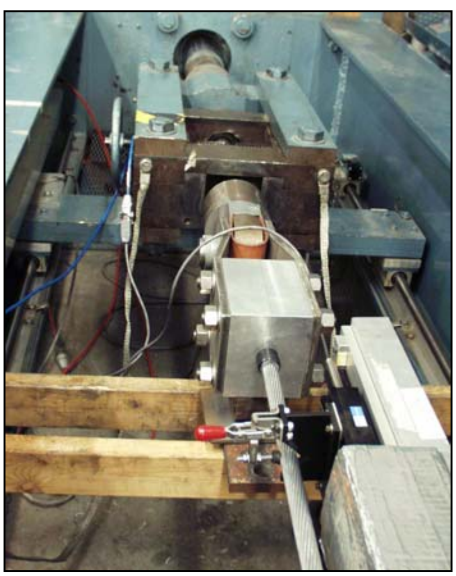
1) Apply load of 1,000 lbs. Remove sag with a mid-span support.
2) Install extensometer, and set to zero.
3) Pull to 30% of RBS (13,100 lbs)
4) Hold for 30 minutes.
5) Relax load to 1,000 lbs.
6) Pull to 50% RBS (21,840 lbs). Hold for one hour.
7) Relax load to 1,000 lbs.
8) Pull to 70% RBS (30,570 lbs). Hold for one hour.
9) Relax load to 1,000 lbs.
10) Pull to 75% RBS (32,760 lbs).
11) Relax load to 1,000 lbs, and remove the extensometer (for its own protection).
12) Pull sample to destruction.

Core strands:

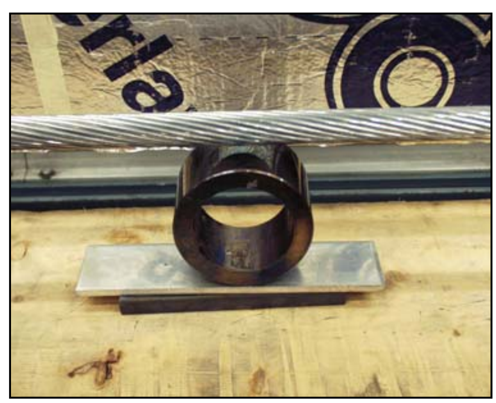
1) Pull to calculated initial tension (in this case, 380 lbs)
2) Install extensometer, and set to zero.
3) Pull to same strain as conductor at start of 30% of RBS test (0.12764%). Hold for 30 minutes.
4) Relax load to 380 lbs.
5) Pull to same strain as conductor at start of 50% of RBS test (0.21708%). Hold for one hour.
6) Relax load to 380 lbs.
7) Pull to same strain as conductor at start of 70% of RBS test (0.32384%). Hold for one hour. Relax load to 380 lbs.
8) Pull to 75% of the core RBS (17,720 lbs)
9) Relax load to 380 lbs, and remove the extensometer (for its own protection).
10) Pull sample to destruction.



Photograph 1, Long View of Stress-Strain Test
(conductor shown is 477 ACCR, not sample from this project)



Photograph 2
Load Actuator and Extensometer



Photograph 3
Mid-span Support to Remove Sag

Results:

Data files containing test data were processed using Excel® to obtain engineering values and graphical presentation. Temperature during testing was 21.3° C +/- 0.4° C. Graphs showing data for each test are shown in Appendix 2.

Composite Conductor Properties, direct test:

Initial Modulus for Stress Strain Curve: Stress (psi) = -31623*(Strain%)^2+87144*(Strain%)+818
Final Modulus for Stress Strain Curve: Stress (psi) = 112980*(Strain%) – 12193
Tensile Test, Stress Strain Sample: 47890 lbs (110% RBS)

Composite Conductor Properties, model values (see Figure 2 on page 9)[1]:

Initial Modulus for Stress Strain Curve: Stress (psi) = -31846*(Strain%)^2 + 87852*(Strain%)
Final Modulus for Stress Strain Curve: Stress (psi) = 112980*(Strain%) – 12925

Core Properties, direct test:

Initial Modulus for Stress Strain Curve: Stress (psi)=-41809*(Strain%)^2+360329*(Strain%)+2971
Final Modulus for Stress Strain Curve: Stress (psi) = 365886*(Strain%) - 2906
Tensile Test, Core Stress Strain Sample: 23420 lbs (99% RBS)[2]

Core Properties, model values (see Figure 2 on page 9)[1]:

Initial Modulus for Stress Strain Curve: Stress (psi) = -42073*(Strain%)^2 + 361082*(Strain%)
Final Modulus for Stress Strain Curve: Stress (psi) = 365904*(Strain%) - 7002

Aluminum Properties (from Figure 2, direct measurement is not possible)[3]:

Initial Modulus for Stress Strain Curve: Stress (psi) = -30899*(Strain%)^2 + 53862*(Strain%)
Final Modulus for Stress Strain Curve: Stress (psi) = 81877*(Strain%) – 13830

[1] Model coefficients different from the measured values. The load offset is adjusted along the strain axis to correct for initial load offset needed for the test. Because this is a second order equation, the coefficients and the offset are both different after the curve is shifted. Final modulus coefficients are linear, and remain the same after shifting. The offset is adjusted to match the end of the initial modulus curve.

[2] Core strand may have been nicked by the extensometer during removal following the stress-strain test. The break occurred at the location where the sample was bumped. A small nick may have affected the test result.

[3] Aluminum properties are from Figure 2, but the adjustment for area ratio has been removed.

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 is +/- 0.0002", or 0.92 PPM. The instrument directly measures a stable internal reference rod. 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 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: 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. Ambient temperature changed –0.2 to +0.7^{o}C from the starting value during the core test, and –0.2 to +0.3^{o}C during the composite conductor test. The calculated error for the core test is –11.7 ppm. For the composite conductor the calculated error is -1.7 ppm. Temperature compensation was used for both the composite and core test data to ensure this error is as low as practical. With compensation, errors due to temperature effects are estimated at less than 0.2% of reading. For both the core and the composite data, temperature adjustments are too small to show on the graphs (less that the line width).
>
> 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

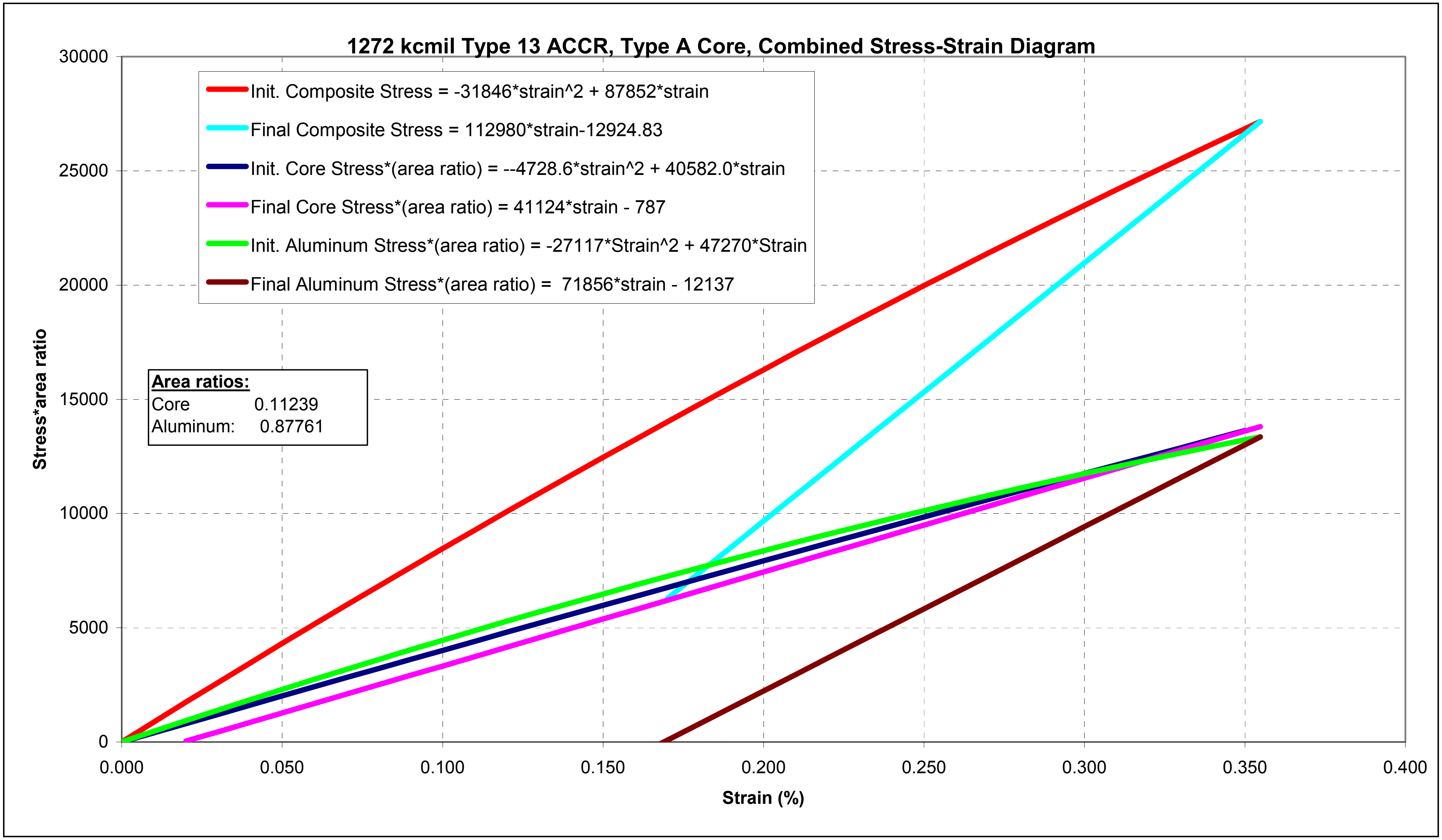


Figure 2, Summary Stress-Strain Plot (all values normalized to area ratio)

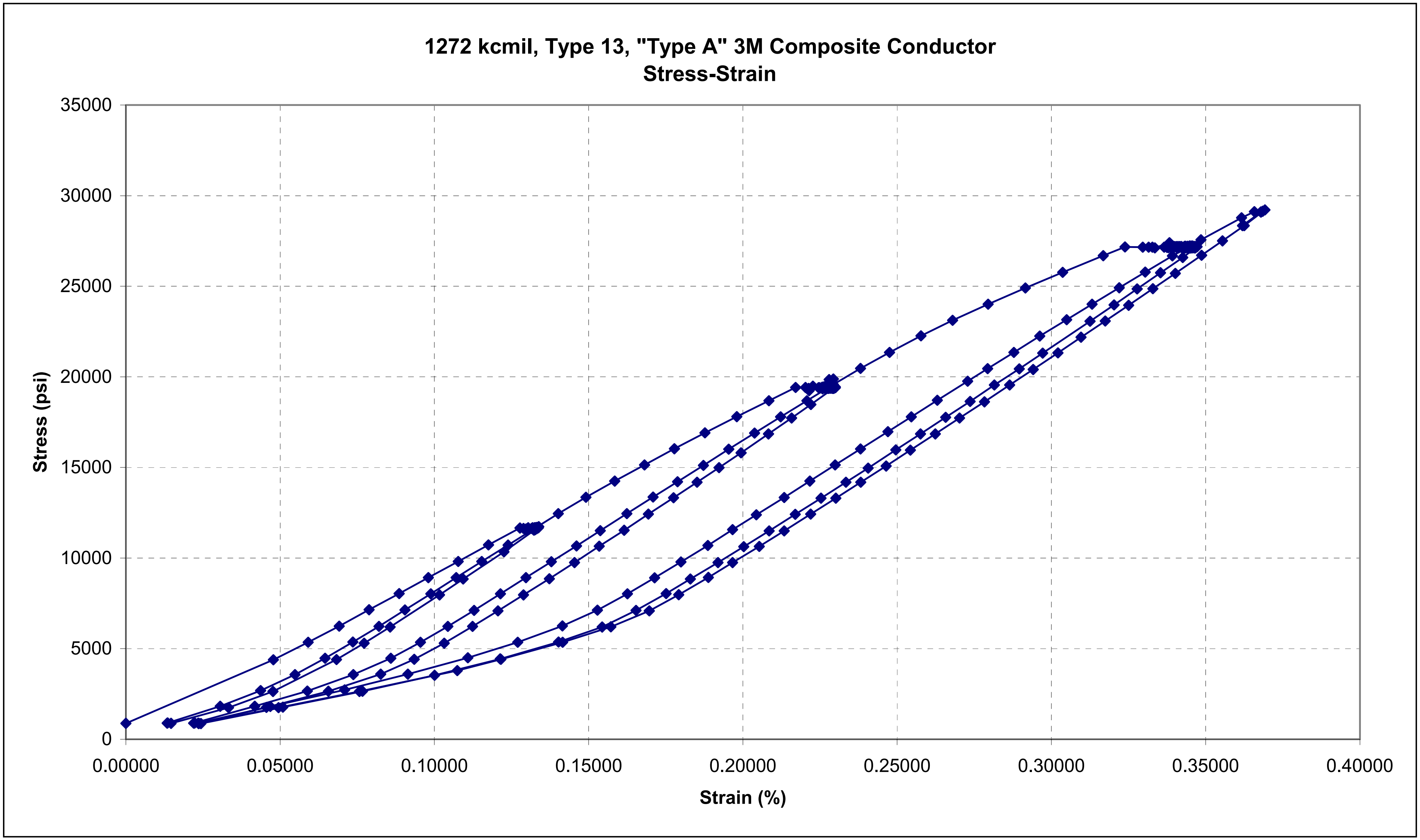


Figure 3, Temperature-compensated Conductor Stress-Strain Data

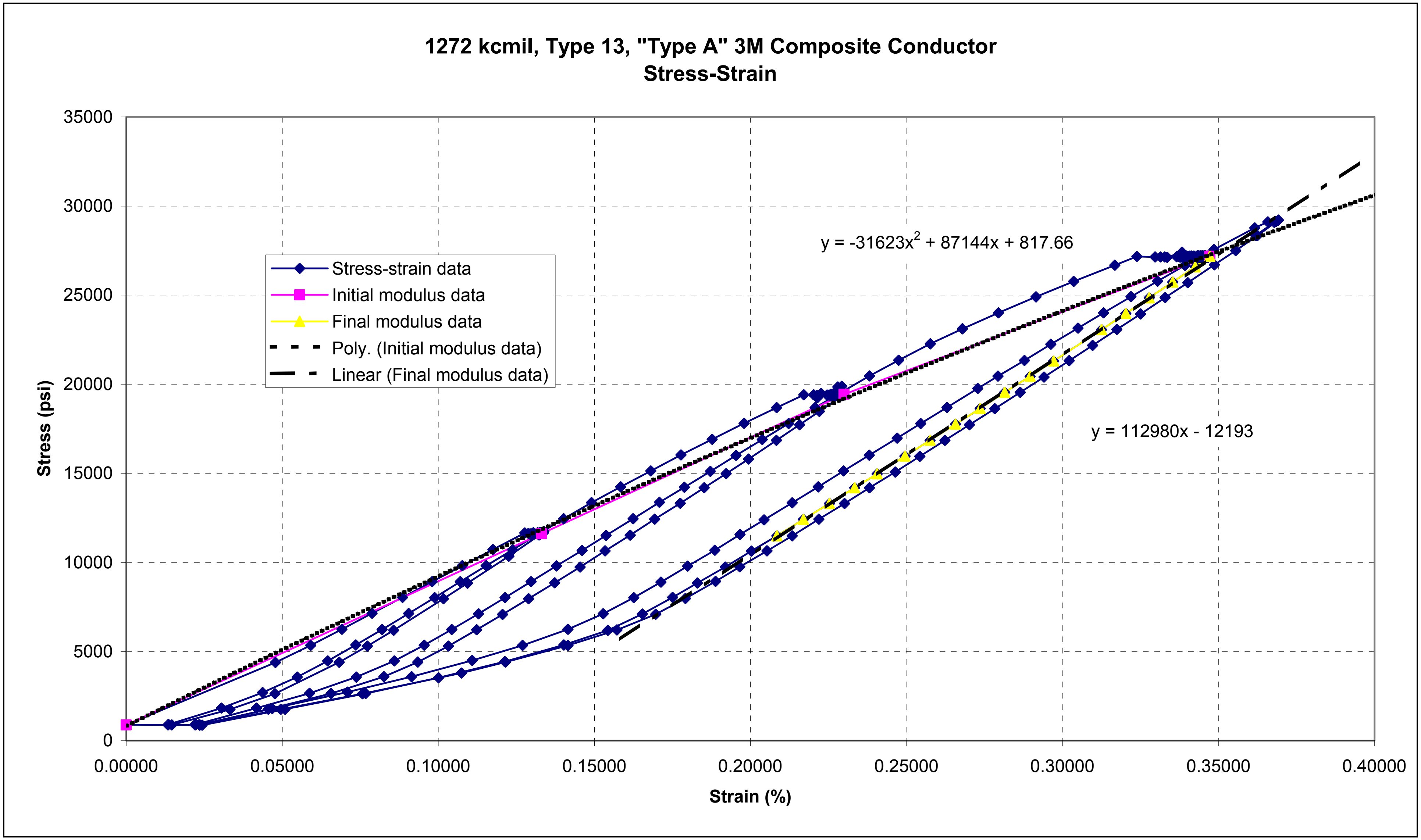


Figure 4, Composite Stress-Strain Plot with Data Fits for Initial and Final Modulus

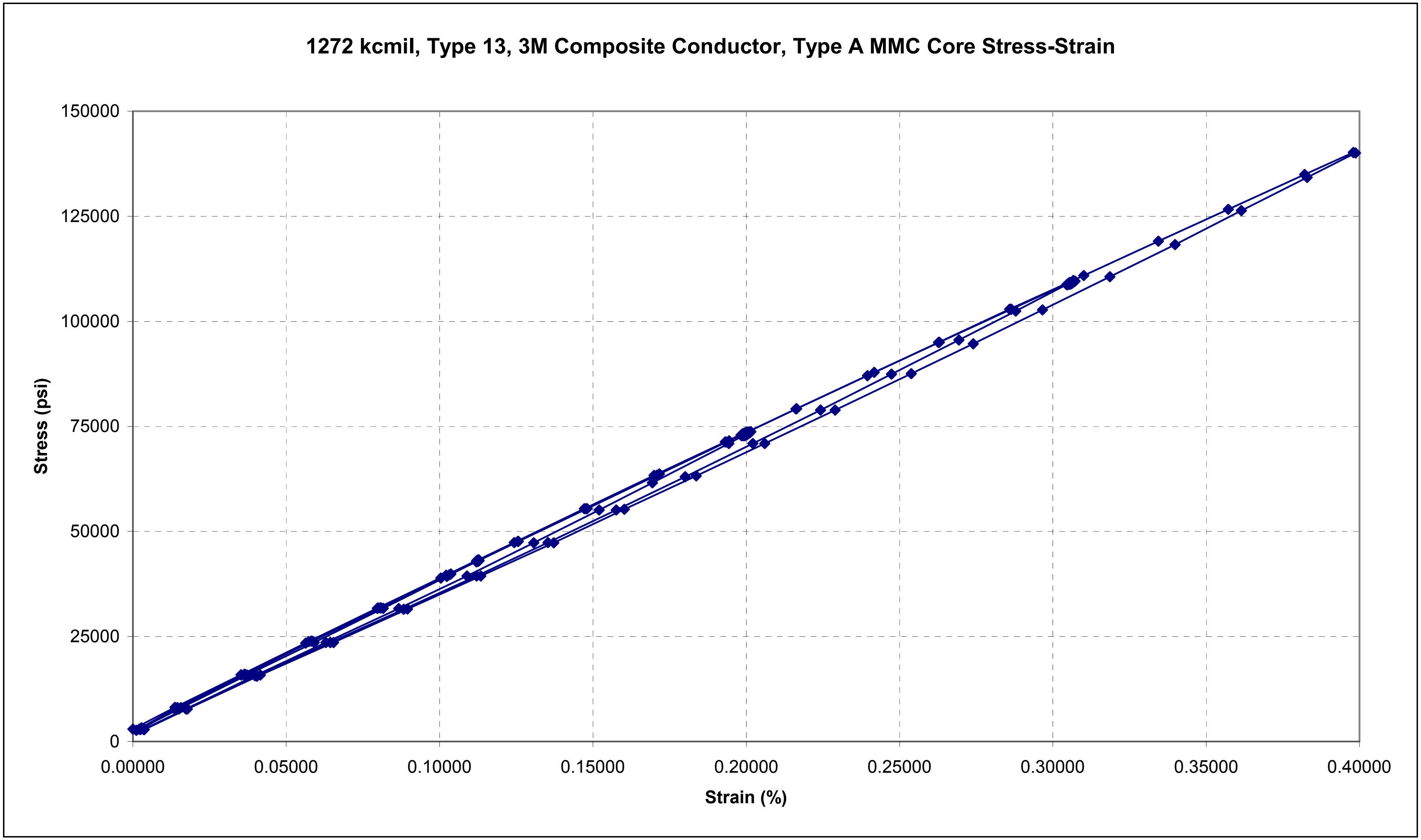


Figure 5, Temperature-compensated Core Stress-Strain per Aluminum Association Guide

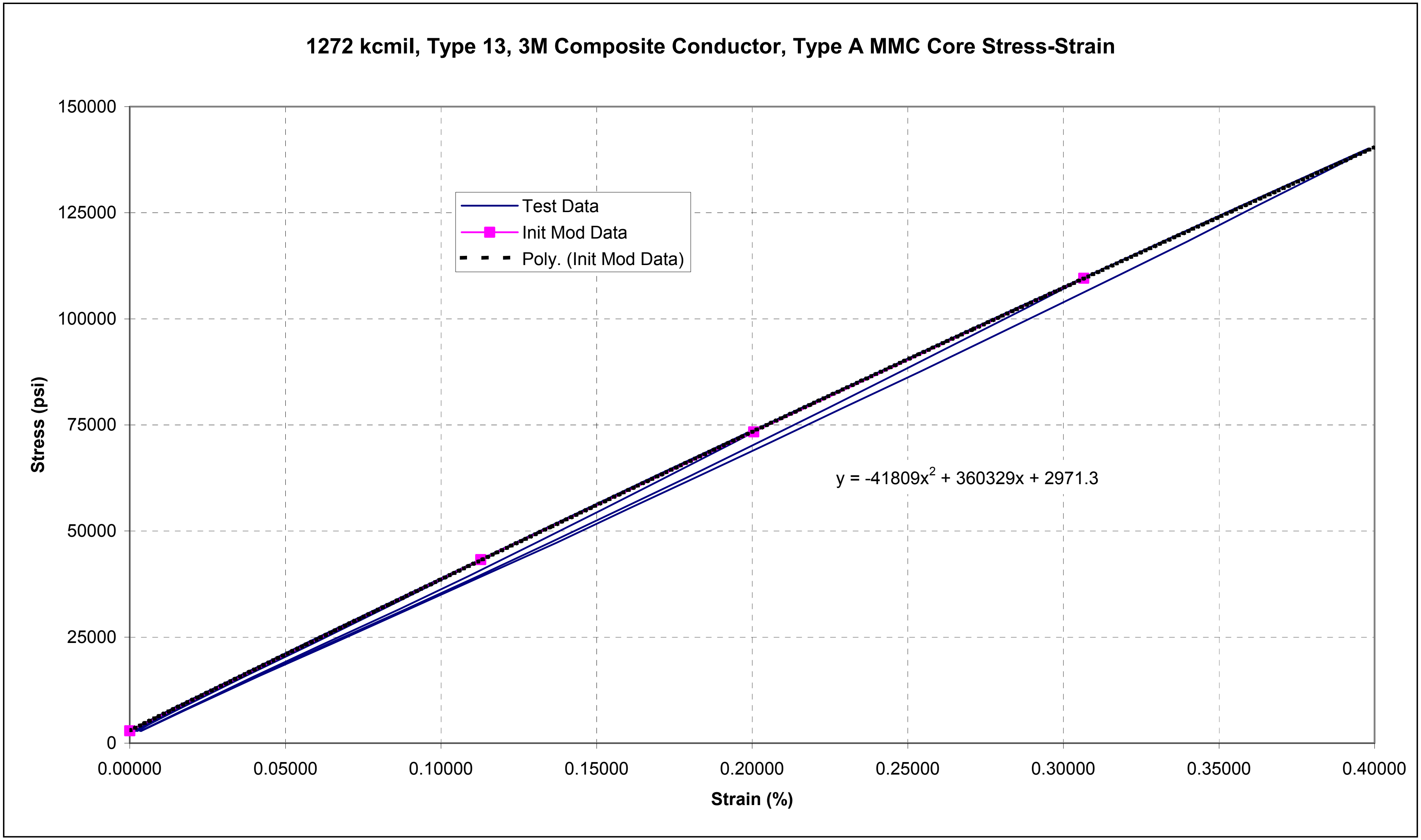


Figure 6, Core Graph with Initial Modulus Data

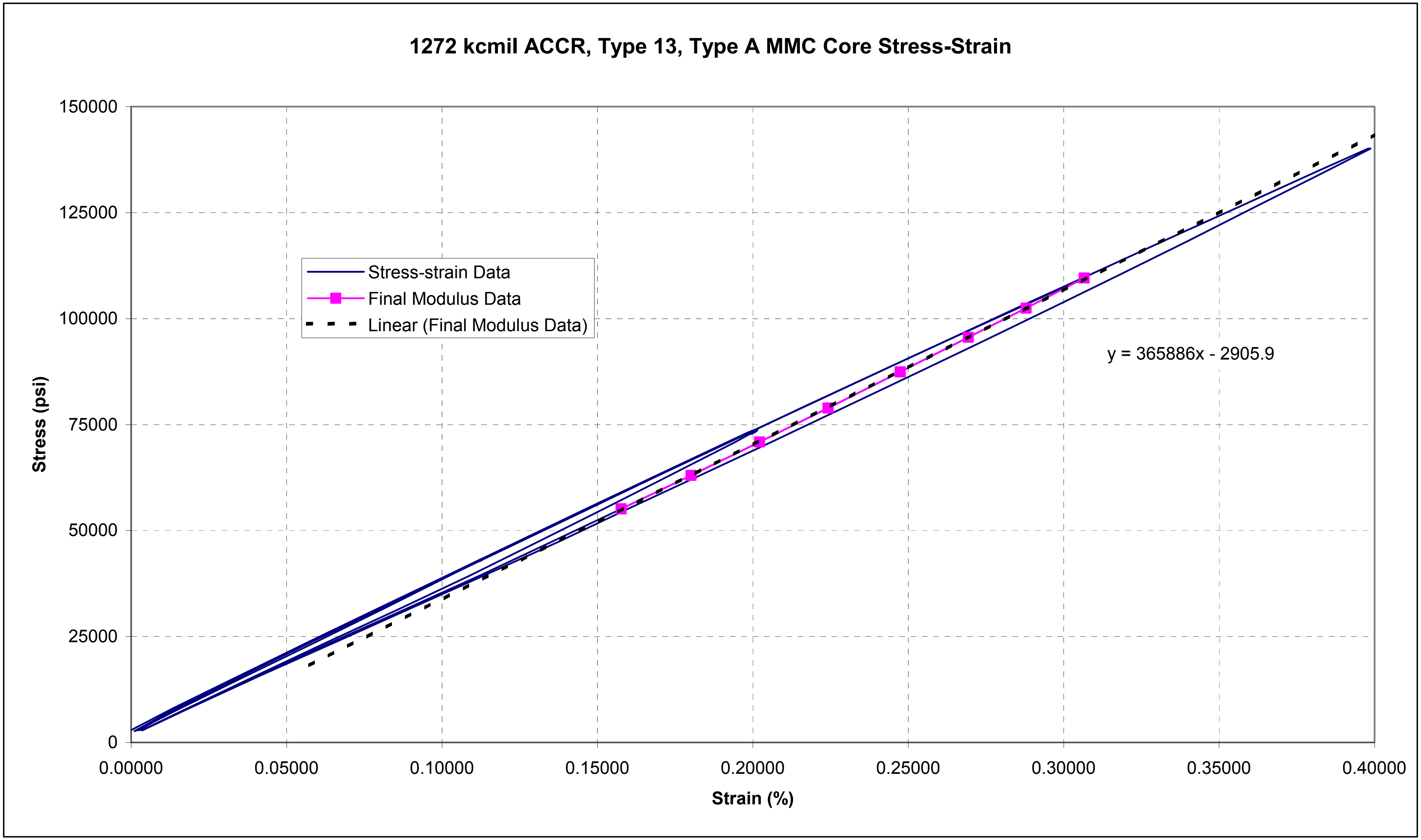


Figure 7, Core Graph with Final Modulus Data