



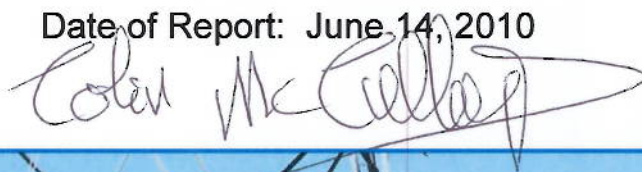
**3M Composite
Conductor
477-T16 ACCR**

**Coefficient of Thermal Expansion
for 477-T16 ACCR**

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Reviewed by: Dr. Herve Deve

Date of Report: June 14, 2010



Coefficient of Thermal Expansion for 477-T16 ACCR

Summary:

The Coefficient of Thermal Expansion (CTE) was measured for a 477-T16 ACCR conductor. Thermal expansion as a function of temperature displays a bi-linear behavior, which yields two thermal expansion coefficients: one above the kneepoint and one below. For ACCR, the CTE above the kneepoint was measured as $6.69 \times 10^{-6}/^{\circ}\text{C}$ (76-250°C) and the CTE below the kneepoint was measured as $16.7 \times 10^{-6}/^{\circ}\text{C}$ (25-160°C). These values are very close to theoretical predictions.

Test Laboratory:

NEETRAC (National Electric Energy Testing Research & Applications Center), Atlanta, Georgia, USA. The tests were directed by Mr. Paul Springer.

Samples:

- 1) Eight (8) meters of 477 kcmil, type 16, 3M Composite conductor, from reel received on 6/3/02

References:

- 1) "Proprietary Information Agreement" Dated 3/27/01
- 2) 3M Purchase Order 0000593746
- 3) PRJ 02-223, NEETRAC Project Plan

Equipment Used:

- 1) MTS Servo-hydraulic tensile machine, Control # CQ 0195
- 2) National Instruments AT-MIO-16XE-50 computer interface
- 3) Yokogawa Model DC100 data acquisition system, Control # CN 3022
- 4) Omega Engineering type T sheathed thermocouples
- 5) NEETRAC/DRC cable extensometer, Control # CQ 3002
- 6) High current AC test set, Control # CN 3007

Date:

February 2003

Procedure:

The experiment is to measure the thermal expansion of the conductor as a function of temperature. The rate of change of expansion with temperature (slope of the expansion-temperature graph) is the Coefficient of Thermal Expansion (CTE).

Testing was conducted in accordance with a NEETRAC procedure entitled "PRJ02-223, CONFIDENTIAL – MMC Conductor Evaluation, Coefficient of Thermal Expansion

Measurement”. The procedure controls all technical and quality management details for the project.

Samples from the reel were cut using a portable band saw. Hose clamps were applied on both sides of any cut to ensure that the “as-manufactured” position of all conductor layers was preserved. Samples were terminated on each end using cast-resin. The process is designed to ensure that no slack or deformation is introduced in the sample. The goal is to have a laboratory sample that behaves in a manner consistent with long spans in service.

Sample elongation was measured using a purpose-built instrument capable of measurements in the presence of high AC currents. An AC power supply was used to raise the sample temperature. Temperature was monitored using thermocouples at the following locations:

- Gage rod/ambient (1 thermocouple)
- Sample ends, surface, near each extensometer knife edge (2 thermocouples)
- Sample center, surface (1 thermocouple)
- Sample center, core (1 thermocouple)

The purpose for the gage rod thermocouple is to compensate for its elongation due to heating in proximity of the hot sample. Ambient temperature rose by approximately 7° C during the test because the testing machine was covered to minimize sample thermal gradients due to drafts and normal cycling of the room environmental controls. The thermocouples in the sample are used to measure the temperature and the temperature distribution in the sample gage section. The data show minimal spurious effects from load control errors and temperature gradients. Stable temperatures were reached at the following temperatures:

- Room temperature (23° C)
- 50° C
- 100° C
- 150° C
- 200° C
- 250° C

Heating and stabilization of temperature was conducted in these increments to ensure thermal equilibrium in the sample.

Prior to testing, conductor samples were pre-conditioned to remove short-term creep. This was done by pulling tension to 40% RBS, and holding for 2 hours. This process removed most of the initial room-temperature creep, and thereby limited any creep effects on the test data.

Sample heat-up and cool-down was performed at two tensions of 10% RBS, and 20% RBS. During a temperature cycle the load was kept constant. The actual measurements taken to measure the thermal expansion were recorded during the cool-down cycle. Because the tension is kept constant during the heat cycle, the so-called kneepoint (change between thermal expansion behaviors) is a strong function of the actual tension. For conductors in a

catenary span in a transmission line, the thermal expansion due to heating leads to sag, which in turn reduces tension and which in turn makes the kneepoint only mildly dependent on the tension. Therefore in this experiment two tensions are used. The lower tension of 10% RBS forces the kneepoint to lower temperatures and thus is suitable for an accurate determination of the CTE above the kneepoint (large temperature range). Conversely, the higher tension of 20% RBS forces the kneepoint to higher temperatures making it suitable for an accurate determination of the CTE below the kneepoint.

Figures 1 and 2 show the profile of the heat-up and cool-down for the tests performed. Figure 1 (477 ACCR at 10% RBS) is a composite of four different tests performed as instrumentation problems were debugged. The data are considered reliable based on numerous crosschecks and basic repeatability of the test. Figure 2 (477 ACCR at 20% RBS) contains continuous data from a single test. Data related specifically to thermal expansion characteristics are plotted on separate graphs in Figures 3 and 4.

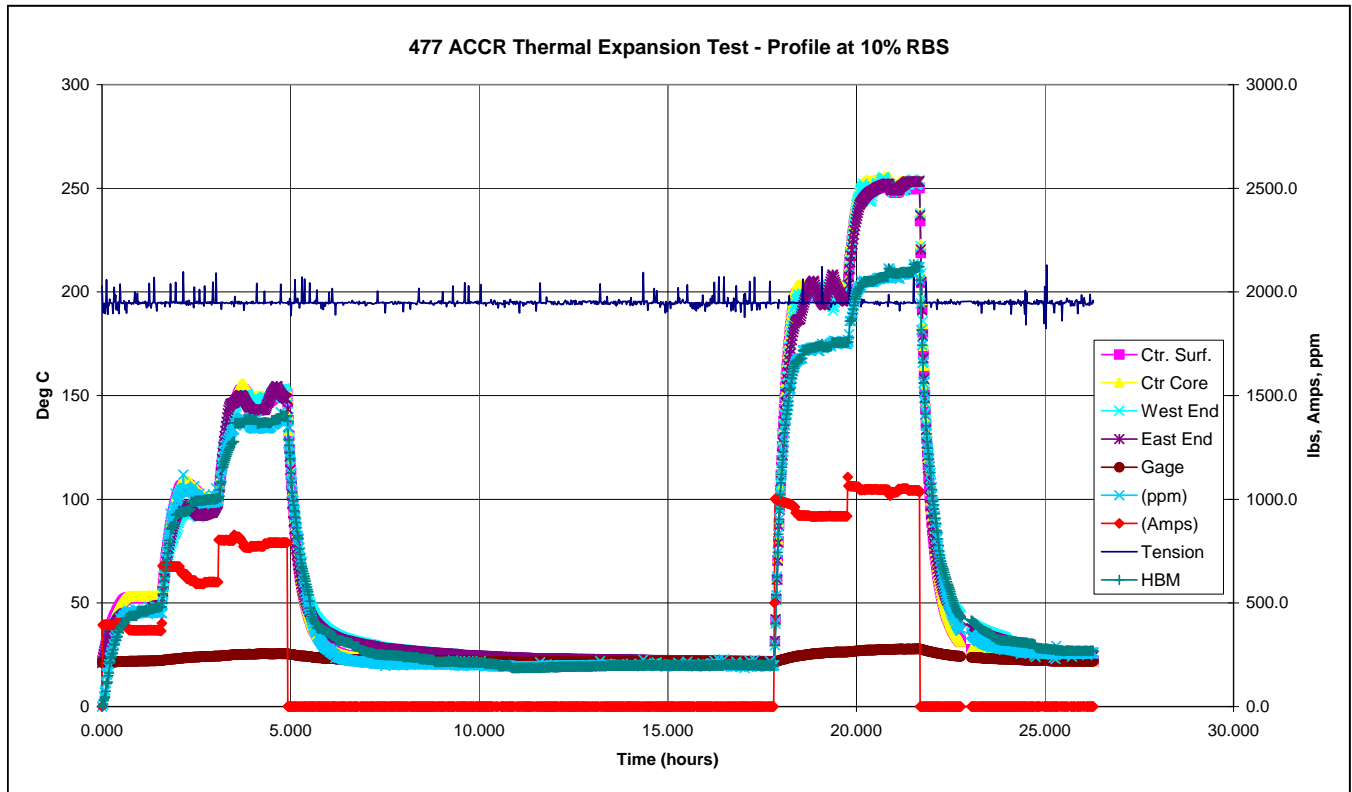


Figure 1, Temperatures, current, load, and elongation data for 477 ACCR at 10% RBS
 “HBM” curve is crosshead data scaled to look like the elongation data

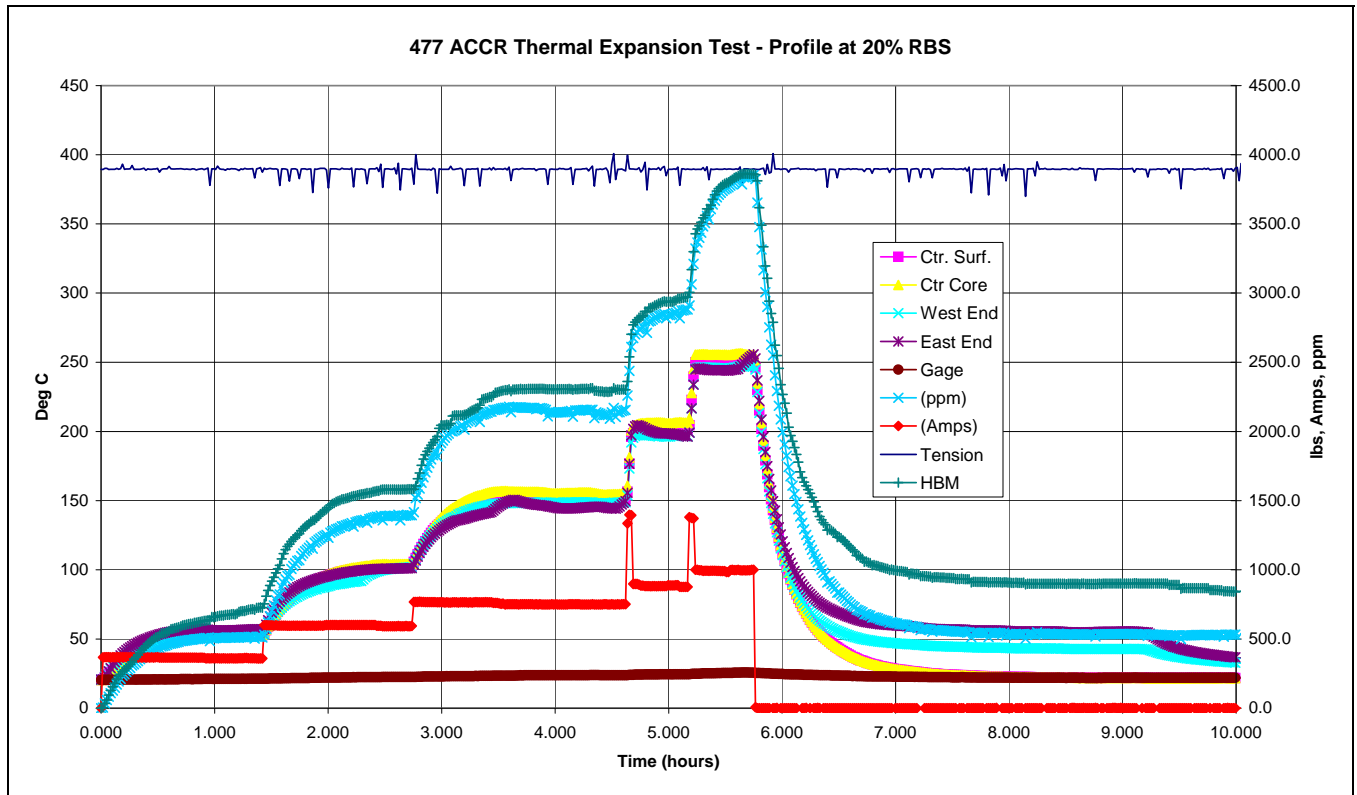


Figure 2, Temperatures, current, load, and elongation data for 477 ACCR at 20% RBS

Results:

Large differences between the characteristics of the metal matrix composite core and the outer aluminum strands of the conductor result in complex mechanical behavior as the conductor is stressed or heated. The thermal coefficient should exhibit a change in slope (knee) when the aluminum expands sufficiently to go slack or possibly go into compression. Note from the data versus time (Figures 1 and 2) that there are long delays at temperature during heat-up, but cool down is rapid. Delay periods were intended to permit thermal stabilization, and thereby optimize accuracy. Extra creep elongation during the delay periods frustrated that goal. The cool-down data appear to be free from such effects. The elongation effects are absent because the cool down occurred after the conductor had been at temperature and load for several hours. Therefore, the cool down curve was used for determination of the thermal coefficients.

Figures 3 and 4 show the temperature versus strain for the cool-down phase of the test. These curves are the best available representation of the thermal expansion coefficients, because the sample temperature is uniform, and creep effects are minimal. It should be noted, however, that the conductor strain is a composite of numerous effects, including inter-strand and inter-layer friction, stress, and creep.

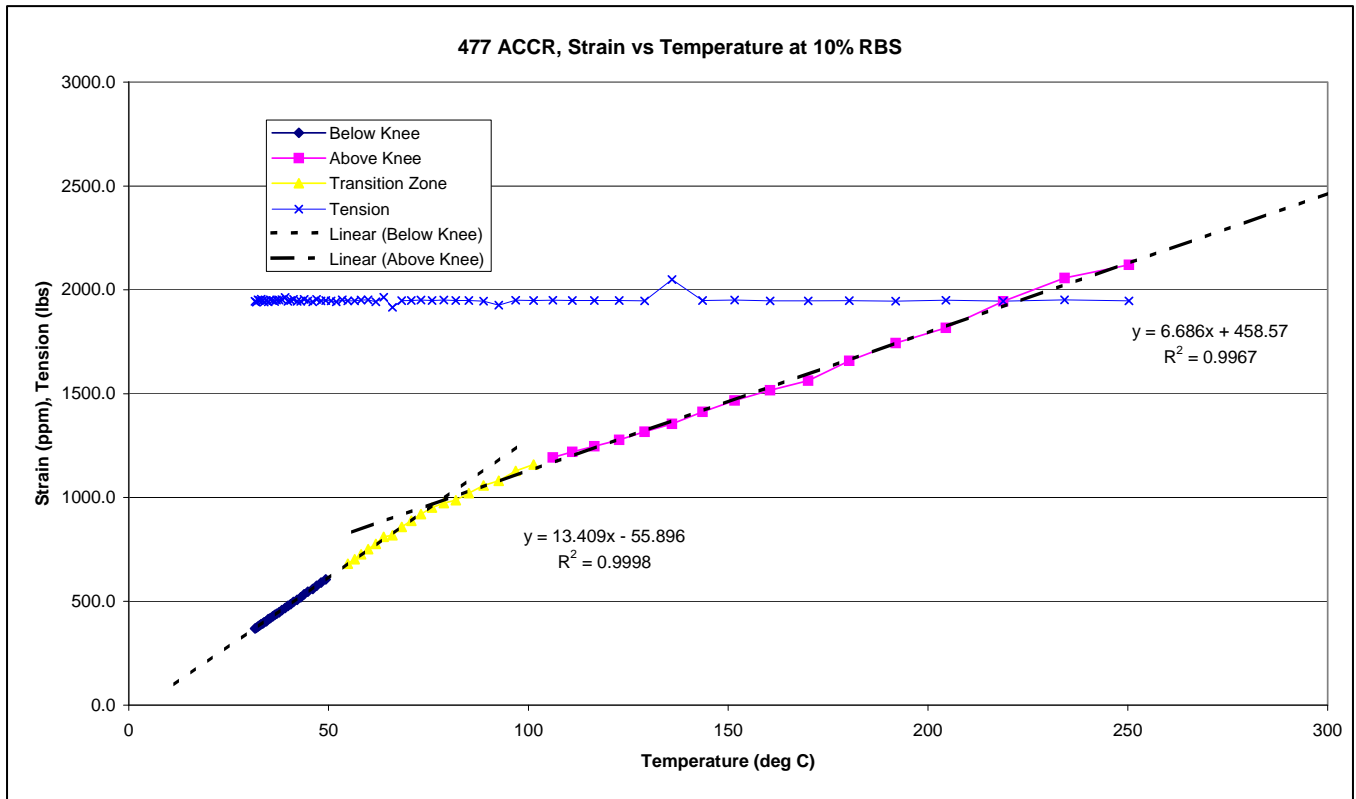


Figure 3, Cool down curve for 477 ACCR at 10% RBS

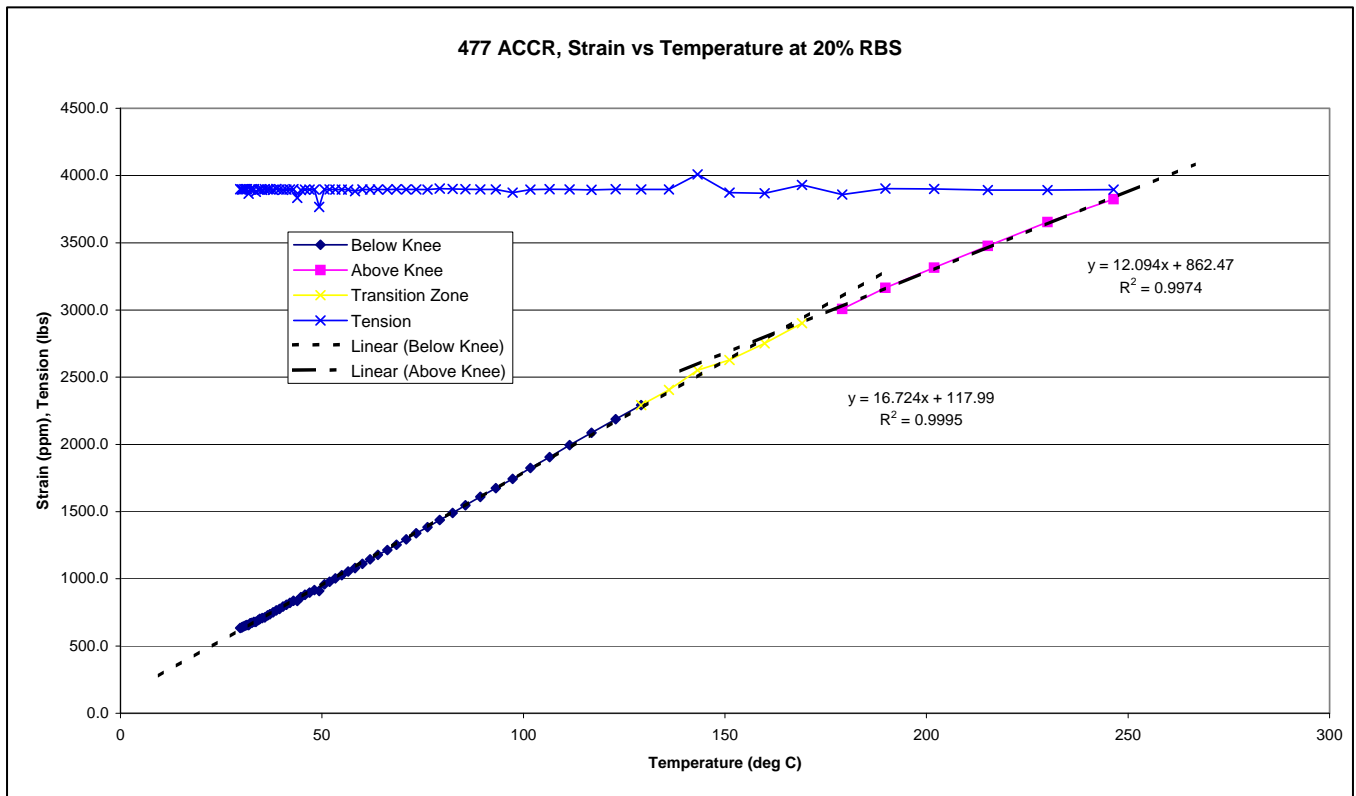


Figure 4, Cool down curve for 477 ACCR at 20% RBS

Conclusions:

Based on the cool-down curves, the following coefficients and knee point temperatures were measured:

10% RBS

Knee temperature:	76° C	
Modulus below knee:	13.9 E-6/C	- short data range – low confidence in value
Modulus above knee:	6.69 E-6/C	- good data range for fit
Theoretical value:	6.3 E-6/C	- good agreement

20% RBS

Knee temperature:	160° C	
Modulus below knee:	16.7 E-6/C	- good data range for fit
Modulus above knee:	12.1 E-6/C	- short data range – low confidence in value
Theoretical value:	16.7 E-6/C	- exact agreement

The values considered statistically significant are 6.69 E-6/C (above the kneepoint) and 16.7E-6/C (below the kneepoint). Both are in good agreement with theoretical values.

Acknowledgement

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

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