Composite Conductor Field Trial Summary Report: ORNL ACCR 675-TW Kcmil

Installation Date	November 2003
Field trial Location	Oak Ridge, Tennessee, USA
Organization	Oak Ridge National Laboratory
Point of Contact	John Stovall, ORNL
Installation Date:	November 2003
Conductor Installed	ACCR 675-TW
Length of line:	2,400 feet (731 meters)
Conductor diameter	0.901 inch, (22.9 mm)
Voltage	400 VDC
Ruling span length	600 feet, (183 meters)
Structure Type	Steel Poles
Instrumentation:	(1) Load cell (2) Current, voltage (3) Weather station (4) Sag (5) Thermocouples in conductor at 25 different locations. (6) Thermocouples in accessories at 50 locations.
Suspension Hardware	Preformed Line Product, THERMOLIGN™ Suspension TLS-675TW-CE
Termination Hardware	Alcoa Compression Dead End B9085-C
Splice	Alcoa Full Tension Splice, B9095-D
Jumper	Alcoa Compression Terminal Connector- B9102-D
Insulator type	Polymer
Dampers	Alcoa Stockbridge Dampers- 1705-7
Results and Measurements	Full range of temperature tests from 30^{o}F – 412^{o}F (0^{o}C – 240^{o}C) with currents ranging from 0 to 1500 amps • Sag-temperature from -10^{o}C – 240^{o}C • SAG after 300 hrs exposure at high temperature • SAG after over 26 cycles from RT to 240 C (464 F) • Accessory temperature profile after repeated thermal cycles • Measured / predicted thermal rating • Conductor and accessory testing after thermal cycles

Acknowledgement:

This material is based upon work supported by the U.S. Department of Energy under Award No. DE-FC02-02CH11111. Any opinions, findings or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the U.S. Department of Energy.

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Abstract:

Under DOE funding Agreement No. DE-FC02-02CH11111, ORNL jointly with TVA installed the 3M ACCR 675TW Conductor on a high temperature test line. The conductor was installed with commercial hardware developed for ACCR conductors. The line was 1200 feet (365 meters) long, and the ruling span was 600 feet (183 meters). Installation of the line was completed on November 6, 2003. The line was fully instrumented with (1) thermocouples in the conductor and accessories, (2) a CAT-1 system to measure tension and (3) a full weather station.

Oak Ridge National Laboratory subjected the line to severe thermal cycling up to 240 C and extended times under high temperature load. Analyzed sag values agreed with predicted models. Sag-temperature-current characteristics are predictable after repeated thermal cycles. Current values agreed with IEEE thermal rating prediction model.

After the line was taken down both conductor and accessories were tested and the results show that they maintained their strength with no degradation or damage. There was no change in electrical conductivity of the conductor.

1 -Background

Reliable high temperature performance is one of the key requirements for implementing new high temperature-low sag conductors. It is imperative to demonstrate in the field that the conductor and accessories can operate safely at high-temperature, under thermal cycling and without degradation. It is also important to demonstrate that the sag-temperature-current characteristics can be predicted after repeated thermal cycles.

Installation and operation of the composite conductor in field trials is typically not well suited for deliberately testing elevated temperature cycling because the thermal load is not easily controlled or predicted. The factors leading to high-temperature excursions include: line current loading under N-1 or N-2 contingencies, emergency conditions, wind, and solar exposure. Depending on these conditions, it can take a year or more for the conductor to experience a single emergency load to temperature greater than 200 C.

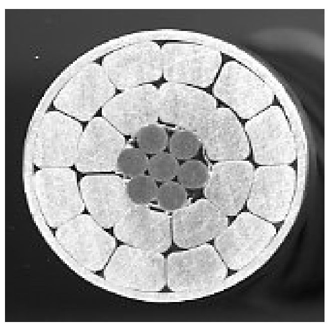
High-temperature exposure and thermal cycling with excursions of the conductor and accessories can be more easily achieved on a test line that operates at low voltage with a controlled current. Such a test line is able to approximately simulate forty years of emergency conditions in three months by implementing sufficient emergency cycles where the conductor temperature exceeds the rating temperature of 210^{o}C, (410^{o}F).

ORNL has built a fully instrumented low-voltage test line to evaluate the high-temperature operation of 3M ACCR conductors. Line instrumentations include mechanical tension, full weather station with anemometer, voltage, current, laser sensor to measure sag, and temperature thermocouples in multiple locations on the conductor and accessories.

This report summarizes ACCR 675TW conductor installation, testing and analysis at ORNL and post thermal cycling examination of the ACCR conductor and accessories.

Aerial view of the line

Towers



ACCR 675 TW

2- Installation and Conductor Stringing

2-1 Overview

A two span test line was constructed on the grounds of the Oak Ridge National Laboratory in Oak Ridge, Tennessee, as a part of a Department of Energy program. Oak Ridge National Laboratory subcontracted the line engineering and construction to the Tennessee Valley Authority, (TVA). The test line (Figure 2) consists of two 600 feet (183 meters) spans between a steel suspension pole and two guyed dual steel dead end poles. The test conductor forms a loop connected to a DC power supply located at one end of the line. Thermocouples were installed along the test conductor and on dead end, suspension and splice hardware to measure the temperature of these components during and after periods of high temperature operation.

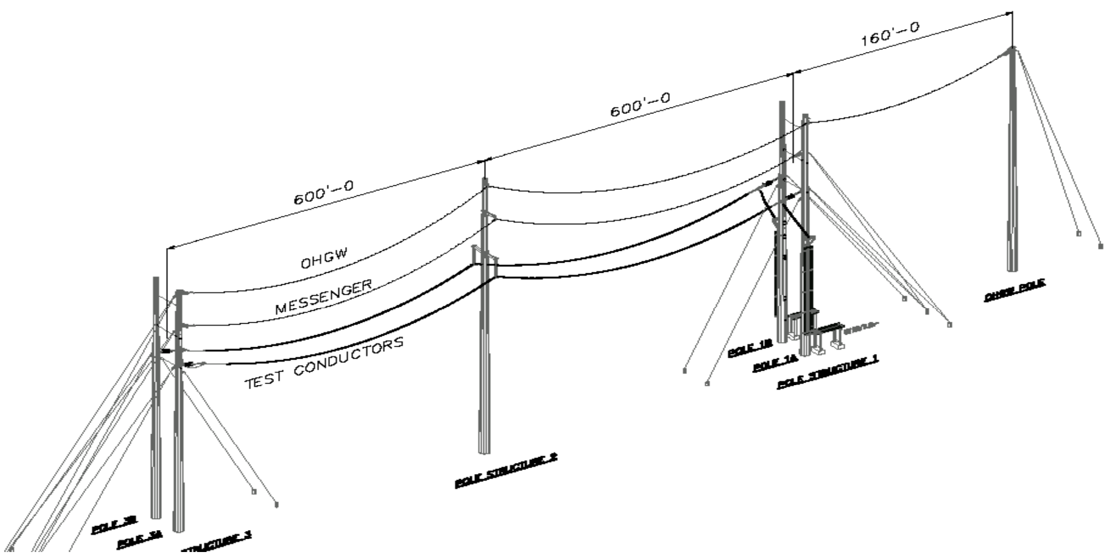


Figure 2- Line Layout and PCAT –1 system

2-2 Installation details:

The installation of the 675 TW ACCR followed the IEEE 524 installation guideline for overhead transmission conductors. The standard applies with the following requirements:

The only conductor stringing method recommended is the tension method. It is important that bending of the composite conductor during installation be carefully estimated to avoid damaging the composite core. If the combination of bending and tension exceeds the allowable core strength it could damage the conductor. Therefore stringing blocks and bull wheels are selected to keep the combined loads well below conductor core strength. Table 2 specifies 28” diameter stringing blocks and 36” diameter or larger bull wheels to meet such criteria. Lined blocks are recommended for use with ACCR. Other installation procedure and hardware are very similar to those used for either ACSR or ACSS. A PLP Distribution Grip was used to pull the conductor to sag and to install full tension splices. Sagging procedures are very similar to that of ACSR, the load cells on the CAT-1 System was used to verify the final sag tensions of the conductor. It is important to allow sufficient length of conductor to apply the permanent Alcoa dead end connector and assembly. The conductor grip was placed on the conductor 12 to 15 feet from the connection point to the insulator string. After the final sag tension was set, the dead ends were installed onto the ACCR.

Table 1- Installation hardware and Procedure Comparison

Installation Equipment	ACSR	ACCR
Stringing blocks	Yes	Yes (28”)
Bull wheels	Yes	Yes (54”)
Drum Puller	Yes	Yes
Sock splice	Yes	Yes
Conductor grip	Any	Distribution grips, DG
Cable spool	Yes	Yes (48” drums)
Cable cutter	Yes	Yes
Reel stands	Yes	Yes
Grounding clamps	Yes	Yes
Running ground	Yes	Yes

Installation Procedure	ACSR	ACCR
Cable stringing	Tension/ slack	Tension
Sag tensioning	Any	Line of sight- Dynometer
Dead ending	Any	DG grips with chain hoist
Clipping	Any	Any

The following images and those under the next section are typical examples of the installation details

Figure 3- Bull wheel tension of conductor during installation

2-3- CAT-1 Instrumentation:

A CAT-1 system with weather station was installed on one of the dead end structures to monitor the conductor tension and weather conditions (temperature, wind speed, and direction) at intervals of 1- minute. The conductor mechanical tension was measured using two 10,000 pounds load cells, Figure 4. The CAT-1 system also includes an anemometer to measure wind speed and direction and a net radiation sensor to measure ambient temperature and solar radiation. Data acquisition was done at 1 minute rate for all channels. The CAT-1 main unit is in a NEMA-enclosed, solar powered, data acquisition and processing unit

4-a- Load cell used to measure tension

4-b- CAT-1 System

4- c Net Radiation Sensor Measures-
No Load Conductor Temperature

Figure 4- CAT-1 system hardware details

Net Radiation Temperature (NRT) is measured by the NRS, Figure 3 below, which provides a simple method of combining ambient temperature with wind and solar effects to simplify measurements and rating calculations.

2- 4 Conductor and Accessories Temperature Measurements:

The temperature was measured using thermocouples as follows:

Thirty thermocouples were mounted at various locations along the span, including four thermocouples directly touching the composite core.

The other thermocouples were located on the conductor surface; however not all were active at the same time:

a. Eighteen thermocouples in three different ALCOA dead ends
b. Eight thermocouples in one ALCOA compression splice
c. Four thermocouples in a PLP THERMOLIGN^{TM} Suspension
d. Four thermocouples in Alcoa jumpers

A separate data acquisition system was used to collect the information from the thermocouples. To accommodate the multiplicity of points along the conductor and withstand the accumulated voltage drop, many fiber-connected, isolated measurement nodes were used. A thermocouple measurement node is fabricated using a multiplexer (ICPCON I-7018) and a RS-485-to-fiber modem (B&B FOSTCDR). Up to eight thermocouples are monitored per node. The node requires 120 VAC power and is data connected through a duplex fiber optic network. The multiplexer, fiber modem, and a power supply are housed in a Preformed Line Product enclosure.

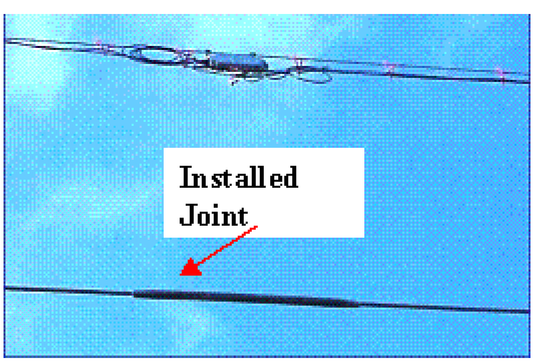
2-5 Controls

The line was operated under constant either current and / or constant conductor temperature with thermal cycles lasting from less than one hour to several days.

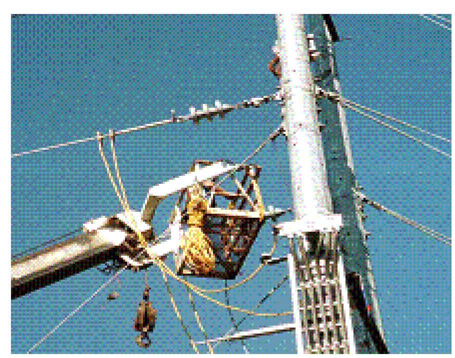
2-6 Accessories:

Compression type dead end and splice made by Alcoa were installed. The following specific parts were used: (1) Four ALCOA compression dead ends; part/ drawing # B9085- those dead ends consist of both direct core gripping parts and conductor gripping sleeve. (2) One ALCOA full tension splice part# B9095-D; it has the same design as the dead-end for both direct core gripping and conductor. (3) Two high-temperature commercial PLP THERMOLIGN^{TM} Suspensions, (240 C conductor temperature), Part # TLS-675TW-CE. (4) Six Alcoa terminal connectors; part# B9102-D; those are all

Aluminum sleeve parts (5) Four Alcoa Stockbridge dampers, part# 1705-7



5- a compression splice



5-b Terminal connector / jumper installation

5-c Alcoa compression dead end

5-d PLP suspension system

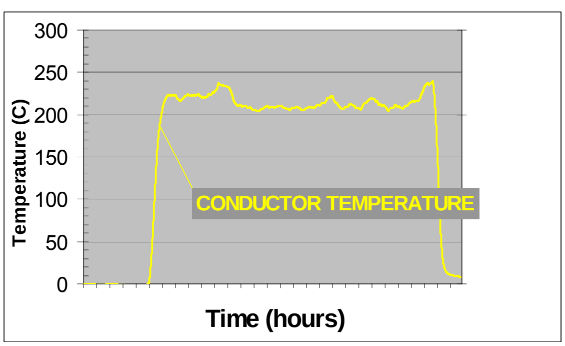
Figure 5 Examples of both installed Alcoa compression accessories and PLP suspension

3- Thermal Cycles and High Temperature Exposure:

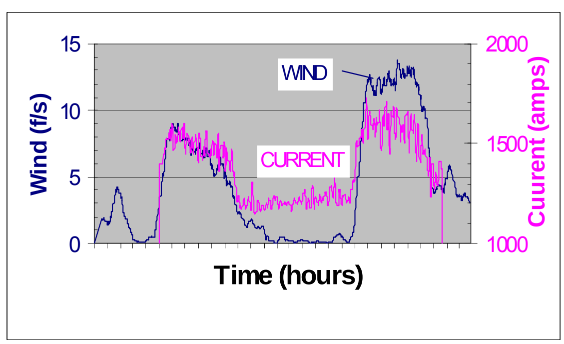
The 675TW conductor was thermally cycled from November 2003 to March 2004 with a total of 32 cycles ranging from one hour to twenty hours; see Table 2. Cycles were either in temperature control where the conductor was held at constant temperature (210-240 C) for the duration of the cycle, or in current control, where the conductor was held at a constant current for the duration of the cycle. The power supply used to energize the line had a dual rating of 400 Vdc and 5000 amps or 600 Vdc and 3750 amps. The input voltage to the power supply was 4.16 KV, 3-phase. A dry-type ABB transformer was used to step down the voltage from a 13.8 KV distribution line.
Figure 6-a, b, shows the core temperature of the conductor during a typical thermal cycle in temperature control mode along with current and wind speed. The temperature is maintained at 210-240 C by controlling the current from 1000 amps to 1800 amps while the wind fluctuates between 0 f/s and 15 f/s, Figure 6-b.

Table 2- Details of Thermal/ Current cycling

Cycles	Date	Run Hours	Hours> 200C	Total Hours >200C	Comment
1	11/12/2003	2	0	0	T controlled, 200C+
2	11/13/2003	6	6	6	T controlled, 200C+
3	11/14/2003	5.5	5.5	11.5	T controlled, 200C+
4	11/17/2003	6	6	17.5	T controlled, 200C+
5	11/18/2003	6	6	23.5	T controlled, 200C+
6	12/1/2003	6	6	29.5	T controlled, 200C+
7	1/13/2004	8	8	37.5	T controlled, 200C+
8	1/14/2004	8	8	45.5	T controlled, 200C+
9	1/16/2004	8	8	53.5	T controlled, 200C+
10	2/12/2004	1		53.5	T controlled, 200C+
11	2/18/2004	3	3	56.5	T controlled, 200C+
12	2/19/2004	7	7	63.5	T controlled, 200C+
13	2/20/2004	5	5	68.5	T controlled, 200C+
14	2/23/2004	7	7	75.5	T controlled, 200C+
15	2/24/2004	7	7	82.5	T controlled 200 C+, Rained, 0.1"
16	2/25/2004	7	7	89.5	T controlled 200C+, Windy
	2/26/2004			89.5	T controlled 200C+, Snow
17	2/27/2004	6.5	6.5	96	
18	3/1/2004	6	6	102	T controlled 200C+ Windy,
19	3/2/2004	9	9	111	T controlled 200C+, Rainy day. 0.69"
20	3/3/2004	9	9	120	T controlled 200C+, Foggy morning
21	3/4/2004	16	16	136	T controlled, 200C+,Overnight run
22	3/5/2004	16	16	152	T controlled, 200C+,Overnight run
23	3/10/2004	14	14	166	T controlled 200C+, Overnight run
24	3/11/2004	20	20	186	
25	3/12/2004	0.5	0	186	T controlled, 200C+
26	3/22/2004	6.5	6.5	192.5	T controlled, 200C+
27	3/23/2004	14	0	192.5	Constant current, 1000 A
28	3/24/2004	24	0	192.5	Constant current Midnight - 4 PM @ 1000 A; 4 PM - Midnight @ 750 A
29	3/25/2004	19.5	0	192.5	Constant current, Midnight - 4 PM @ 750 A; 4 PM - 7:30 PM
30	3/26/2004	17	5	197.5	Constant current, 6:40 AM to Midnight @ 1200 A
31	3/27/2004	24	8.5	206	Constant current, Midnight to 10:25 AM @ 1200 A;10:25 A to Midnight @ 575 A
32	3/28/2004	12	0	206	Constant current, Midnight to Noon @ 575 A



6-a—Core temperature



6-b- Current and wind speed

The

Figure 6- Example of conductor constant temperature cycle with wind and current

For 24 hours followed by 575 amps for another 24 hour. In this case, the conductor temperature fluctuates between 230C and 50 C.

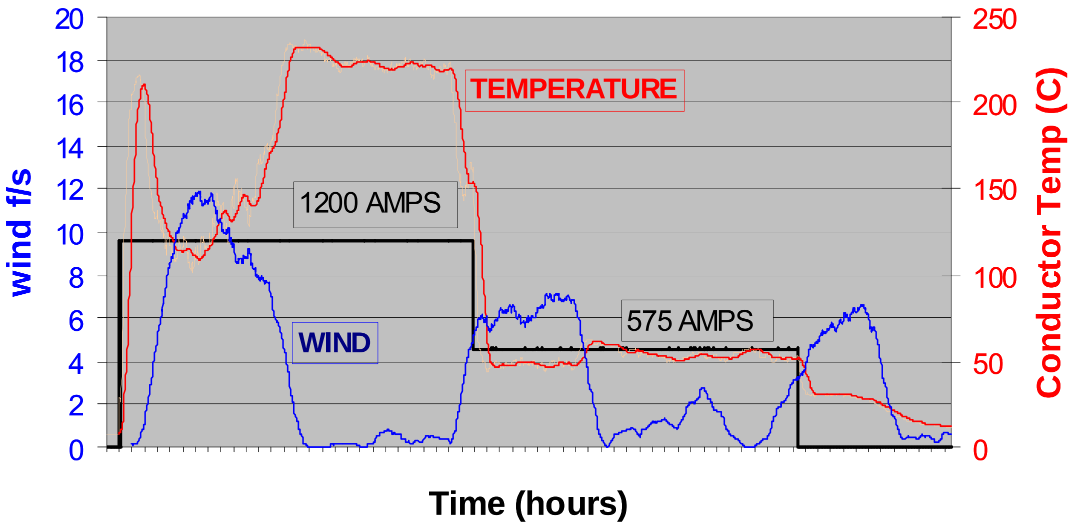


Figure 7-Typical constant current cycle for 675 TW

4- Measured and Predicted Line Tension and Sag:

The following are two video frames showing the line before being energized and at maximum sag after application of current.

11:29:08 – Before

11:54 – Maximum Sag

Figure 8- Observation of line sag changes during current cycling

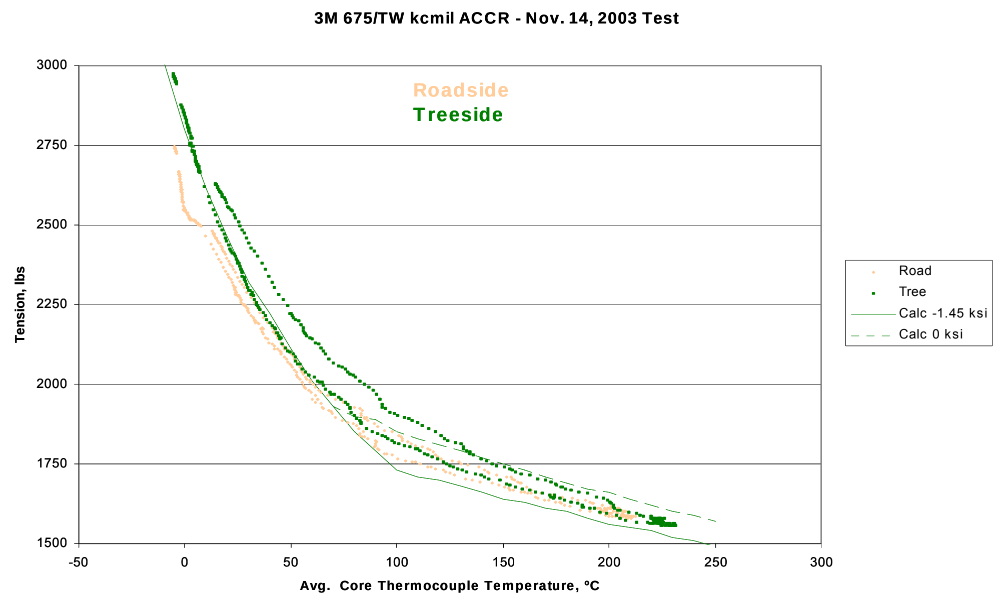


Figure 9- Measured VS predicted tension

The sag was predicted with two methods: the Strain Summation Method to account for the full loading history, and the more commonly used Graphic Method, (Alcoa SAG-10). The Strain Summation Method of Sag-Tension Calculation takes into account both creep and wind conditions as a function of time. A conductor data file was created based on stress strain tests performed by NEETRAC on the conductor. Compressive stresses of 0 and 1.45 Ksi were used to compute sag. Predicted sag values appear to agree reasonably well within 2" sag value, see figure 9 and 10.

Data generated from November 2003 to March 2004, after additional 192.4 hours exposure at > 200C is shown below in Figure 10. The data shows no change in the test line and conductor as compared to its the initial performance in November (Figure 9). There has been virtually no creep since Nov. 14/03; see figure 11

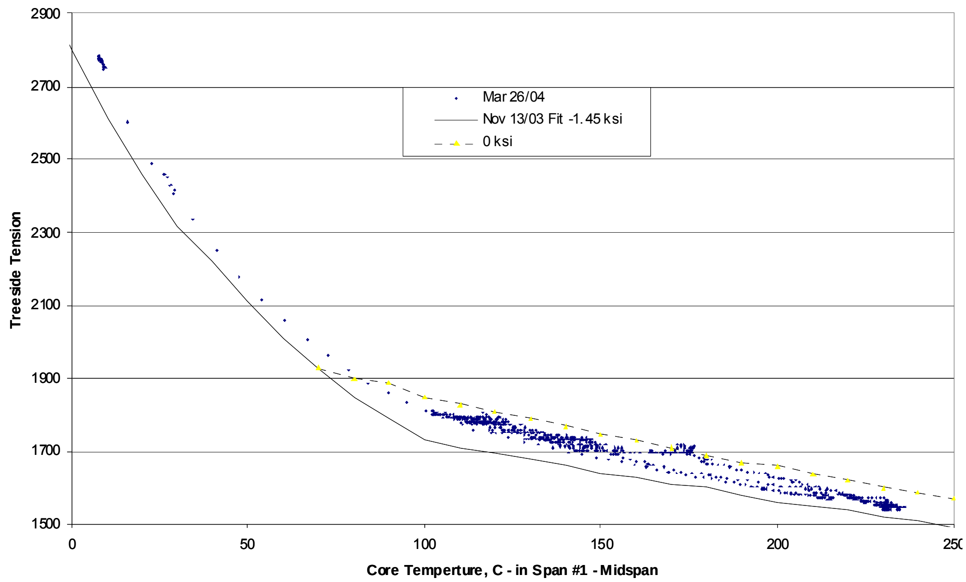


Figure 10- Measured and predicted span tension (tree side) VS conductor core temperature after 192.4 hours above 200 C

5- Additional Conductor Field Test data

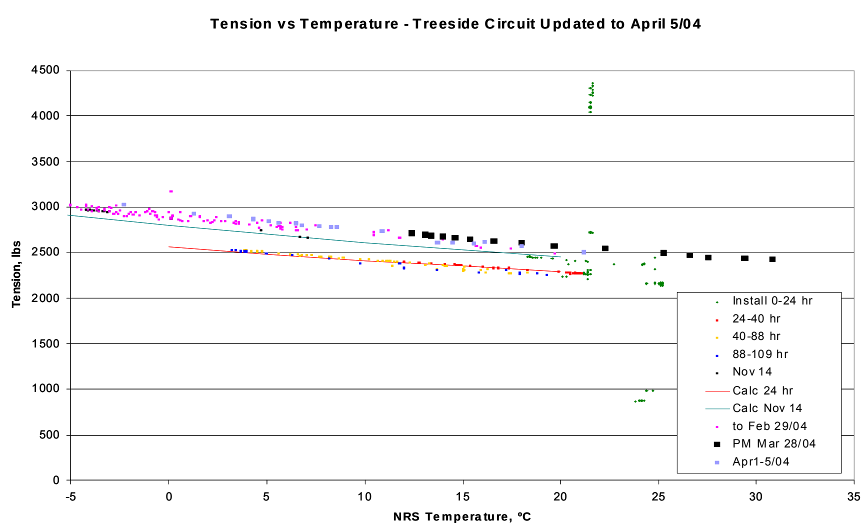


Figure 11- ACCR 675 TW showing almost no creep after 192.4 hours above 200 C

The next set of graphs 12, 13 show effect of both ice and rain on the conductor line tension. Ice build up produced a 300 lbs increase in tension for about 17 hours, Figure 13.

There was no effect of rain on either conductor temperature or tension when line was energized above 200C. The PCAT test line sag remained stable during the field trial. High temperature was negligible.

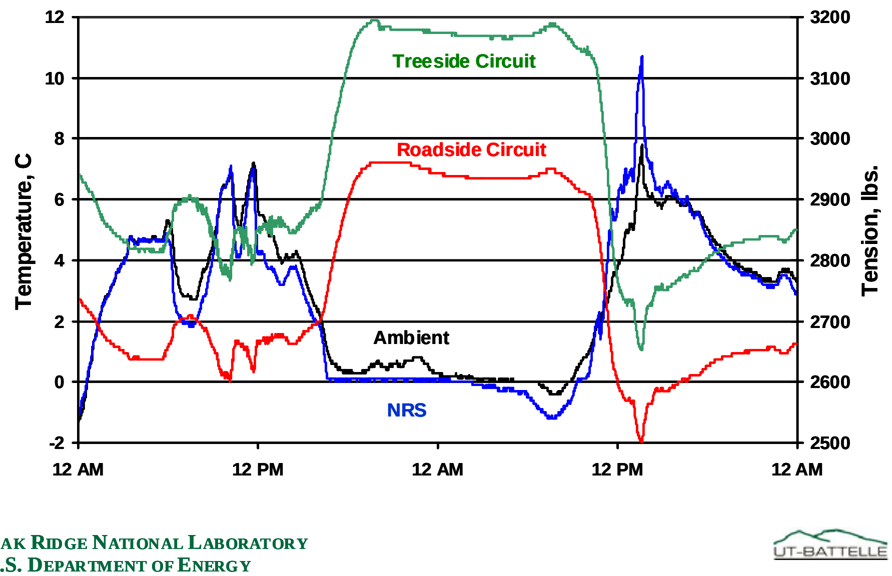


Figure 12- Ice build up for 17 hours on ACCR 675 TW on February 15- 16, produced about 300 lbs increase in line

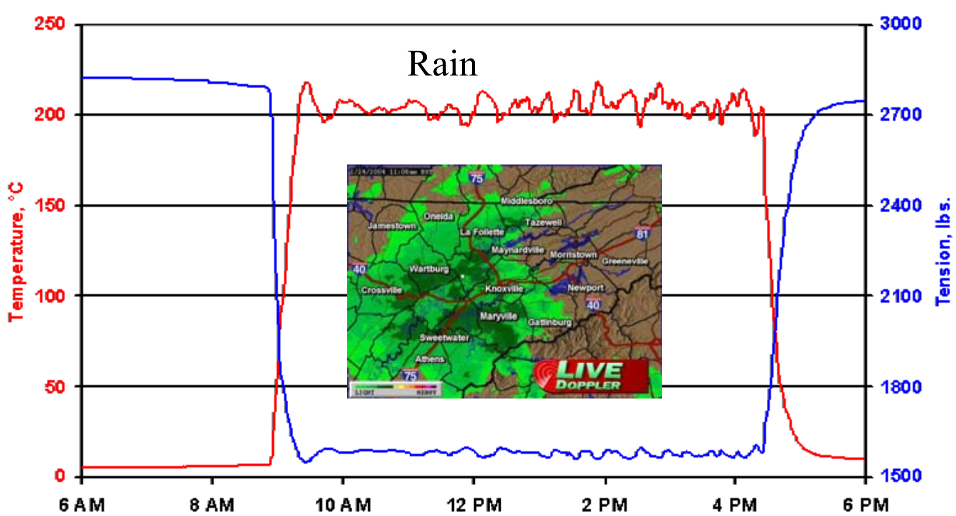


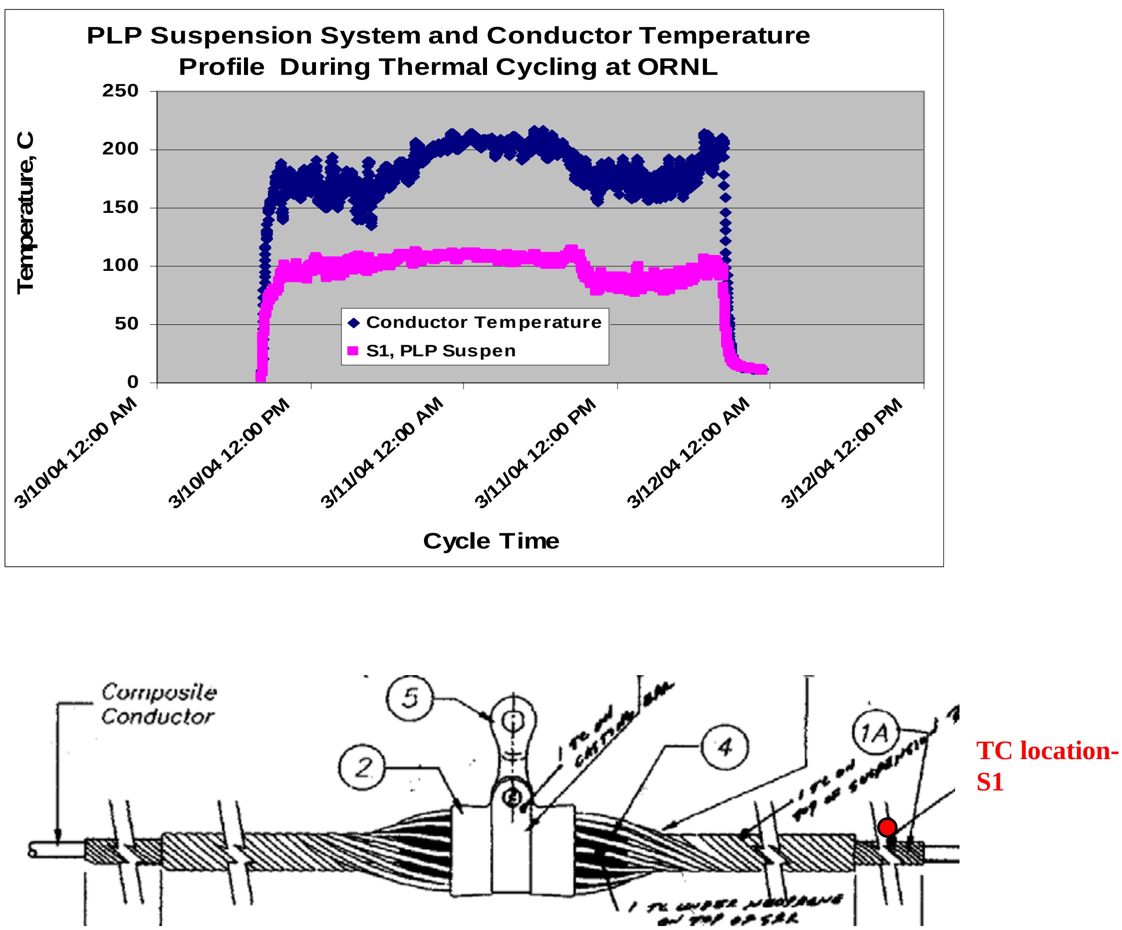
Figure 13- Rain on February 24, 2 hour shower (0.1") had no effect on conductor temperature)

6- Accessories Response at High Temperature:

Over 300 hours of high temperature operation were performed under either temperature or current control. The line was subjected to a range of weather conditions during thermal cycling (-10 C to 250 C, wind, rain, and ice). All accessories performed well; maximum accessories temperature remained under 140 C as illustrated in Figures 15- 17.

6-1 PLP Accessories:

PLP THERMOLIGN^{TM} Suspension System ran under 100 C during high temperature cycling

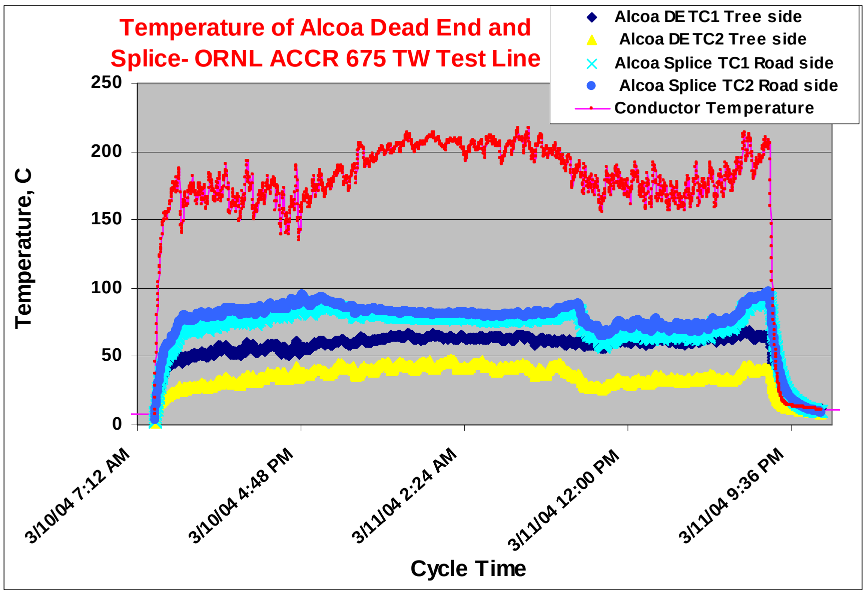


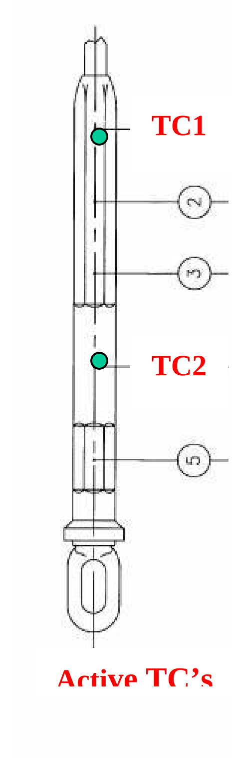
End of inner rod TC location

Figure 14- PLP THERMOLIGN^{TM} Suspension ran cool at conductor temperature of > 200^{0} C

6-2 Alcoa Accessories:

All Alcoa compression accessories showed normal behavior with no over heating during conductor thermal cycling; examples are shown in figures 15 and 16.





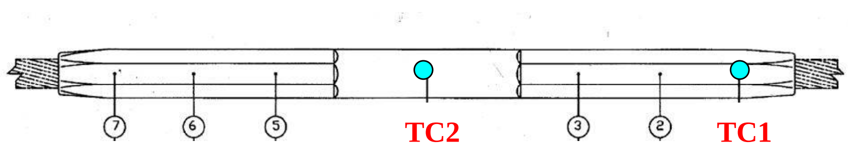
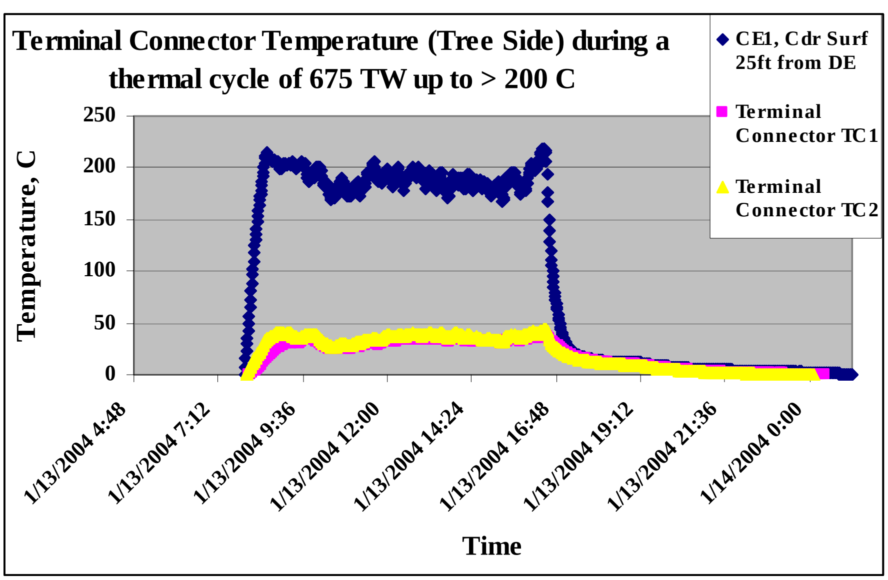
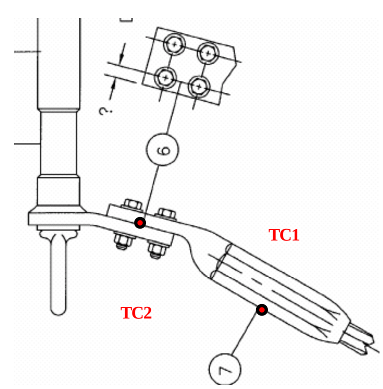


Figure 15 Alcoa dead-end and splice temperature stayed below 100 C while conductor was cycled to above 200 C. TC locations are in green cicles; Locations 1 and 4 are for TC1 and TC2





Thermocouple on locations in red

Figure 16- Alcoa Compression terminal connector temperature- connector ran < 55 C when conductor was at 200 C

7- Ampacity and Thermal Rating of Conductor

Conductor current was computed using IEEE STD 738-1993- "Standard for Calculating the Current Temperature Relationship of Bare Overhead Conductors**"**. Steady State data, where both conductor current and wind speed were constant, was selected. Wind speed data was averaged over 30 minute intervals. The following input parameters were used in the model calculations:

Emissivity:	0.27 (measured by ORNL- see details in appendix)
Solar absorption:	0.5
Conductor elevation:	800 feet
Conductor latitude:	30 degrees
Total solar flux:	1 w/ft^2
Thermal conductivity:	0.01 w/ft K
Sun altitude:	54 degrees

The IEEE current prediction model provides good agreement with actual line-measurements current over a range of current from 400 to 1200 amps with the conductor in the 60 C to 230 C temperature range, Figure 18

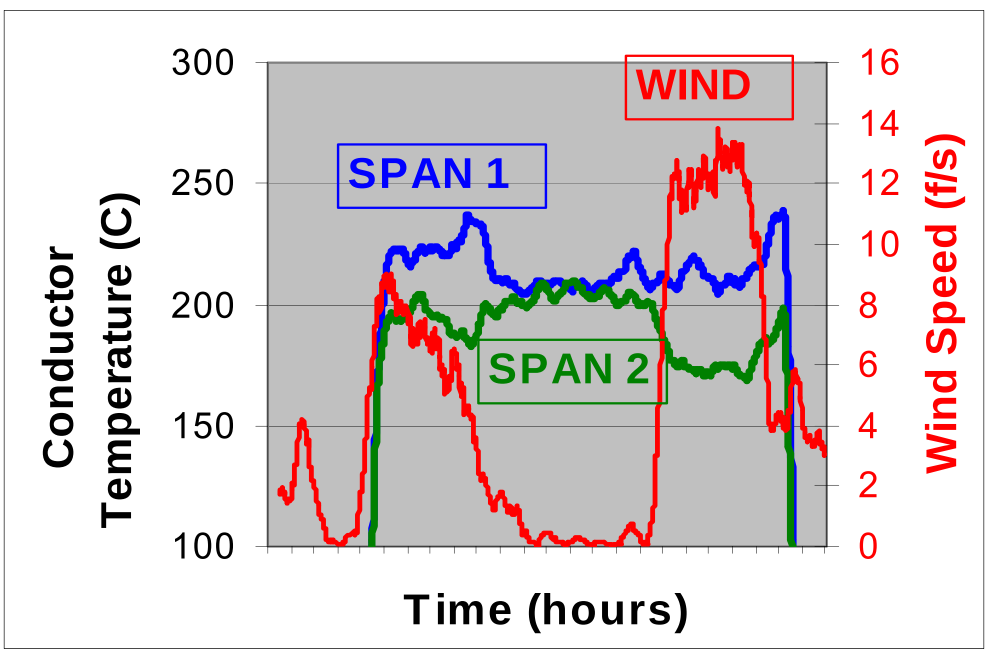


Figure 17- An example of steady state conductor temperature and wind speed data used in the model

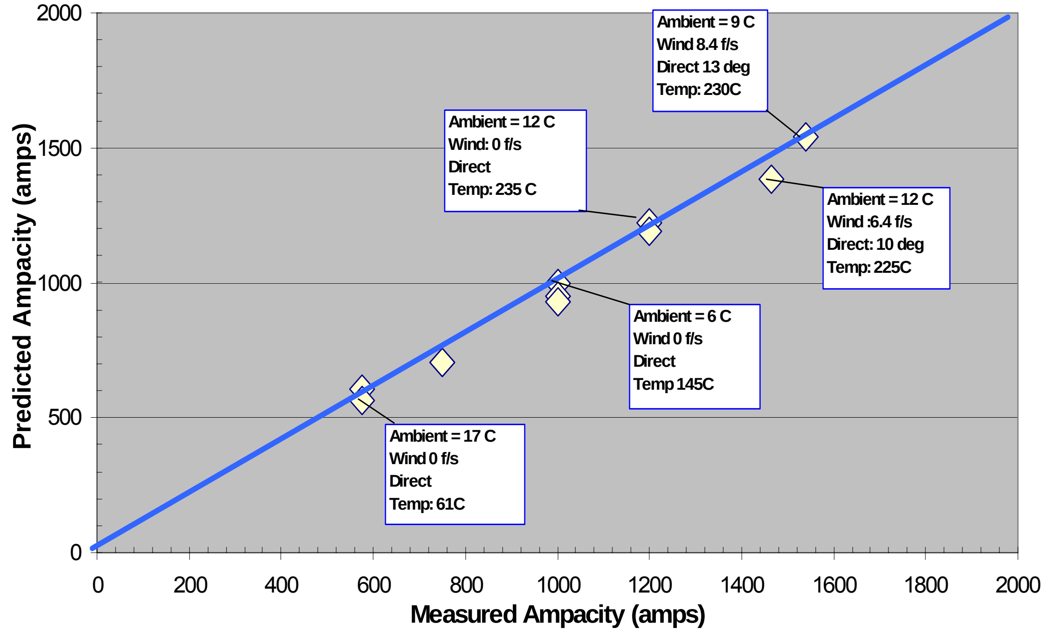


Figure 18-Good agreement between Measured and predicted current. Predicted values were computed using IEEE ampacity rating steady state model

8- Post ORNL Conductor and Accessories Evaluation

The following tests & measurements were carried out on the conductor and accessories after thermal cycling at ORNL:

8-1 Conductor tensile tests:

Three samples from the "free-span" conductor were terminated using cast-resin terminations. Clamps were used to preserve the as-received position of the conductor layers until the resin cured. The sample preparation method ensures that the laboratory tensile test loads each conductor strand in the same manner as a field overloads, and thereby measures the in-service conductor strength. Free conductor between the end fittings is 20 feet (6 meters).

A sample from the free-span section was terminated with cast-resin using a process that ensures that each conductor layer and strand is not displaced from its in-service position. The 1999 Aluminum Association guide for conductor stress-strain testing was followed with the exception of special values for the elastic properties of the metal matrix composite (MMC) core were used instead of values for steel core used in ACSR conductors. The core strand from another sample is used to measure core stress-strain, and determine the elastic properties of the composite conductor.

The conductor maintained its strength after thermal cycling at above 200C. The average of five measurements is 109 % RBS as shown in Table 3.

Table 3- Conductor test data

Sample	**Breaking load, Lbs**	**% RBS**	**Failure Mode**
04121T1	24,770	110	All strands fractured in the gage section
04121T2	25,430	113	All strands fractured in the resin fitting
04121T3	22,780	101	All strands fractured in the gage section next to a drilled thermocouple
Stress- Strain-conductor	25,250	112	Mid span break, all strands failed
Stress Strain-Core	12,820	111	Mid span break, all strands failed

8-2 Conductor Stress-strain:

Stress-strain results are similar to results from the same conductor prior to the field test. The principal difference is that creep during the 30% load hold phase is less on the field sample, apparently because the field loads caused the initial creep to be removed from the conductor as shown in Figures 19 to 21.

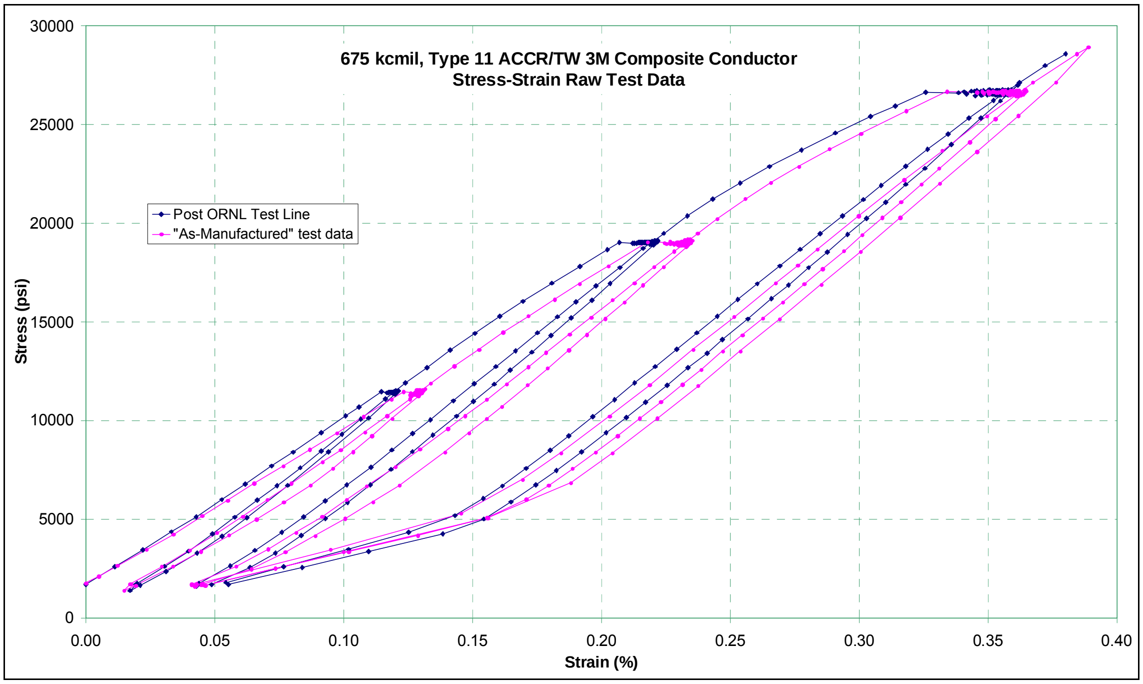


Figure 19- Plot of raw data recorded during conductor stress-strain test (blue), Agrees with data for conductor tested from same lot before the field test

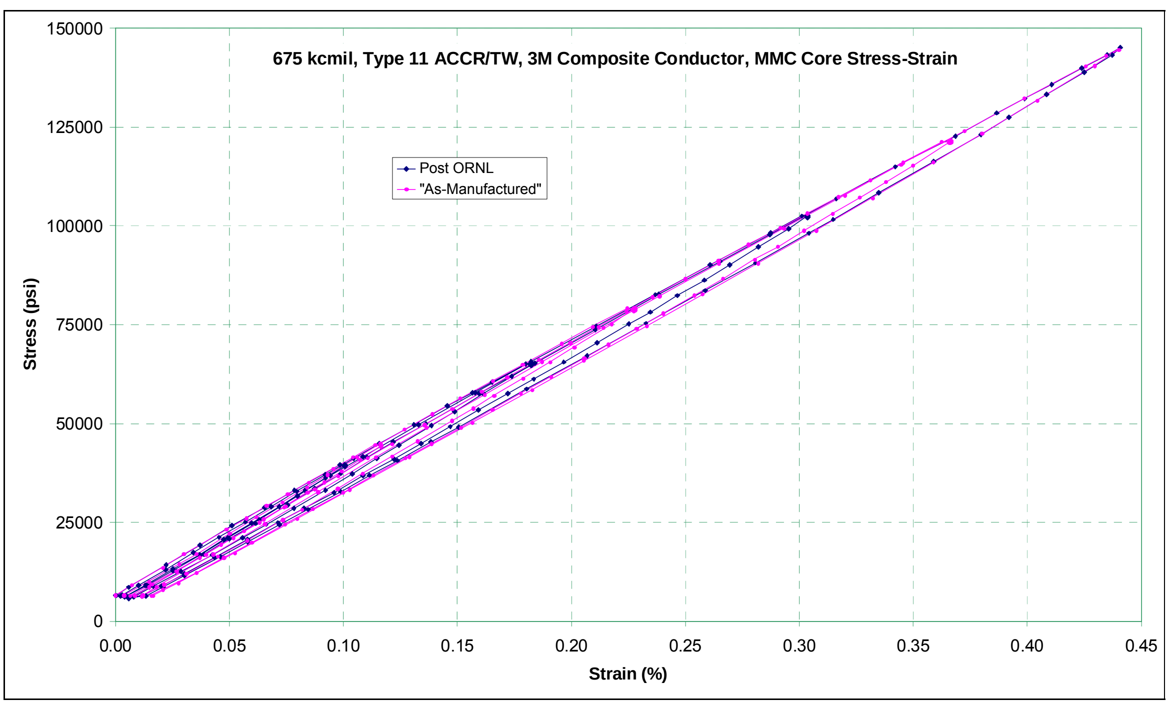


Figure 20- Core stress-strain shows essentially no change due to field test

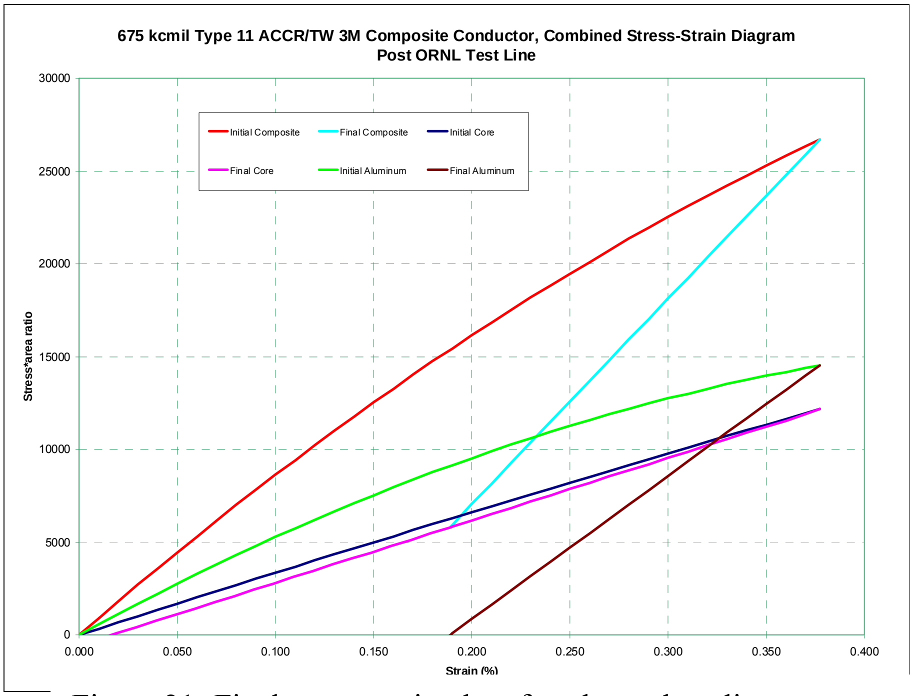


Figure 21- Final stress strain plot after thermal cycling

8-3 Conductor resistance test:

Welded equalizers were installed at each end of a 22-foot long sample from the free-span section. A second set of voltage equalizers in the form of tightly wrapped solid copper strands are applied nominally 20 feet apart in the test section. The sample is placed on a flat surface, and pulled with sufficient tension to remove any residual curvature in the conductor. Tension was about 200 – 300 lb. A digital low-resistance Ohmmeter was used to make a 4-wire resistance measurement for the conductor section between the two voltage equalizers. A digital multi meter was used to verify that the sample was electrically isolated.

22- a- Power connection to sample

22- b Sample-tensioning device

Figure 22- Set- up for conductor resistance measurements post ORNL field-testing

Conductor resistance for an average of 5 readings on a 20 feet long sample was 0.1332 Ω/mile at 20°C; it is close to the conductor resistance of 0.1346 Ω/mile at 20° C before thermal cycling.

8-4 Connector tensile tests:

8-4-1 Alcoa compression accessories

Two dead-ends and two splices were provided with cast resin fittings at free ends

The procedure preserves the "as received" position of the conductor components, and thereby assures that the breaking strength is the same as existed when the samples were in service on the test span.

Both splice and dead end maintained their load carrying capability of 100% RBS or more; details in table below

Table 4- Connector tensile tests

Sample	Breaking Load, Lbs	% RBS	Failure Mode
04121SP1 (Splice)	24,010	107	All strands fractured at the resin fitting
04121SP2 (Splice)	24,530	109	All strands fractured ~5" inside splice
04121DE1 (Dead end)	24,730	110	All strands fractured ~6" inside dead end
04121DE2 Dead end)	22,330	99	All strands fractured ~5" inside dead end

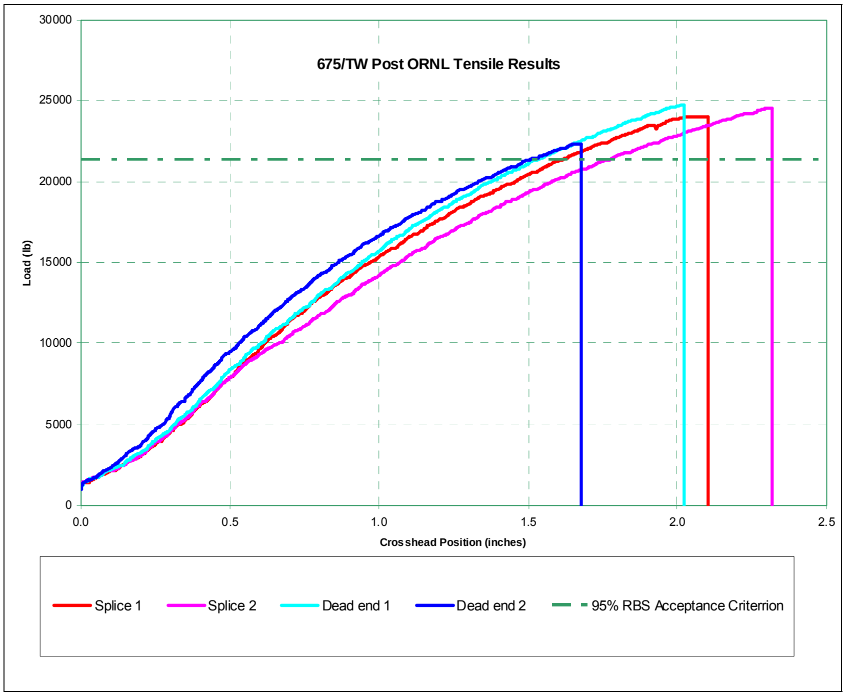


Figure 23 Tensile test data for accessories post ORNL Cycling current cycling

8-5 PLP Suspension:

Visual examination of the suspension components showed neither fatigue nor wear damage; conductor did not distort. Conductor segments which were inside the suspension were pulled in tension and gave 24,740 Lbs (110% RBS) load to failure, conductor failed in an area that was not under the suspension assembly

8-6 Connector Microscopic Examination:

One dead end and one splice were dissected using a milling machine to split the aluminum sleeve and reveal the internal splice components. Correct installation is verified by observing proper placement of the core grip, proper conductor preparation, and proper injection of inhibitor compound prior to compression.

The dissections and inspections showed good workmanship for core and aluminum insertion depth, component placement, and the crimping operation. Both conductor and accessories gave >100% RBS. It was however noticed that the center cavity contained no oxide inhibitor compound, showing that this step was omitted. Compound was applied liberally on the conductor OD, so this is not a serious issue for a short-term, field test Nevertheless installation instructions stipulate that the center cavity should be filled with oxide inhibitor compound through an injection port. There is no evidence that the conductor was wire-brushed prior to splice installation. AFL requires wire- brushing of the conductor OD only in cases where the connector is installed on weathered conductor. Proper wire brushing and the use of inhibitor compound have been reinforced in the installation guide.

9- Summary

ACCR 675 TW conductor was installed successfully on ORNL- PCAT Line using commercial hardware and normal installation procedures. The conductor and accessories were thermally cycled from ambient to > 200C for several hundred hours, using DC power supply and as high current as 1500 amps. The measured sag matched the SAG-10 prediction. Data analysis shows that the measured conductor current agrees well with the IEEE thermal rating model predicted values. After-de installation the conductor and accessories were tested for residual strength and degradation. Residual strength exceeded 100% RBS and neither conductor nor accessories showed any signs of damage. Conductor resistance after cycling is equivalent to that of conductor not exposed to thermal cycling

10- Appendix

10-1 Conductor Specs (Table 1)

Conductor Physical Properties		
Stranding		20/7
kcmils	kcmil	676
Area Fraction Core	%	10.25%
Weight Fraction Core		12.50%
Diameter		
indiv Core	in	0.105
indiv Al	in	
Core	in	0.315
Total Diameter	in	0.902
Area		
Al	in^2	0.5309
Total Area	in^2	0.5915
Weight	lbs/linear ft	0.726
Breaking Strength		
Core	lbs	11,564
Aluminum	lbs	10,923
Complete Cable	000's lbs	22,487
Modulus		
Core	msi	31.4
Aluminum	msi	7.6
Complete Cable	msi	10.1
Thermal Elongation		
Core	$10^{-6}/C^{o}$	6.35
Aluminum	$10^{-6}/C^{o}$	23.00
Complete Cable	$10^{-6}/C^{o}$	17.69
Heat Capacity		
Core	W-sec/ft-C	13
Aluminum	W-sec/ft-C	275
Conductor Electrical Properties		
Resistance		
DC @ 20C	ohms/mile	0.1317

AC @ 25C	ohms/mile	0.1348
AC @ 50C	ohms/mile	0.1481
AC @ 75C	ohms/mile	0.1615
Geometric Mean Radius	ft	0.0355
Reactance (1 ft Spacing, 60hz)		
Inductive Xa	ohms/mile	0.4052
Capacitive X'a	ohms/mile	0.0973

10-2 Detailed Resistance Data:

NEETRAC Project No. 04-121					
AVO (Biddle) DLRO, Calibration Control # CQ1097					
Temperature coefficient for resistance:	0.0036				
Resistance measurement on a 20' gage section of 675 ACCR/TW setup in the tensile room on the MTS frame, welded equalizers, pulled to ~200 lbs tension w/a come-a-long					
These readings taken manually 10/14/04 @ 9:54 am					
Conductor Temperature:	21.5	deg C			
Test Section:	20.000	ft			
Resistance Readings	506.8	μΩ	At	21.5	deg C
	506.7	μΩ	At	21.5	deg C
	506.7	μΩ	At	21.5	deg C
	506.73	μΩ	At	21.5	deg C
Ω/ft:	2.5337E-05	Ohm/ft	At	21.5	deg C
Ω/ft:	2.5200E-05		At	20.0	deg C
Ω/mi	0.13378	Ohm/mi	At	21.5	deg C
Ω/mi @ 20C:	0.13306		At	20.0	deg C
These readings taken manually 10/14/04 @ 10:32 am					
Conductor	21.8	deg C			

Temperature:					
Test Section:	20.000	ft			
Resistance Readings	507.4	µΩ	At	21.8	deg C
	507.4	µΩ	At	21.8	deg C
	507.3	µΩ	At	21.8	deg C
	507.37	µΩ	At	21.8	deg C
Ω/ft:	2.5368E-05	Ohm/ft	At	21.8	deg C
Ω/ft:	2.5231E-05		At	20.0	deg C
Ω/mi	0.13394	Ohm/mi	At	21.8	deg C
Ω/mi @ 20C:	0.13322		At	20.0	deg C

These readings taken manually 10/14/04 @ 10:53 am					
Conductor Temperature:	21.8	deg C			
Test Section:	20.000	ft			
Resistance Readings	507.4	µΩ	At	21.8	deg C
	507.4	µΩ	At	21.8	deg C
	507.3	µΩ	At	21.8	deg C
Average	507.37	µΩ	At	21.8	deg C
Ω/ft:	2.5368E-05	Ohm/ft	At	21.8	deg C
Ω/ft:	2.5231E-05		At	20.0	deg C
Ω/mi	0.13394	Ohm/mi	At	21.8	deg C
Ω/mi @ 20C:	0.13322		At	20.0	deg C
These readings taken manually 10/14/04 @ 2:34 pm					
Conductor Temperature:	21.9	deg C			
Test Section:	20.000	ft			
Resistance Readings	507.4	µΩ	At	21.8	deg C
	507.4	µΩ	At	21.8	deg C
	507.5	µΩ	At	21.8	deg C
Average	507.43	µΩ	At	21.8	deg C
Ω/ft:	2.5372E-05	Ohm/ft	At	21.9	deg C

Ω/ft:	2.5235E-05		At	20.0	deg C
Ω/mi	0.13396	Ohm/mi	At	21.9	deg C
Ω/mi @ 20C:	0.13324		At	20.0	deg C
These readings taken manually 10/14/04 @ 4:52 pm					
Conductor Temperature:	21.7	deg C			
Test Section:	20.000	ft			
Resistance Readings	506.9	μΩ	At	21.8	deg C
	507.0	μΩ	At	21.8	deg C
	506.9	μΩ	At	21.8	deg C
Average	506.93	μΩ	At	21.8	deg C
Ω/ft:	2.5347E-05	Ohm/ft	At	21.65	deg C
Ω/ft:	2.5210E-05		At	20.0	deg C
Ω/mi	0.13383	Ohm/mi	At	21.65	deg C
Ω/mi @ 20C:	0.13311		At	20.0	deg C
Errors:	Gage length	0.05%			
	Instrument	0.20%			
	Temperature	0.18%			
RMS Error:		0.27%			
Average, all readings:	0.13317	Ω/mi	At	20.0	deg C
3M nominal	0.13170	Ohm/mi	At	20.0	deg C

10-3 Emissivity Measurements:

Oak Ridge National Laboratory measured various 3M composite conductor emissivity using IR Imaging. A calibrated IR Camera and Mikron M305 Blackbody calibration source were used. Graph 24 shows the hardware used; the calibrated black body target was multiplied by various emissivity values until a good fit occurs with the conductor received signal. Such fit yielded an average emissivity value of 0.27 within +- 2%

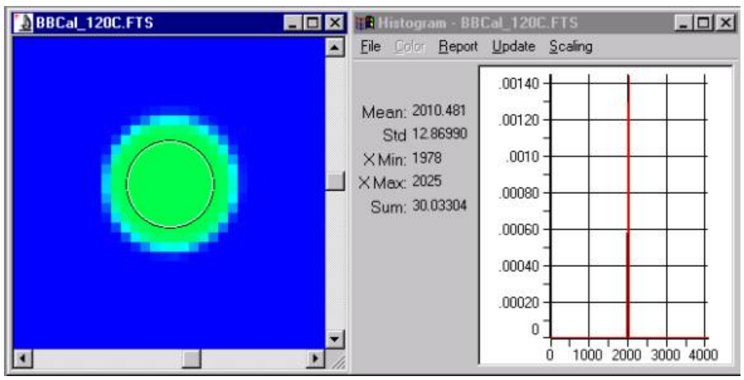


Figure 24 Calibrated IR Camera and Mikron M305 Blackbody calibration source used for measuring emissivity