Composite Conductor Field Trial Summary Report: ORNL ACCR 477 Kcmil

Installation Date	July 25, 2002
Field trial Location	Oak Ridge, Tennessee, USA

Line Characteristics

Organization	Oak Ridge National Laboratory
Point of Contact	John Stovall, ORNL
Installation Date:	July 25, 2002
Conductor Installed	ACCR 477
Length of line:	1,200 feet (365.7 meters)- 4 spans
Conductor diameter	0.858 inch, (21.8 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 and accessories

Hardware

Suspension Hardware	Preformed Line Product, THERMOLIGN^R Suspensions TLS-0101-SE
Termination hardware	PLP THERMOLIGN^R Dead End TLDE-0104 Alcoa Compression dead end B9085-A PLP THERMOLIGN^R Splice TLSP-0104 Alcoa compression splice B9095-A Alcoa terminal connector B9102-A
Dampers	Alcoa Stockbridge dampers 1704-7
Insulator type	Polymer

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 1,400 amps

- Conductor temperature (surface and core)
- Sag temperature from 0^{o}C – 240^{o}C
- Accessory temperature profile during thermal cycling
- Conductor and accessory strength after thermal cycling
- Measured vs predicted thermal rating

Acknowledgement:

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Abstract:

Under DOE funding Agreement No. DE-FC02-02CH11111, ORNL jointly with The Tennessee Valley Group, TVA, successfully installed the ACCR 477 conductor on a high temperature test line at ORNL in July 2002. The test line consists of two 600 foot spans; two on the road side and two on the tree side between a steel suspension pole and two guyed, dual steel pole dead-end poles. The test conductor forms a loop connected to a DC power supply located at one end of the line, therefore a total of 2400 feet of conductor was tested.

The conductor was installed with commercial hardware developed for ACCR conductors. 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 and extended high temperature load using 400 V DC and about 1200 amps depending on weather conditions. The conductor was thermally cycled from May 2003 to October 2003 between ambient and over 200^0 C for 200 hours. The conductor experienced over 100 cycles to elevated temperature. During the course of the cycling, conductor tension and temperature were monitored. The measured conductor tension - temperature response agreed with predictive models.

Predicted conductor current, using IEEE thermal rating ampacity method, agrees well with measured values. Conductor's emissivity of 0.347 was measured using IR method and used in the IEEE conductor- rating model.

Conductor and accessories were taken down from the line after thermal cycling and tested. The results showed that mechanical and electrical properties of the conductor and accessories were unchanged.

1- Background

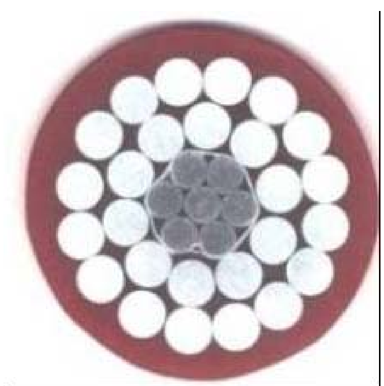
Reliable high temperature performance is one of the key requirements for implementing new high temperature-low sag conductors. It is imperative to demonstrate in the field that the conductor and accessories can operate as predicted at high-temperature, under thermal cycling and without degradation. It is also important to demonstrate that the sag-temperature-current characteristics can be predicted after repeated thermal cycles. High-temperature exposure and thermal cycling of the conductor and accessories can be achieved on a test line that operates at low voltage with a controlled current. Such a test line is able to simulate lifetime field conditions in three months by applying dozens of emergency cycles where the conductor temperature exceeds the normal operating temperature of 210^{o}C, *(410^{o}F)* and where the line is exposed to a range of wind speeds, directions, and tension.

ORNL built a fully instrumented low-voltage test line to evaluate the high-temperature operation of ACCR conductors. The instrumentation includes mechanical tension, full weather station with anemometer, voltage, current, laser sensor to measure sag, and temperature thermocouples in multiple locations in the conductor and in all accessories, Figure 1.

This report summarizes the ACCR 477 conductor installation, testing and analysis at ORNL as well as post thermal cycling evaluation.

Aerial view of the line

Towers



Conductor cross section

Figure 1- View of the ORNL test line and conductor cross-section

2- Installation and Conductor Stringing

2-1 Overview

A four 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 2, 600 feet (183 meters) spans between a steel suspension pole and two guyed dual steel dead end poles. The test conductor forms a loop over two spans connected to a DC power supply located at one end of the line. Thermocouples were installed along the test conductor and on the dead ends, suspensions and splices to measure the temperature of these components during and after periods of high temperature operation.

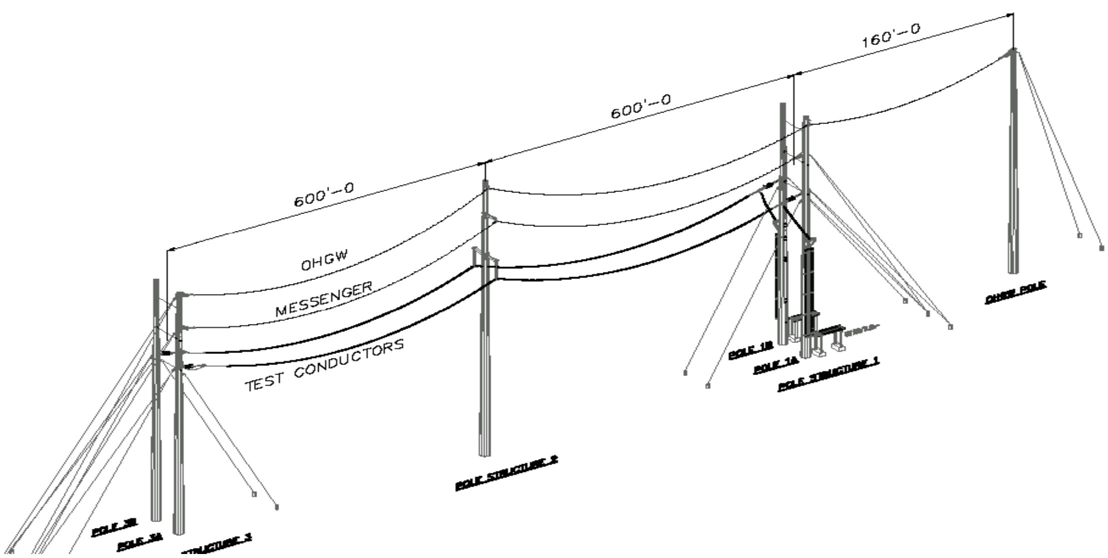


Figure 2- Line layout and CAT-1 system

2-2 Installation details:

The installation of the 477 ACCR follows the IEEE 524 installation guideline for overhead transmission conductors. The only conductor stringing method recommended is the tension method. It is important that bending of the composite conductor during installation be carefully planned to avoid damaging the composite core. The combination of bending and tension could damage the conductor if it exceeds the allowable core strength. Therefore stringing blocks and bull wheels were selected to keep the stringing loads below the conductor core strength. The crew used 28” diameter stringing blocks and 36” diameter bull wheels diameter to meet such criteria; Table 2. Lined blocks are recommended for use with ACCR. Cable spools around which the conductor is wrapped must have 40” diameter to avoid core damage. Other installation procedure and hardware used were very similar to that used for ACSR. PLP DG- Grips were used to pull the conductor to sag and to install full tension splices.

Sagging procedures of ACCR conductor are very similar to that of ACSR. During installations of this type of conductor, a dynometer was used to verify the final sag tensions of the conductor. By using a chain hoist and a dynometer between a temporary conductor grip and the tower structure, the final sag tension was set. Sufficient length of conductor was provided to install the permanent Alcoa dead end. The conductor grip was placed on the conductor at least 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. With the initial placement of the conductor grip at 12 to 15 feet, this allowed enough slack in the conductor to maneuver it and apply the dead end assembly.

Table 1- Installation Equipment and Procedure

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- Conductor stringing

Figure 4- Sagging with chain hoist and dynometer

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 one-minute intervals. Conductor tension was measured by the CAT-1 load cells, see Figure 5. The CAT-1 system 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 1minute rate for all channels.

The CAT-1 main unit is in a NEMA-enclosed, solar powered, data acquisition and processing unit. Net Radiation Temperature, (NRT), was measured by the net radiation sensor, (NRS).

5-a Load cell to monitor tension

5-b CAT1 system

5-c Net radiation sensor, Measures no - load conductor temperature and solar radiation

Figure 5 CAT 1 System hardware

2- 4 Conductor and Accessories Temperature Measurements:

Temperature was measured using thermocouples mounted at various locations along the span, including ones directly touching the composite core and the conductor surface. Additional thermocouples were mounted on all accessories.

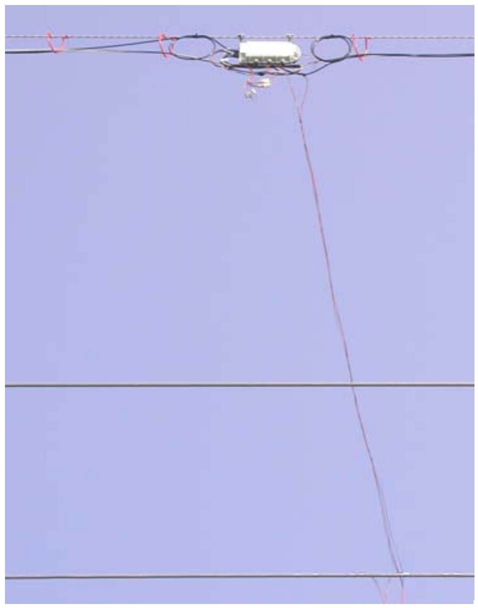


Figure 6- Thermocouple enclosure

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 COYOTE^{R} RUN T 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. The circuitry needed for controlling the 2MW power supply via software and analog to digital modules was built and installed. Also, a lower panel was added to permit remote control (in the instrumentation trailer) of the power supply's reset, contactor, and DC circuit. Previously, these were manually controlled at the power supply trailer only.

The power supply has a dual rating of 400 Vdc and 5000 amps or 600 Vdc and 3750 amps. The input voltage to the power supply is 4160 V, 3-phase. A dry-type ABB transformer is used to step down the voltage from a 13.8 KV distribution line.

2-6 Accessories:

Two types of full tension connectors were installed; a compression type made by Alcoa and a formed wire type made by Preformed Line Products, see Figures 7 to 9. The following is a list of all the accessories:

- Two ALCOA compression dead ends; part # B9085-A; those dead ends consist of both direct core gripping parts and conductor gripping sleeve.
- One ALCOA full tension splice part# B9095-A; it has the same design as the dead end for direct core gripping..
- Two THERMOLIGN^R PLP Suspensions, part # TLS-0101-SE
- Two PLP THERMOLIGN^R Dead Ends, part# TLDE-0104.
- One PLP THERMOLIGN^R Splice, Part #TLSP-0104.
- Six Alcoa all aluminum terminal connectors; Part# B9102-A
- Four Alcoa Stockbridge dampers; part # 1704-7.

Figure 7- THERMOLIGN^R Suspension

Figure 8- Installation of Alcoa compression splice.

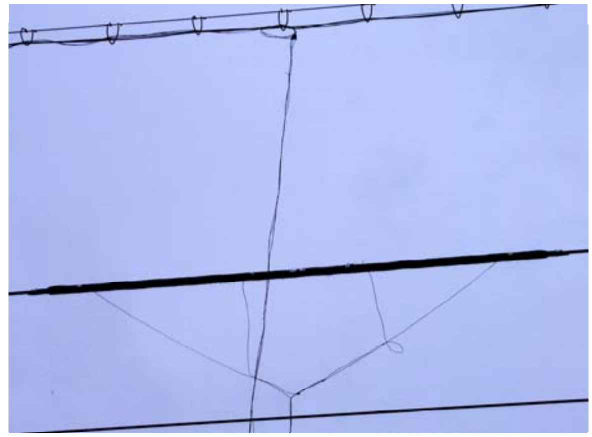


Figure 9- Installed PLP THERMOLIGN[R] Splice

3- Thermal Cycles and High Temperature Exposure:

The 477 conductor was thermally cycled from May 2003 to October 2003 between ambient and over 200^0 C for more than 200 hours under a wide range of weather and load conditions, Table 2. Figure 10 shows the composite conductor core temperature during a typical thermal cycle in temperature control. The temperature is maintained at 210-240 C by controlling the current from 1000 amps to 1200 amps while the wind fluctuates between 0 fpm and 15 fpm.

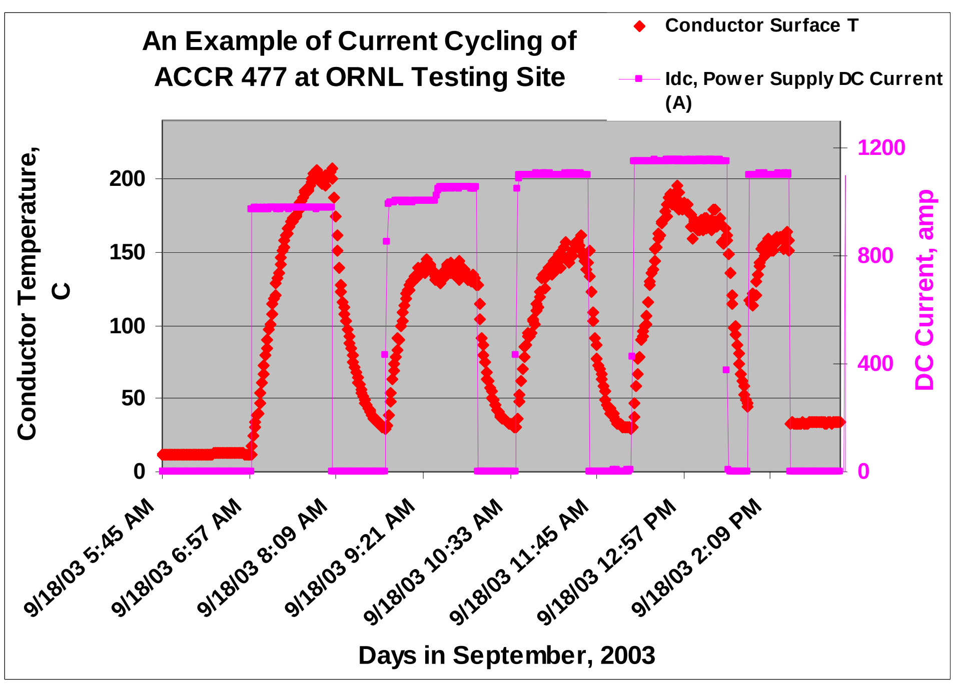


Figure 10- shows an example of thermal cycling in one day at ORNL test line

Table 2- Summary of Thermal Cycling of ACCR 477 at High Temperature

Date	#Cycles Per day	Total Cycles	Hours Per day	Total Run Hours	Nature of cycle	Maximum Current, amp
5/1/2003	1	1	10	10	Current controlled	1295
5/2/2003	1	2	7	17	Current controlled	992
6/2/2003	1	3	12.5	29.5	Current controlled	1177
6/4/2003	0	3	11	40.5	Current controlled	1060
6/5/2003	0	3	3	43.5	Current controlled	1053
6/9/2003	0	3	12	55.5	Current controlled	1057
6/10/2003	0	3	11.5	67	Current controlled	1031
8/27/2003	1	4	2.5	69.5	Current controlled	975
9/8/2003	5	9	5	74.5	Current controlled	1033
9/11/2003	5	14	10	79.5	Current controlled	1057
9/16/2003	4	18	14	83.5	Current controlled	1052
9/17/2003	7	25	21	90.5	Current controlled	1102
9/18/2003	5	30	26	95.5	Current controlled	1153
9/19/2003	8	38	34	103.5	Current controlled	1126
9/23/2003	8	46	42	111.5	Current controlled	1152
9/24/2003	7	53	49	118.5	Current controlled	1153
9/25/2003	8	61	57	126.5	Current controlled	1201
9/26/2003	8	69	65	134.5	Current controlled	1191
9/29/2003	8	77	73	142.5	Current controlled	1292
9/30/2003	7	84	80	149.5	Current controlled	1290
10/1/2003	4	88	84	153.5	Current controlled	1275
10/2/2003	8	96	92	161.5	Current controlled	1291
10/3/2003	8	104	100	169.5	Current controlled	1401
10/7/2003	1	105	(7hours/100 C)	176.5	Current controlled	861
10/13/2003	1	106	10	10	Temperature controlled	1172
10/14/2003	1	107	5	15	Temperature controlled	1370
10/15/2003	1	108	10	25	Temperature controlled	1236
10/16/2003	1	109	10	35	Temperature controlled	1256
10/17/2003	1	110	10	45	Temperature controlled	1114
10/18/2003	1	111	10	55	Temperature controlled	1225
10/21/2003	1	112	8	63	Temperature controlled	1311
10/22/2003	1	113	9	72	Temperature controlled	1288
10/23/2003	1	114	6	78	Temperature controlled	1201
10/24/2003	1	115	10	88	Temperature controlled	1213
10/27/2003	1	116	6	94	Temperature controlled	1225
10/28/2003	1	117	6	100	Temperature controlled	1214

Thermocouples were installed along the length of the conductor in two different spans and at different radial positions going from the conductor surface to contacting the composite core, Figure 11. The thermocouples indicated that there were significant temperature differences along the axial location and moderate gradients along the radial position.

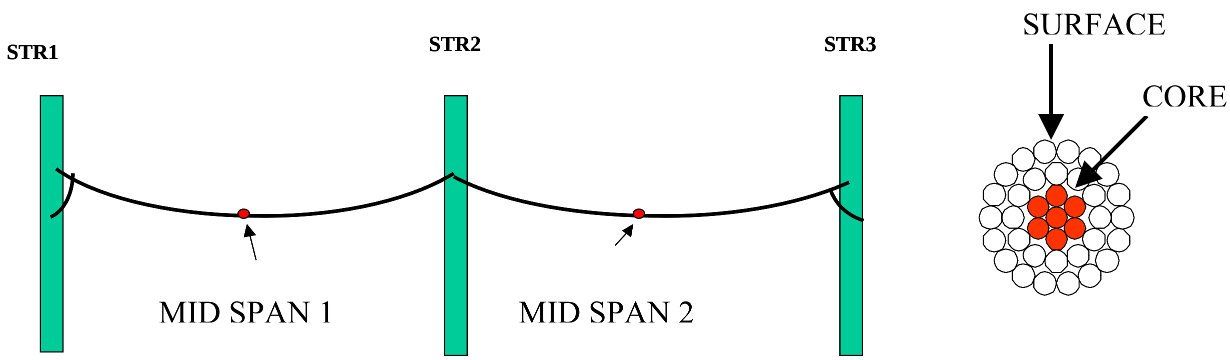


Figure 11- Thermocouples were positioned along the length and in different radial positions.

The radial gradient, when the conductor was above 200°C, was measured to fluctuate between 2°C and 15°C. In average, the radial gradient was about 8°C when the conductor was at 200°C, Figure 12a. Variation in wind speed and direction affected the magnitude of the radial gradient with greater wind speeds causing a larger gradient.

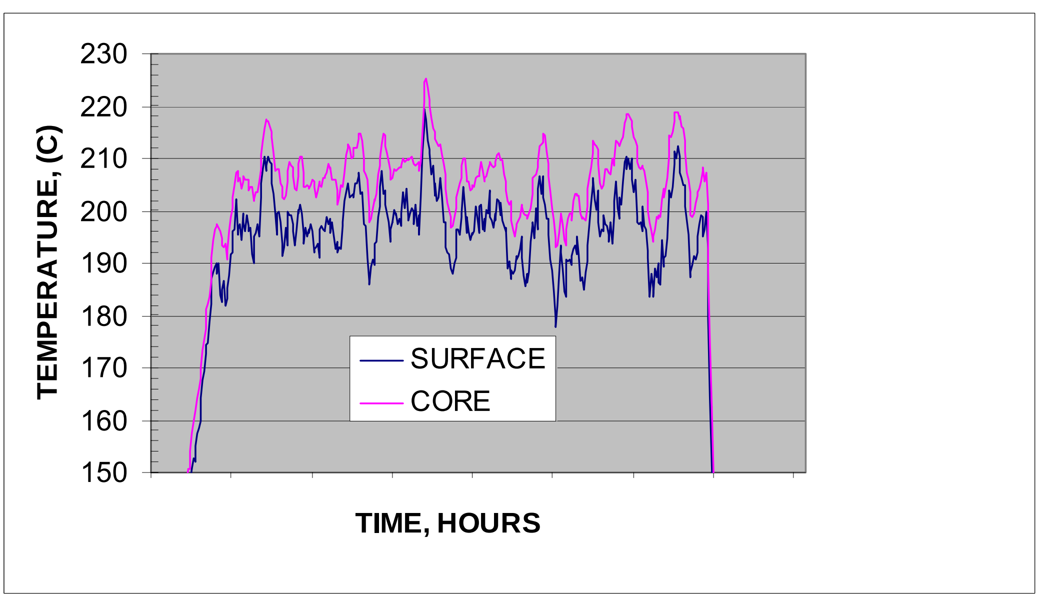


Figure 12- a- Temperature difference between conductor surface and core at mid span

Temperature fluctuation along the length of the conductor varied between 5°C to 50°C depending on wind conditions. Span 2 was more sheltered by trees than span1 and consistently experienced higher temperatures. The difference between span 1 and 2 was in average about 20°C when the conductor was above 200°C, Figure 12b. In some cycles the difference between span 2 and 1 was as high as 50°C for a short period of time. As a result the maximum temperature in span 2 reached as high as 270°C when the average temperature was at about 230°C.

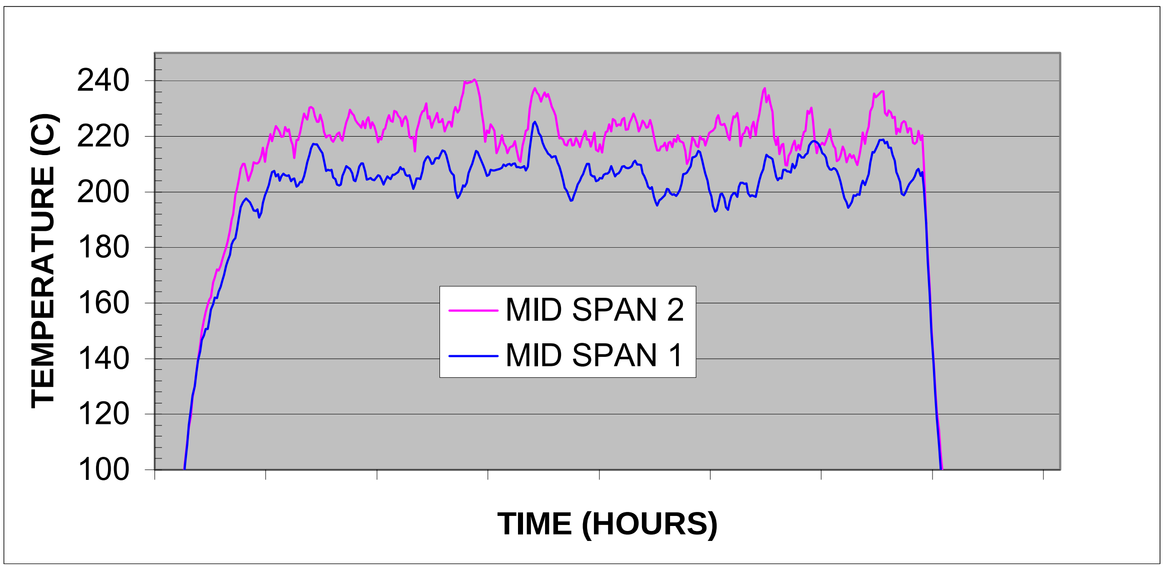


Figure 12- b An example of temperature difference along the conductor length.

4- Measured and Predicted Line Tension and Sag:

Sag was computed using the Strain Summation Method (which accounts for the full loading history) and the Graphic Method (Alcoa SAG-10). The main events, which cause permanent- elongation, were included (creep, low temperatures).

The calculated and measured tension and sag values are plotted in Figures 13 to 16 as a function of both conductor core and surface temperatures. The knee-point measured at about 80° C matches the prediction. It confirms the validity of the stress-strain, creep properties and thermo-elastic behavior of the conductor.

Figure 13 shows good agreement between measured and predicted tension in the range of 0^0 C and 250^0 C. The measured line tension lies in between values predicted using either the strain summation method or the graphic one. The predictions assumed a compressive stress of –1.45 Ksi in the aluminum after the knee point. The "October 28th" cycle was the last of over 100 cycles after the conductor experienced over 200 hours of high temperature exposure. It shows that the tension response remained predictable and stable after long thermal exposure and numerous cycles.

There is a small hysteresis observed between the heating and cooling cycles mostly due to variation in conductor temperature along the length of the line, and wire settling when passing through the knee point.

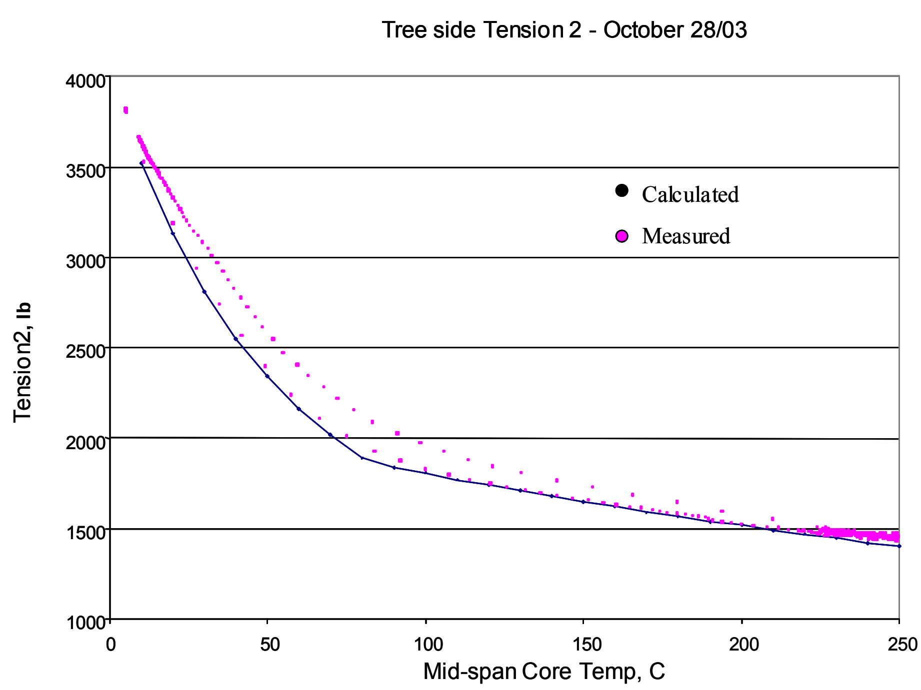


Figure 13- Good agreement between calculated and measured tension for the last cycle on October 28,2003. The Strain Summation method was used with a 1.45 ksi compressive stress.

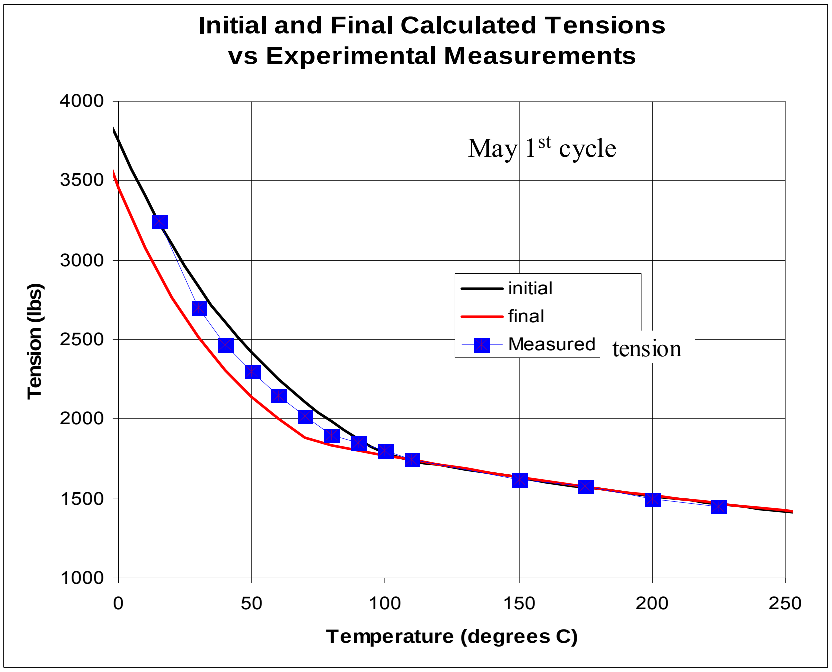


Figure 14- Initial and final tensions calculated using the SAG- 10™ with 10 MPa (1.45 Ksi) compressive stress agree well with CAT-1 measured values.

Figure 13 shows the last high temperature cycle and Figure 14 shows both the first and last cycle. The measured conductor response was accurately predicted with the models using a –1.45 Ksi stress after the knee point.

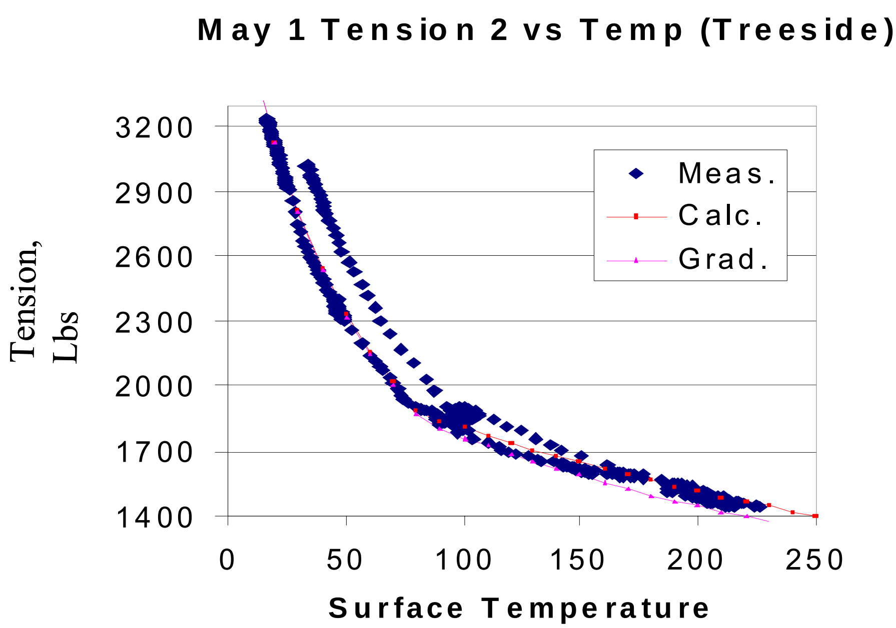


Figure 15- Measured vs. calculated tension, using the Strain Summation method, as a function of conductor temperature.

Figure 16 shows the tree-side line sag vs. conductor core temperature. The sag was directly measured at the mid- span with a laser monitor. The sag measurements agree with those calculated from tension within 0.2 feet.

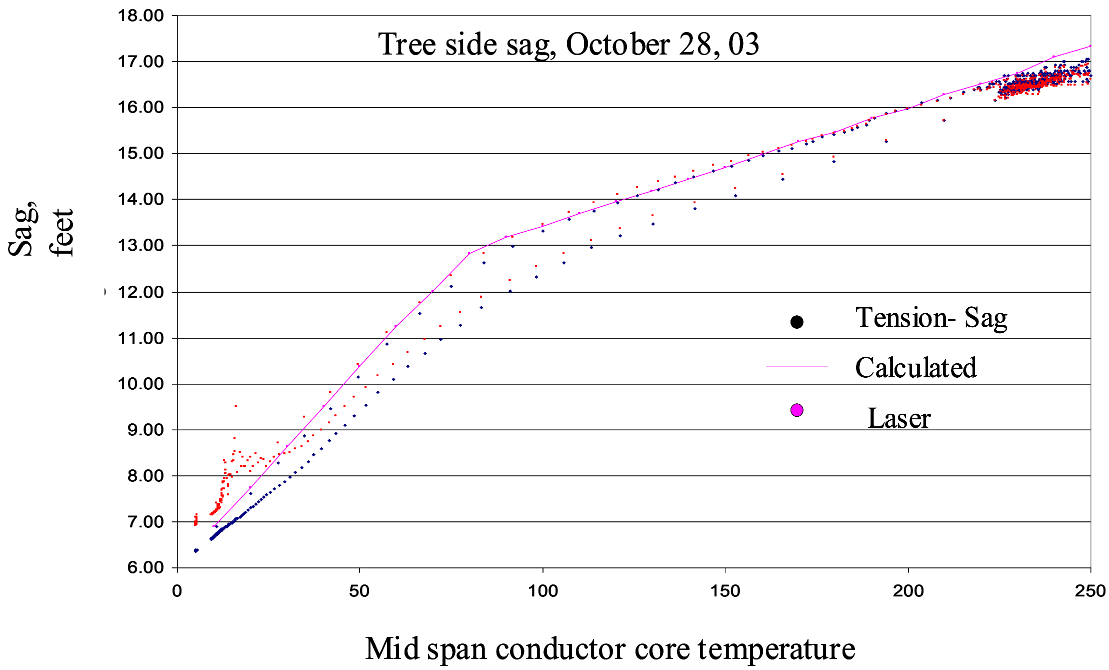


Figure 16- Measured Sags Compared with Those Calculated from Tension.

Summary:

Predicted sag agrees well with measured values in the range of 0^0 C to 250^0 C. The sag remained predictable after thermal cycling and long exposure to high temperature. There has been virtually no creep.

5- Accessories Response at High Temperature:

The accessories performed well during conductor thermal cycling and high temperature exposure; overall their maximum temperature was less than 120^0 C.

5-1 PLP Accessories:

Figure 17 shows that the inner reinforcing rods in the Thermolign^{R} Suspension had the highest temperature rise while the external housing had the lowest temperature rise, the neoprene insert did not see temperature higher than 100^{0} C.

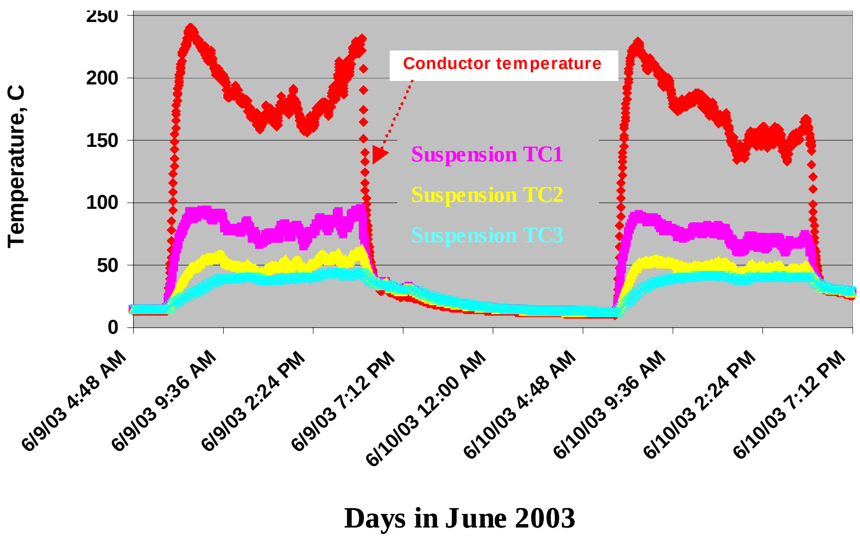


Figure 17- a shows the PLP THERMOLIGN^{R} suspension running at temperature < 100^{0} C when conductor was thermal cycled to above 200^{0} C

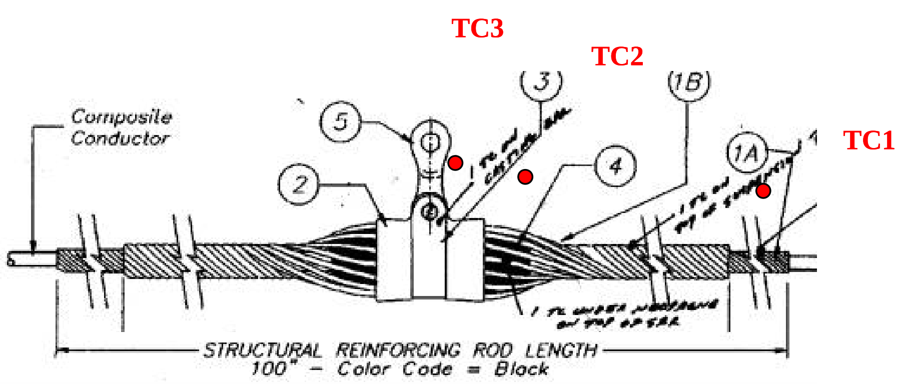


Figure 17-b PLP THERMOLIGN^{R} Suspension System thermocouples location (3 locations, TC1, 2 and 3) during current cycling.

The PLP THERMOLIGN^{R} dead end temperature profile along its length (6 locations- marked in red circles in Figure 18 shows a much lower temperature than that of the conductor, Figure 19. The inner rods maximum temperature was about 90^{0} C while the outer rods never exceeded 75^{0} C, Figure 20.

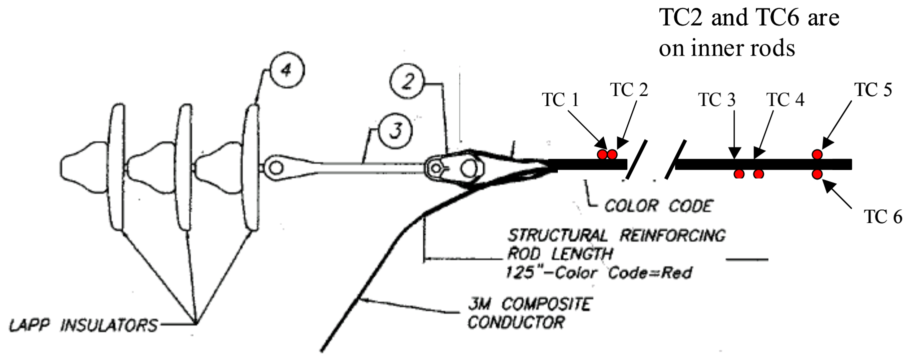


Figure 18-a- Location of thermocouples in red, TC's, on PLP THERMOLIGN[R] dead end

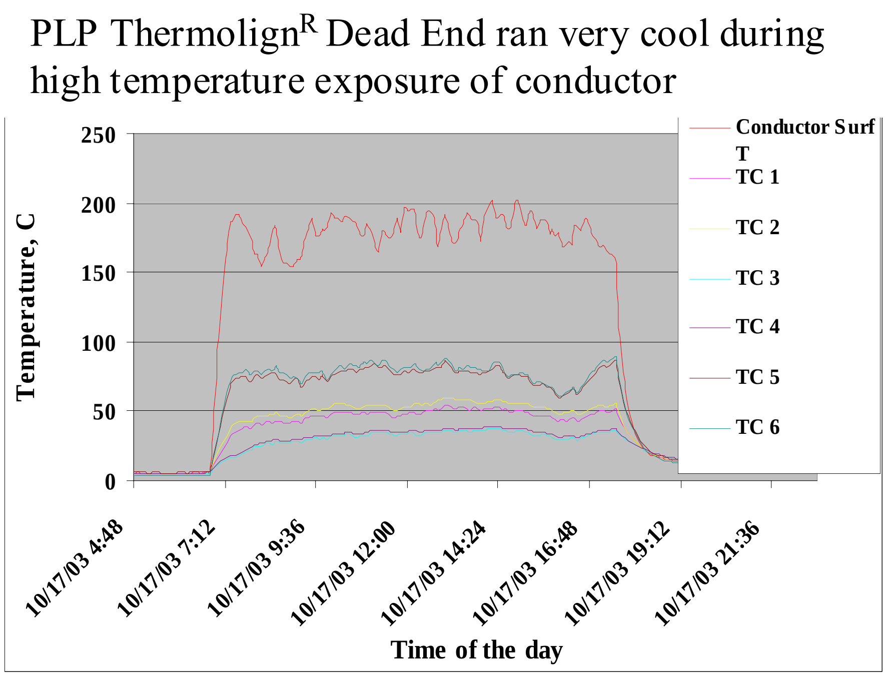


Figure 18-b An example of PLP THERMOLIGN[R] Dead End temperature profile thermal cycling of conductor to 200^0 C.

The PLP THERMOLIGN[R] Splice temperature was monitored at 4 locations on both the inner stiffening rod and the outer one (Figure 19). The inner rod temperatures (PS1, 2) were slightly higher than those measured on the outer one- rod (PS3) and the inner center of the splice (PS4) where conductor segments come together (because of its proximity to the conductor); both splice rods ran cool (Figure 19).

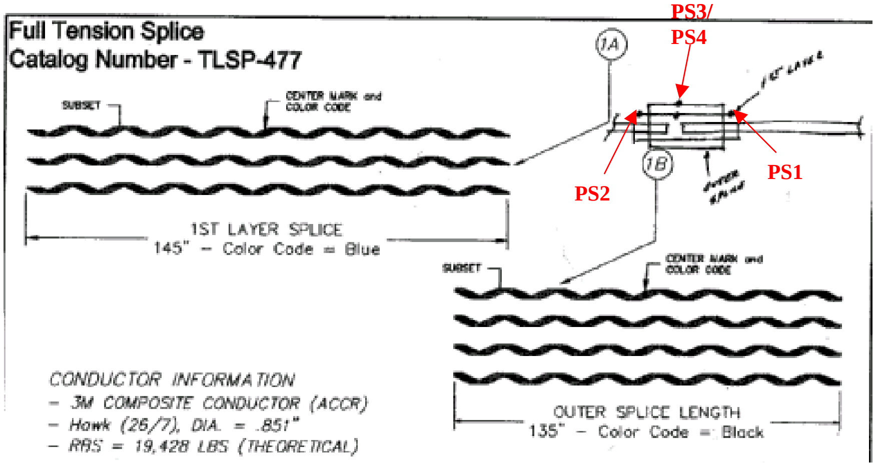


Figure 19- a- Thermocouple locations for temperature measurement of splice inner and outer rods.

PLP THERMOLIGN^R splice shows temperature gradient between inner and outer rods as shown in figure 19-b; two thermocouples were mounted on each rod.. Both rods ran much cooler than conductor, well below 100^0 C.

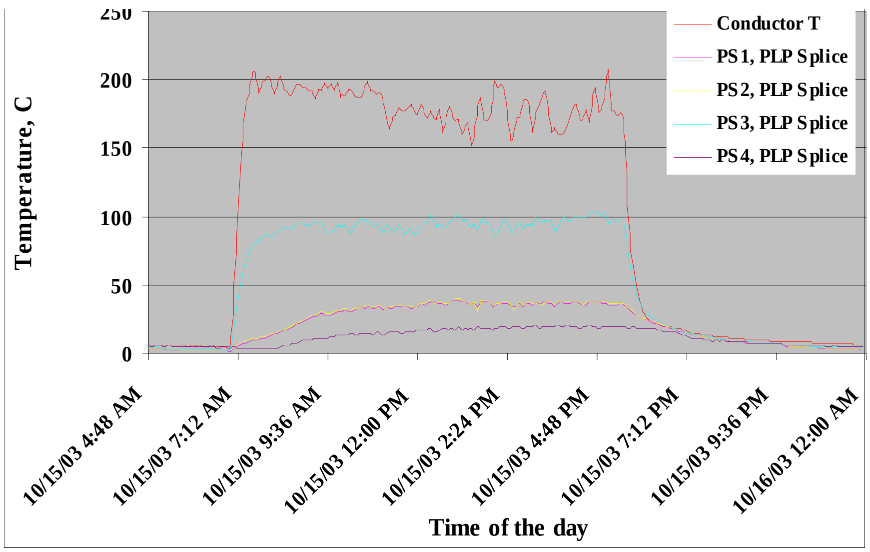


Figure 19-b An example of a single thermal cycle showing the PLP THERMOLIGN^R splice running very cool, temperature < 100^0 C when conductor was around 200^0 C.

To summarize all PLP accessories (dead end, splice and suspension) behaved normally during high temperature exposure of the ACCR 477 conductor, their maximum surface temperature was at or below 100^0 C.

5-2 AFL Telecommunications (Formerly Alcoa) Accessories:

Both AFL splices, dead end and terminal connector ran well below 100^0 C when conductor temperature was above 200^0 C as recorded by numerous thermocouples (five on dead ends, two on terminal connector and five on splice). Accessories temperature near the tapered mouth close to conductor was higher than at other locations but below 100^0 C (see Figures 20 to 22).

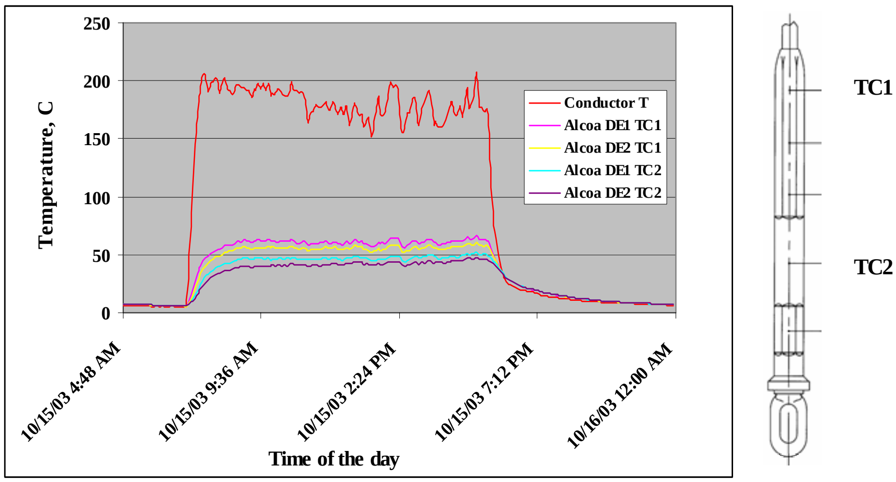


Figure 20- AFL compression dead ends temperature was below 70^0 C when conductor temperature was greater than 200^0 C

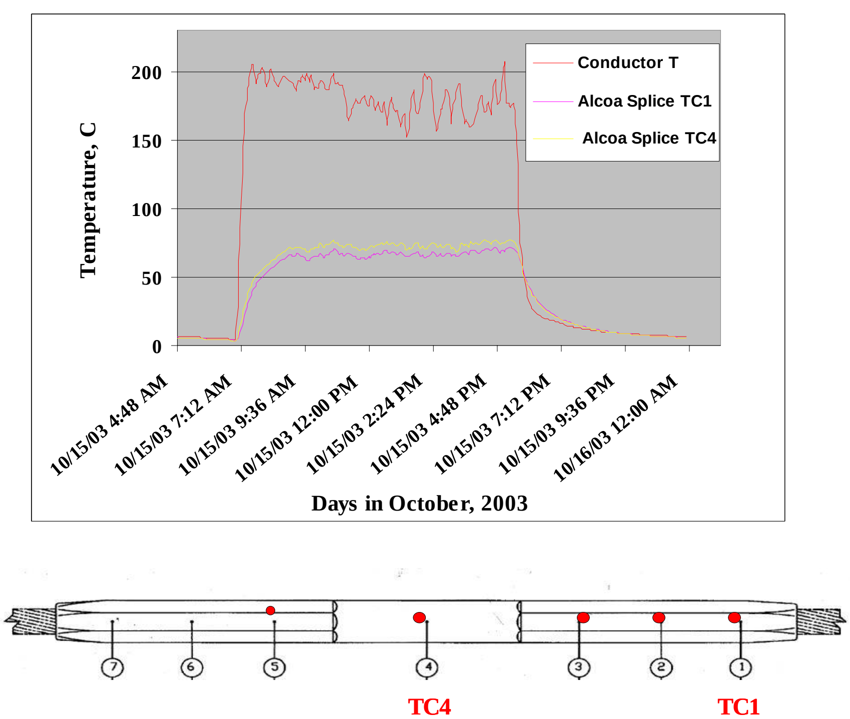


Figure 21 AFL Splice temperature during conductor cycling at around 200^0 C- Splice remained cool never exceeded 80^0 C

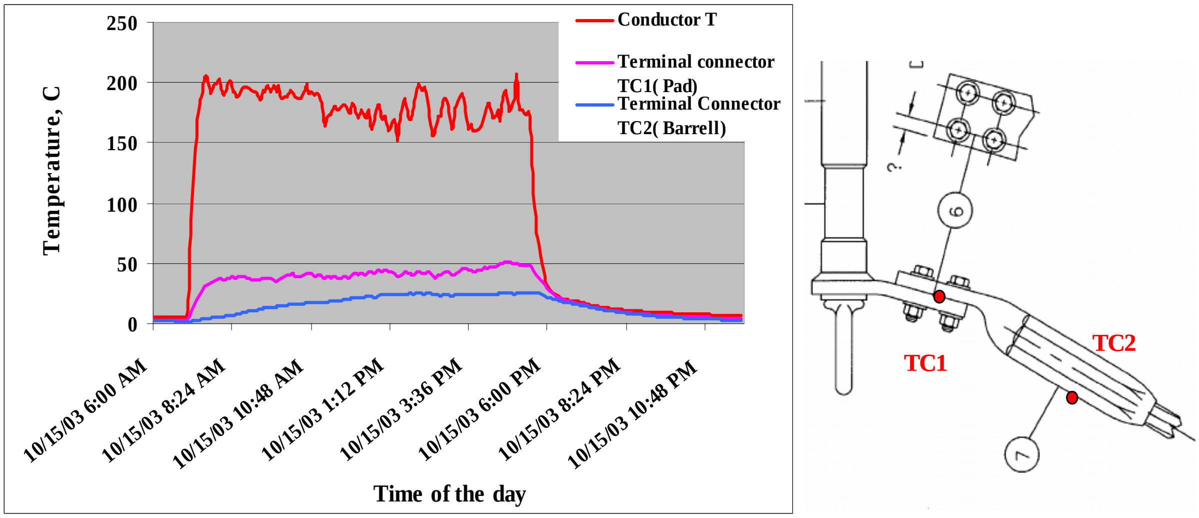


Figure 22- AFL compression terminal connector temperature less than 50 C when conductor temperature was greater than 200 ^{0}C

7- Ampacity and Thermal Rating of Conductor

The steady state version of the IEEE STD 738-1993 “Standard for Calculating the Current Temperature Relationship of Bare Overhead Conductors” was used to predict conductor current during thermal cycling. The model balances resistive losses, solar heating, convective and radiative heat losses. The data for current, wind speed and direction was used in the model; wind speed and direction were averaged over 60 minutes interval. Conductor emissivity ε = 0.347 was measured by ORNL using IR method. Both Figure 23 and table 3 show measured and predicted current. Table 4 lists values of parameters used in the model

Table 3 - Ampacity Rating Conditions and Data

Conductor temperature, C	Ambient Temperature, C	Wind speed, f/s	Wind angle, degrees	Measured Current. Amp	Computed current, amp
196	14	5	3	1004	1011
145	16	7	9	981	1011
119	18	8	9	994	978
162	20	9	9	1098	1120
223	25	4	19	1135	1160
162	26	4	20	986	1015
203	17	4	13	1050	1065
164	20	6	15	1050	1078
169	27	5	22	1047	1076
233	15	0	27	1049	1063
174	26	4	24	1050	1075
222	19	0	23	1025	1029
186	25	3	18	1025	1008
235	19	0	9	1024	1057
157	30	8	10	999	1032

Conductor temperature was used as input to the model along with other variables of Table 4. The agreement between model and measurements is good.

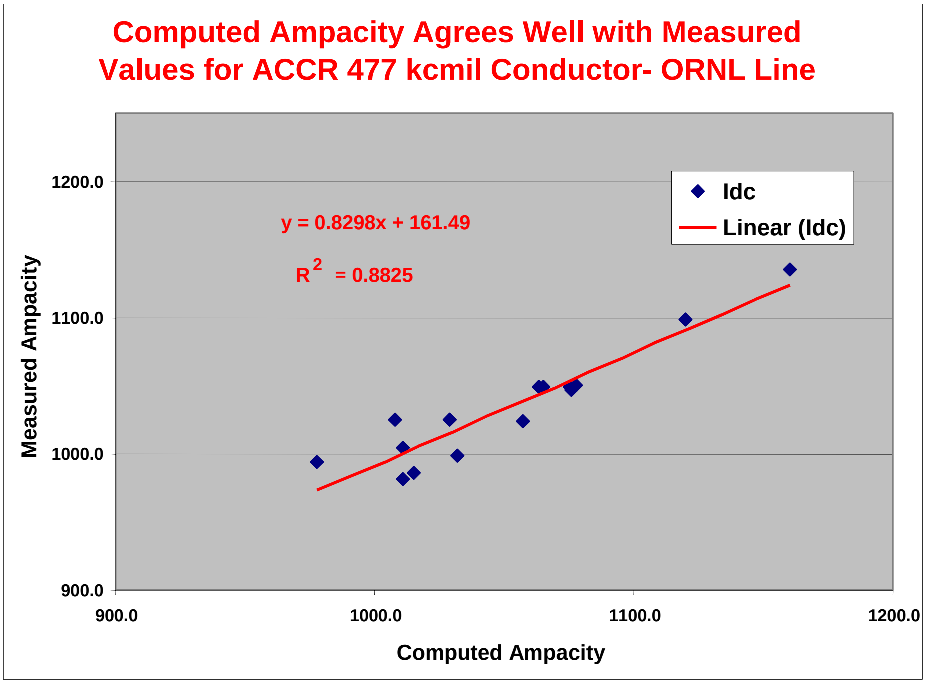


Figure 23- Predicted *vs.* Measured Steady State conductor current / rating

Emissivity		0.35
Solar Absorbtion		0.50
Conductor Elevation	ft above sea level	800.00
latitude	degrees	30.00
Zc		180.00
Sun Altitude	degrees	54.00
Theta	radians	1.57
density air	lb/ft^3	0.0765
Absolute Viscosity Air	lb/h-ft	0.0433
Thermal Conductivity Air	W/ft.degreeC	0.01

In summary the IEEE model predicted conductor current agrees reasonably well with that measured during thermal cycling at ORNL test line. The ACCR 477 conductor was rated at 1169 amps for continuous operation at 210^0 C and 1266 amps for emergency at 240^0 C using the model and 40^0 C ambient temperature, 2 f/s wind speed, emissivity & solar absorption of 0.5 at Sea Level. Thermal cycling history reported in Table 2 shows that the conductor was exposed to a maximum current in excess of 1350 amps without any degradation or damage, see Section 8 for details.

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).

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 results show that 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 5- Conductor test data

Sample	Breaking load, Lbs	% RBS	Failure Mode
04114T1	20,710	106	All strands fractured in the gage section
04114T2	19,860	102	All strands fractured in the resin fitting
04114T3	20,800	107	All strands fractured at the resin fitting

Stress- Strain-conductor	20,350	104	Mid span break, all strands failed
Stress Strain-Core	12,910	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 24 to 26.

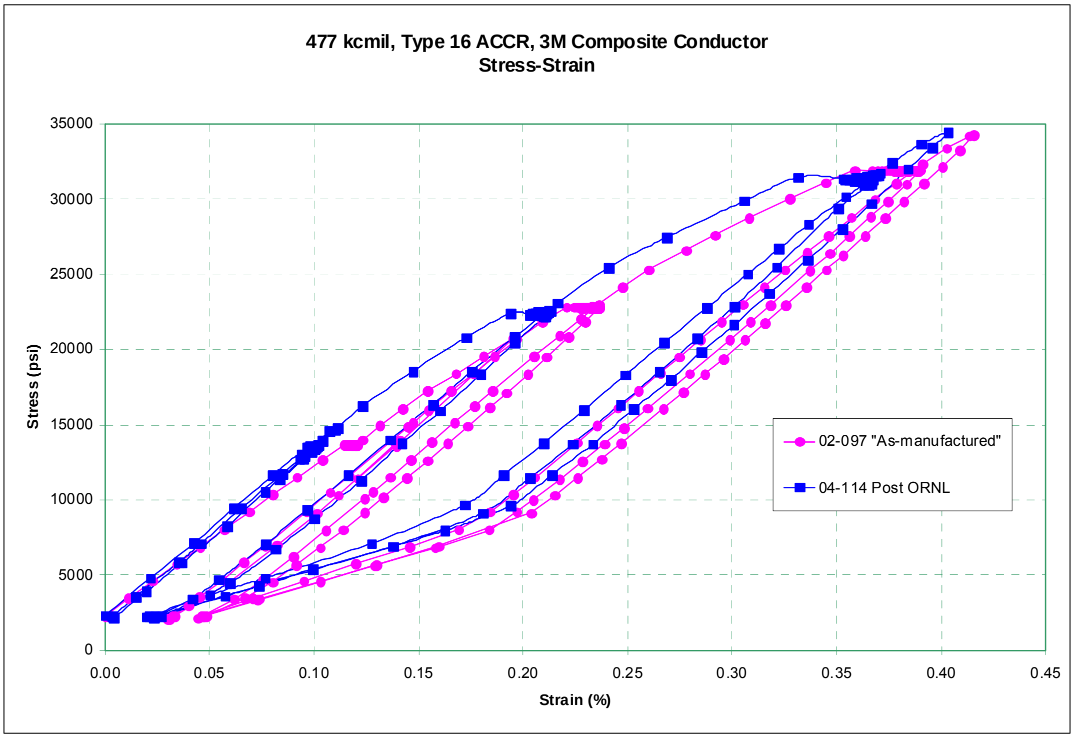


Figure 24- Plot of raw core stress-strain data recorded during conductor stress-strain test (blue),

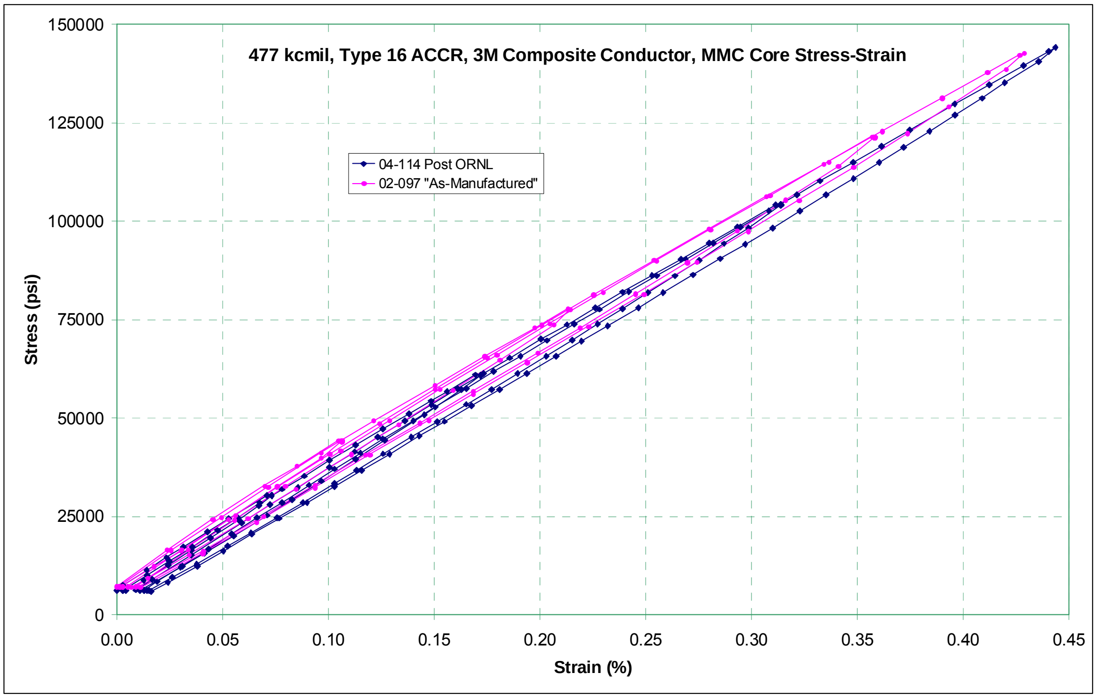


Figure 25- Core stress-strain shows essentially no change due to field test

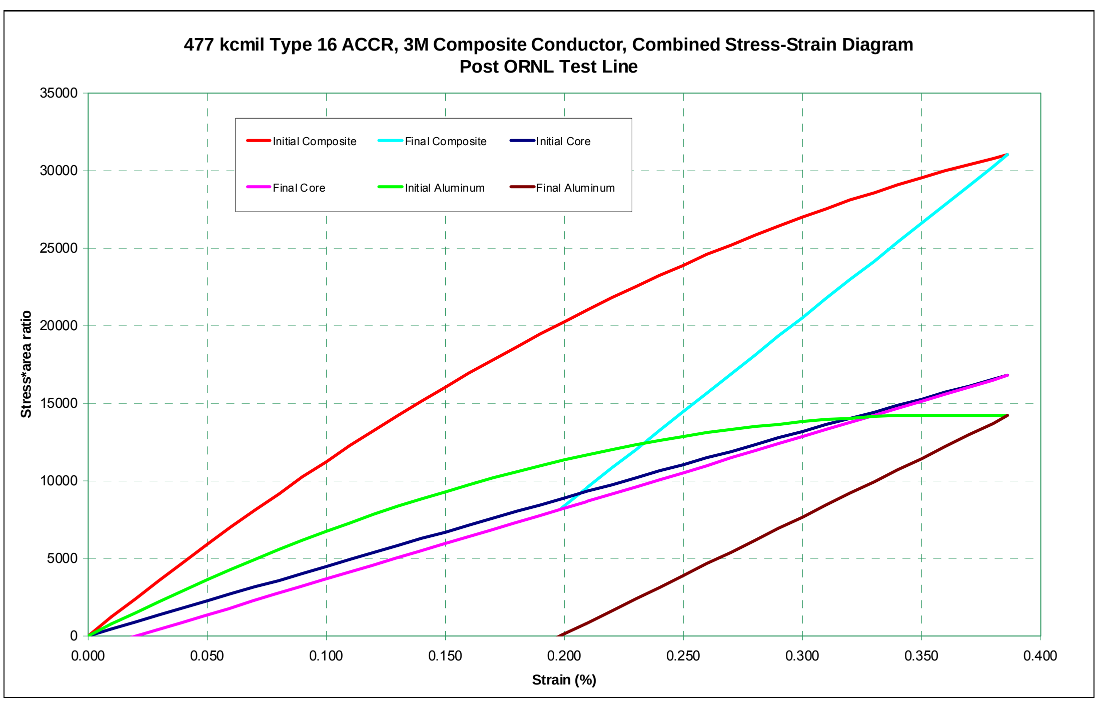


Figure 26- Combined stress- strain plot

8-3 Conductor resistance test:

Welded equalizers were installed at each end of a 19-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 the sample was electrically isolated (see Figure 27).

Figure 27- Resistance measuring set up and sample

Resistance of a 19 ft test section was measured. Readings were repeated later in the day as noted below. The average of all readings is 0.1834 Ω/mile at 20° C. The published value is 0.1832 Ω/mile at 20° C, very close to the measured value.

8-4 Connector tensile tests:

8-4-1 Alcoa compression accessories

Two dead-ends 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. Dead ends maintained their load carrying capability of 100% RBS or more (see Table 6 and Figure 28).

Table 6- Connector tensile tests

Sample	Breaking Load, Lbs	% RBS	Failure Mode
04114DE1	20,380	105	All strands fractured ~ 5" inside dead end
04114DE2	19,550	100	All strands fractured ~ 5" inside dead end

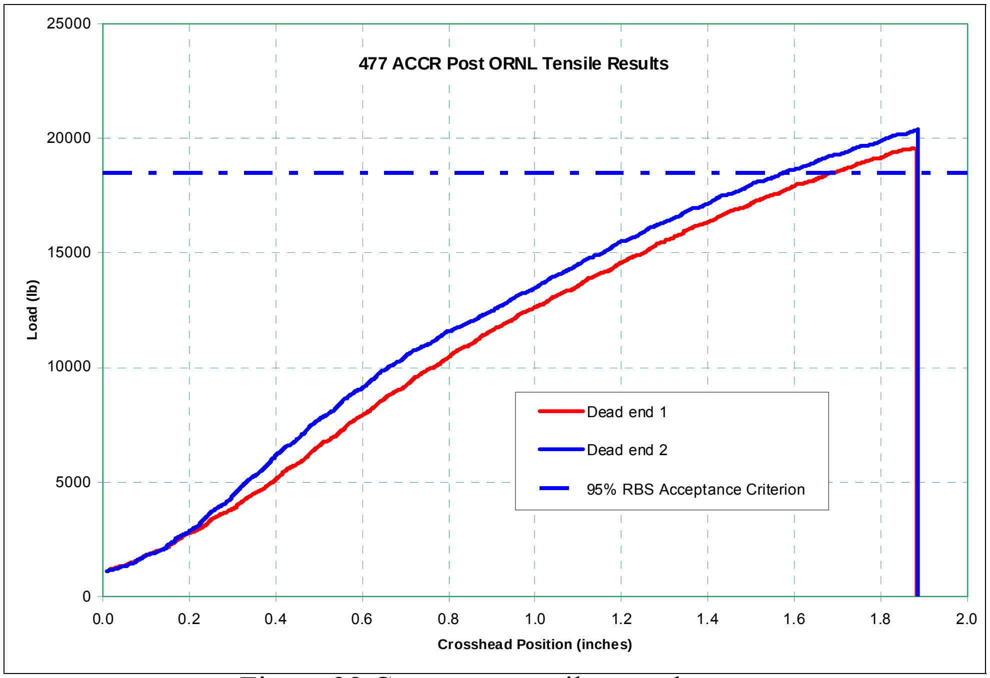


Figure 28 Connector tensile test plots

8-4-2 Alcoa (AFL Telecommunications) Connector Microscopic Examination:

Connector dissection (one dead): A milling machine was used to split the aluminum sleeve and reveal the internal 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. The center cavity was full of oxide inhibitor, and the distribution pattern shows that the injection was done correctly prior to the start of crimping. One discrepancy was noted: There is no evidence that the conductor was wire-brushed prior to splice installation. AFL instructions require wire brushing of the conductor OD only in cases where the connector is installed on weathered conductor. However, most field and lab experience is that failure to wire-brush new conductor can cause premature connector failure.

8-5 PLP Accessories:

The suspension taken down from the ORNL test line after thermal cycling was disassembled and conductor inside the suspension was tested for residual strength. It failed at 19,437 Lbs (100% RBS). The conductor failed 21" from center of suspension. Conductor samples and both the THERMOLIGN^{TM} Splice and Dead End were pulled in tension. Splice/ conductor combination failed at 19428 Lbs (100% RBS) in the conductor within the splice region. Two dead end samples with conductor were pulled to failure; they gave 19,157 Lbs (98% RBS) and 19,817 (102% RBS) Lbs respectively.

9- Summary

ACCR 477 conductor was installed successfully on the ORNL- PCAT line using commercial hardware and normal installation procedures. The conductor and accessories were thermally cycled from ambient to over 200^0C for several hundred hours, using DC power supply and as high current as 1200 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

Conductor Physical Properties		
Designation		477-T16
Stranding		26/7
kcmils	kcmil	477
Diameter		
indiv Core	in	0.105
indiv Al	in	0.135
Core	in	0.32
Total Diameter	in	0.86
Area		
Al	in^2	0.374
Total Area	in^2	0.435
Weight	lbs/linear ft	0.539
Breaking Strength		
Core	lbs	11,632
Aluminum	lbs	7,844
Complete Cable	000's lbs	19,476
Modulus		
Core	msi	31.4
Aluminum	msi	8.0
Complete Cable	msi	11.2
Thermal Elongation		
Core		6
Aluminum		23
Complete Cable		16
Heat Capacity		
Core	W-sec/ft-C	13
Aluminum	W-sec/ft-C	194
Conductor Electrical Properties		
Resistance		
DC @ 20C	ohms/mile	0.1832
AC @ 25C	ohms/mile	0.1875
AC @ 50C	ohms/mile	0.2061
AC @ 75C	ohms/mile	0.2247

10-2 Conductor Resistance Data:

Conductor Resistance

NEETRAC Project No.	04-114		= Data Input Cells
AVO (Biddle) DLRO, Calibration Control #	CQ1097		= Calculated Value
Temperature Indicator (Instrument)	CN3022		
Temperature coefficient for resistance:	0.0036		

Resistance measurement on a 477 ACCR sample from the ORNL test line. Bolted end fitting for equalizer (see photos), pulled to ~200 lbs tension w/a come-a-long

These readings taken manually @ 10/25/04 @ 10:19 AM

Conductor Temperature:	21.8	deg C			
Test Section:	19.000	ft			
Resistance Reading 1	665.1	uOhms	At	21.8	deg C
Resistance Reading 2	665.1	uOhms	At	21.8	deg C
Resistance Reading 3	664.9	uOhms	At	21.8	deg C
Average of 3 Readings	665.03	uOhms	At	21.8	deg C
Ohms/ft:	3.5002E-05	Ohm/ft	At	21.8	deg C
Ohms/ft:	3.4775E-05		At	20.0	deg C
Ohms/mi	0.184809	Ohm/mi	At	21.8	deg C
Ohms/mi @ 20C:	0.183612	Ohm/mi	At	20.0	deg C

These readings taken manually @ 10/25/04 @ 1:24 pm

Conductor Temperature:	21.3	deg C			
Test Section:	19.000	ft			
Resistance Reading 1	663.5	uOhms	At	21.30	deg C
Resistance Reading 2	663.5	uOhms	At	21.30	deg C
Resistance Reading 3	663.5	uOhms	At	21.30	deg C
Average of 3 Readings	663.50	uOhms	At	21.30	deg C
Ohms/ft:	3.4921E-05	Ohm/ft	At	21.30	deg C
Ohms/ft:	3.4695E-05		At	20.00	deg C
Ohms/mi	0.184383	Ohm/mi	At	21.30	deg C
Ohms/mi @ 20C:	0.183188		At	20.00	deg C

Average					
Ohms/mi @ 20C:	**0.18340**		At	20.0	deg C
3M nominal	0.18317	Ohm/mi	At	20.0	deg C

10-4 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. Figures 29 shows the used hardware; the calibrated black body target was multiplied by various emissivity values until a good fit occurs with the conductor received signal (see Figure 30). Such fit yielded an average emissivity value of 0.345 within +- 2% (see Figure 31).

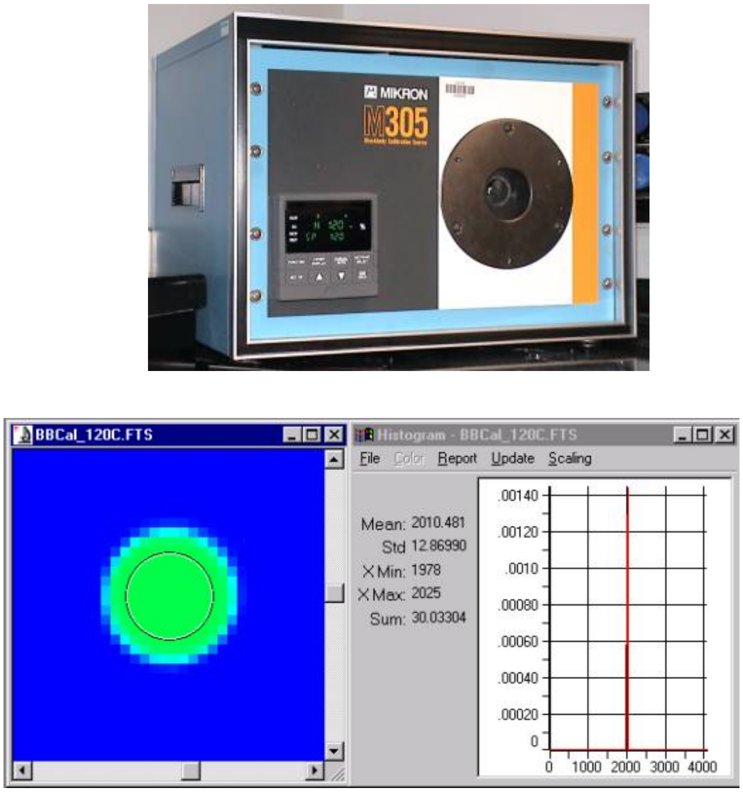


Figure 29- Calibrated IR Camera and Mikron M305 Blackbody calibration source used for measuring emissivity

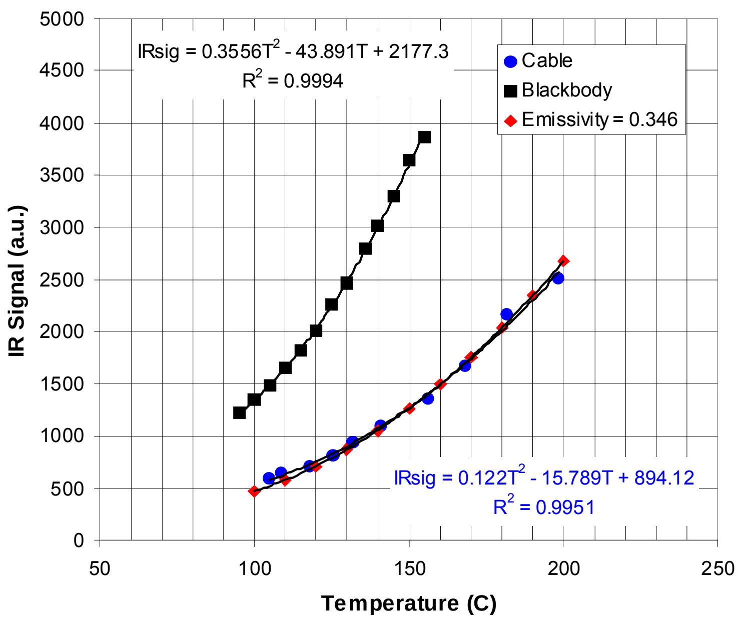


Figure 30- Conductor emissivity of 0.348 was determined using a black body signal matching

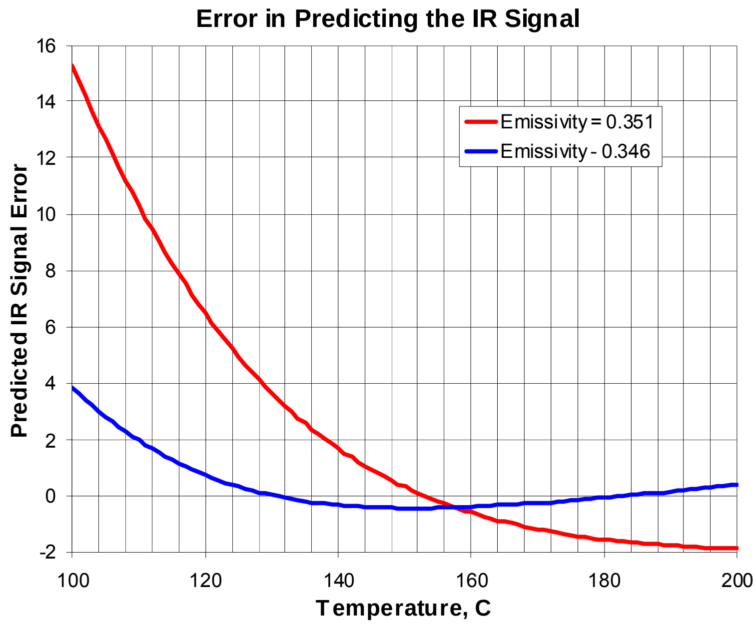


Figure 31- Signal error is < 1% in the temperature range 120 to 200 C with an emissivity value of 0.346