Testing of THERMOLIGN® Full Tension Splice

For

477-kcmil 3M Brand Composite Conductor

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Scope

This report will cover the description and results of laboratory testing of PLP's THERMOLIGN® full Tension Splice and 477-kcmil 3M™ Composite Conductor (also called ACCR – Aluminum Conductor Composite Reinforced) manufactured by 3M.

The specific tests included in this report are:

- Room Temperature Tensile Test
- Sustained Load Test
- Sustained Heat Test
- Splice Temperature Profile
- High Voltage Corona Test
- High Temperature Field Operation and Thermal Cycling

The results for each test are reported separately.

Room Temperature Tensile Test

After completing the design of the Full Tension Splice for the 477 ACCR conductor, a room temperature tensile test was conducted to verify the holding strength. The test sample consisted of a 35 ft (10.7 m) length of 477 ACCR conductor terminated on both ends with PLP Dead-End Assemblies, and cut and spliced at the mid-point with a PLP Splice Assembly.

The PLP Splice Assembly consists of two layers of aluminum alloy rods. The inner layer of rods is directly applied over the ACCR conductors to be spliced (without exposing the conductor's composite core). The outer rods are applied over the inner rods (see test set-up in Figure 1). For the test, the regions around the ends of the rods were painted red to permit inspection for slippage.

The test sample was loaded at a rate of 10,000 lbs per minute in the 55K Tensile Equipment until failure occurred. At a load of 19,231 lbs (99% RBS), the conductor failed between one of the Dead-End Assemblies and the Splice Assembly, but close to the splice (see Figure 2).

Figure 1. THERMOLIGN® Splice Set-up for Tensile Test

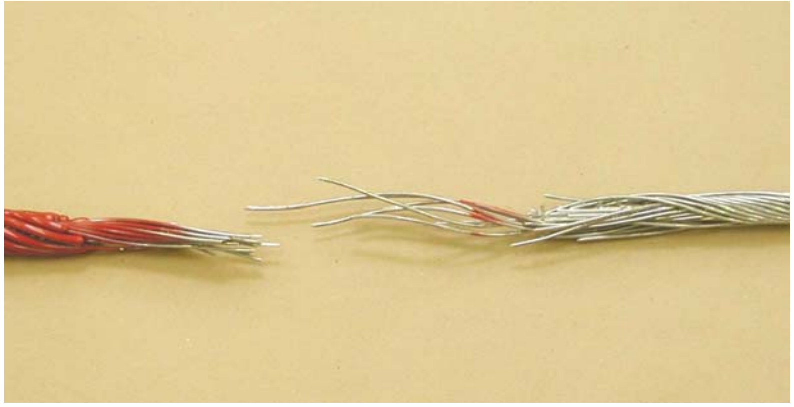

Figure 2. Conductor failure close to the Splice Assembly

Sustained Load Test

The purpose of this test is to determine that the Splice Assembly will hold at a high tension level (77% RBS) at room temperature for an extended period of time (168 continuous hours), per ANSI C119.4.

The test sample consisted of a 51 ft (15.5 m) length of the 477 ACCR conductor terminated on both ends with a PLP Dead-End Assembly, then cut in the middle, after which a PLP Splice Assembly was applied. The tension (14,960 lbs) was maintained throughout the test period with the 55K Tensile Equipment.

The test sample successfully completed the 168 continuous hours, and then was tensioned in the same 55K Tensile Equipment until a failure occurred. The conductor failed between the Splice and the Dead-End at a load of 20,640 lbs (106% RBS).

Sustained Heat Test

The purpose of this test is to demonstrate that the performance of the conductor Splice Assembly will not be affected by continuous conductor operation at an elevated temperature. Specifically, after being exposed to 240C for a period of 168 hours.

The test span consisted of a 65 ft (19.8 m) length of 477 ACCR Conductor, terminated at both ends with a PLP Dead-End Assembly and cut and spliced at mid-span with a PLP Splice Assembly. A tension of 15% RBS (2915 lbs) was maintained throughout the test using a tension beam/weight basket (see Figure 3). The conductor was heated by applying approximately 1,000 Amps of AC current, supplied by a pair of heavy duty power supplies (see Figure 4). Thermo-couples were mounted to the conductor and to locations along one dead-end to monitor temperature.

After completion of the 168 hour test period at 240C, the complete sample was removed from the Heat Test Area and installed in the 55K Tensile Equipment to determine the maximum load at failure.

When loaded at a rate of 10,000 lbs per minute, the conductor broke at mid-span (between one Dead-End and the Splice) at a load of 20,666 lbs (106% RBS). During this test, there was no slippage of or damage to the PLP Dead-End Assemblies or the PLP Splice Assembly. The failure of the conductor is shown in Figure 5.

Figure 3 – Sustained Heat Test Arrangement

Figure 4 – Dual Power Source

Figure 5 – Mid-Span Failure of Conductor

Splice Temperature Profile

The running temperature of the splice was measured in a separate experiment in which a 20ft (6.1 m) length of the spliced conductor, was tensioned to 4870 lbs (25% RBS) and then heated by applying AC current. Thermocouples recorded the temperature on the conductor and at the splice. When the temperature of the conductor reached 195°C, the splice remained cool, with the maximum measured temperature below 50°C (Figure 6).

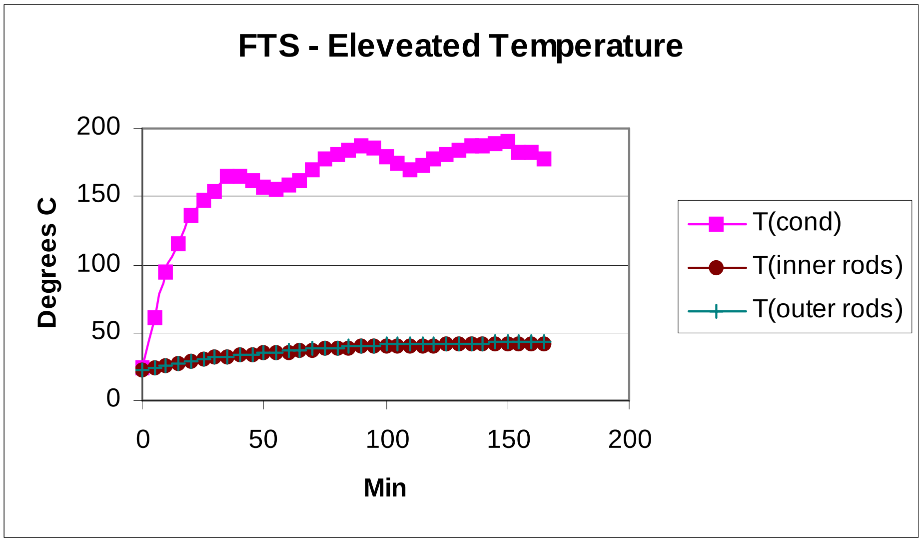

Figure 6. Splice Temperature (°C) vs. Time (min.) showing the temperature at the inner and outer rods remains less than 50°C when the conductor is heated to 195°C.

High Voltage (Corona) Test

The purpose of this testing is to verify that the Splice Assemblies for the 477 ACCR conductor will have acceptable performance when subjected to typical transmission line voltages.

The testing was conducted at the NEETRAC indoor high voltage laboratory.

The 477 ACCR Splice Assembly was installed on a 20' length of 0.840" diameter tubing to simulate the conductor (see Figure 7). The Splice Assembly and tubing were positioned at 12 feet above the ground plane.

Based on both visual observations and radio interference voltage (RIV) measurements, corona onset voltage for the Splice assembly was recorded at 267 KV (phase to phase).

For a single conductor configuration, a 477 conductor would be commonly used on lines operating at voltages up to 169 KV. The results of these high voltage tests show that the electrical performance of the Splice Assemblies are acceptable for these applications. Further, the results allow us to conclude that these hardware assemblies will have acceptable electrical performance if used in a twin configuration at 230 KV.

Figure 7 –Splice Arrangement in the Corona Test

High Temperature Field Operation and Thermal Cycling

One PLP Thermolign® Splice Assembly for 477 ACCR, Part #TLSP-0104, was installed on a controlled outdoor test span at the Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee, (for a full report see "Composite Conductor Field Trial Summary Report: ORNL ACCR 477 Kcmil", 3M Technical Report, 3M Company, 2005). The test line (Figure 8) consisted of four spans, each 600 feet (183 meters) between a steel suspension pole and two guyed dual steel dead end poles. The test conductor formed an out and back loop over two spans, connected to a DC power supply located at one end of the line. 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.

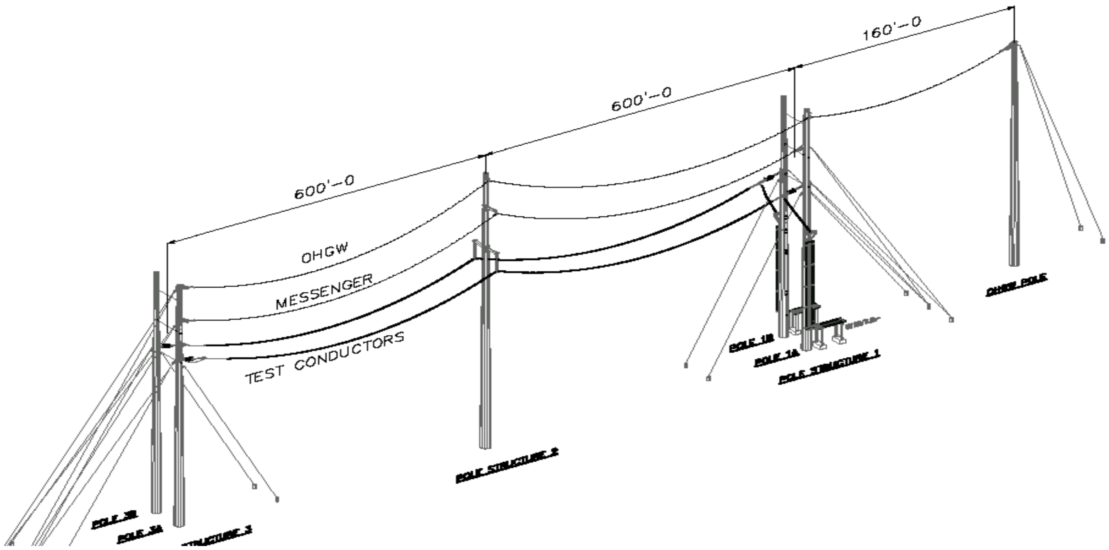

Figure 8- Line layout and CAT-1 system

A separate data acquisition system was used to collect the information from the thermocouples. The line was operated under constant current or constant conductor temperature with thermal cycles lasting from less than one hour to several days.
The power supply has a dual rating of 400 Vdc and 5000 amps and the input voltage to the power supply was 4160 V, 3-phase. A dry-type ABB transformer is used to step down the voltage from a 13.8 KV distribution line.

One PLP Thermolign® Splice for 477 ACCR, Part #TLSP-0104, was installed in the center of one of the spans (Figure 9).

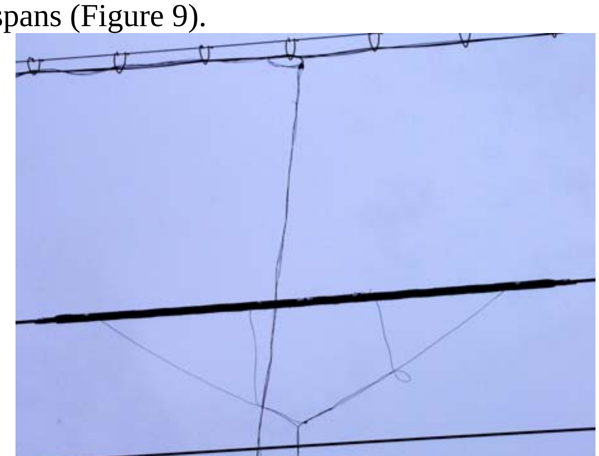

Figure 9- Installed PLP THERMOLIGN® Splice

The 477 ACCR conductor was thermally cycled from May 2003 to October 2003 between ambient and over 200^0 C for more than 200 hours and more than 100 cycles, under a wide range of weather and load conditions. Figure 10 shows the composite conductor core temperature during a typical thermal cycle in temperature control. The temperature is maintained at $210\text{-}240^0$ C by controlling the current from 1000 amps to 1200 amps while the wind fluctuates between 0 f/s and 15 f/s

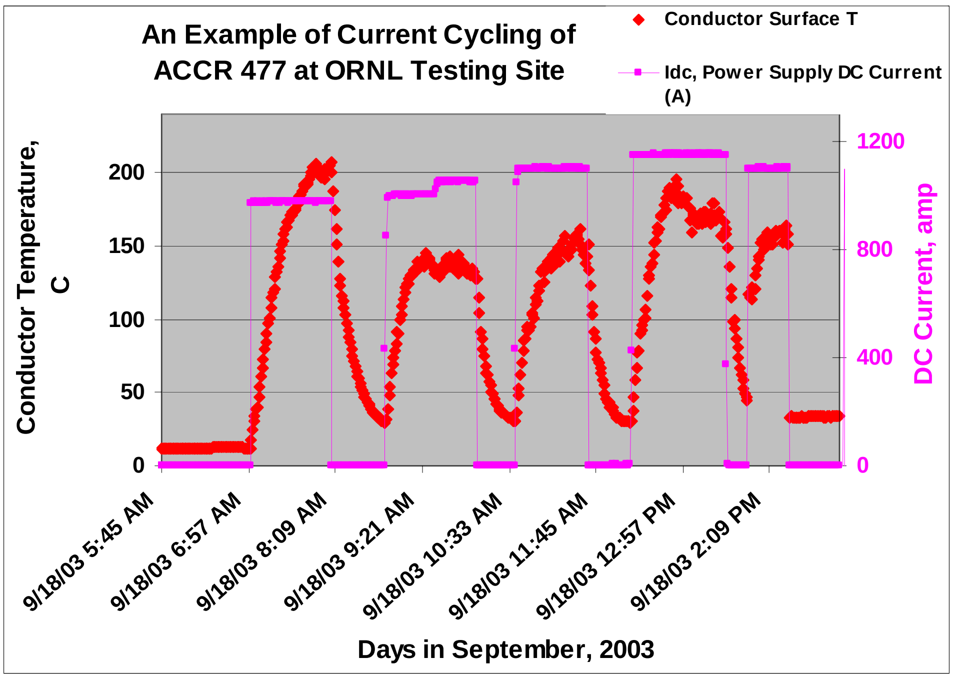

Figure 10- shows an example of thermal cycling in one day at ORNL test line

The Splice temperature was monitored at four (4) locations (Figure 11) on both the inner rods and the outer ones (Figure 4). The inner rod temperatures (PS1, 2) were slightly higher than those measured on the outer rods (PS3) and the inner center of the splice (PS4) where conductor segments come together (because of its proximity to the conductor).

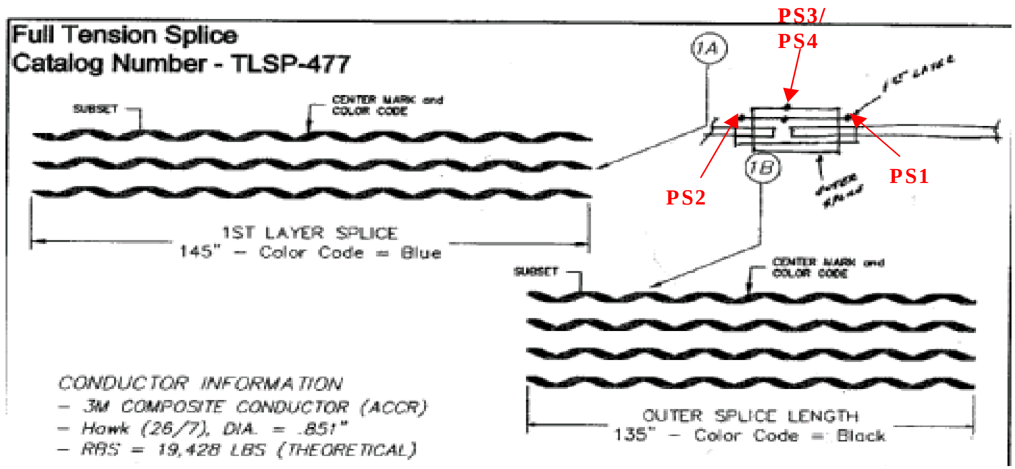

Figure11 Location of thermocouples on PLP splice,
a total of 4 TC's were mounted as shown in red

The splice shows a temperature gradient between inner and outer rods as shown in Figure 12; two thermocouples were mounted on each set of rods. Both sets of rods ran much cooler than conductor, with temperatures below 100^0 C, when the conductor temperatures were close to 200^0 C. The outer rod temperatures were below 50^0 C.

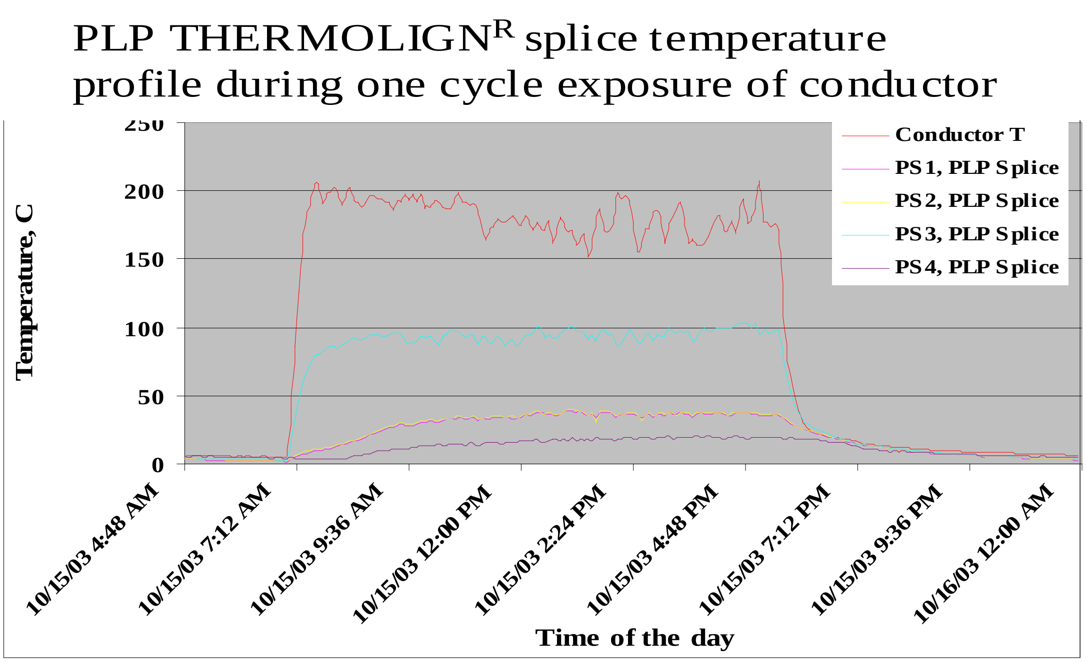

Figure 12. An example of a single thermal cycle showing the PLP splice running very cool, temperature < 100^0 C, when conductor was around 200^0 C.

The line and accessories were taken down from the ORNL test line after thermal cycling was completed. A 50ft section of conductor, including the PLP splice was cut-out, clamped, and shipped to PLP for evaluation and residual tensile strength testing. Dead-ends were applied to the end of the sample to permit testing. The splice/ conductor combination failed at 19428 Lbs (100% RBS), with failure occurring in the conductor located within the splice region.

Acknowledgement

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