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OVERHEAD LINES COMMITTEE

OVERHEAD CONDUCTORS & ACCESSORIES W.G.

THERMAL-MECHANICAL TESTING ON SWAGE TECHNOLOGY CONNECTORS
Thermal-Mechanical Test on Swage Technology: Single Stage ACSR

- Investigate the effects of tension on thermal cycling of single stage ACSR connector systems
- Investigate the effects of inhibitor compound on both temperature and resistance, including post aging mechanical performance
- Compare results to previous tests performed on conventional Single Stage Connector (SSC) systems
Thermal/Mechanical Test on Swage Technology: Single Stage ACSR

Single Stage Connector (SSC)  Two Stage Connector (TSC)

Swage 360° Flex Die Technology
Comparison of Swage 360° degree Flex Die vs. Fixed Die Compression

Swage Force

Swage core

Swage cable

Fixed Die Force

Fixed Die core

Fixed Die cable

Thermal/Mechanical Test on Swage Technology: Single Stage ACSR
Thermal-Mechanical Cycling Test: current is passed through connector/conductor assemblies while under mechanical tension

ANSI C119.4 Current Cycling Test: current is passed through connector/conductor assemblies while static
Test loop included:

- Two (2) 795 kcmil ACSR “Drake” spans
- Two (2) dead-ends and two (2) splices each on span

One (1) span included oxide inhibitor compound prior to connector installation

One (1) span was installed without inhibitor compound for connector installation
Using previously established protocol as a guideline, Single Stage Swage Type Connectors were tested in an accelerated aging process:

- Steady state temperature = 150°C
- Total number of current cycles = 1,100
- Soaking Time (at 150°C) = 2 hours

Pass/Fail Criteria:
- Connector temperature shall not exceed control temperature (150°C)
- Subsequent Tensile Test > 95% RTS
Both spans tensioned to 25% RTS of ACSR Drake (7,800 lb) using a hydraulic cylinder and threaded push rod
Thermocouples drilled and peened/cemented to monitor connector and conductor temperatures

Twisted copper wire positioned one (1) inch from connector ends for contact resistance measurements
Temperature plot of typical current cycle

- **Temperature (°C)**
  - 0 to 160

- **Tension (lb)**
  - 0 to 8000

**Legend**
- Red: Control Temperature
- Blue: Tension

**Time (hours)**
- 0.0 to 4.5
Temperature profile of Deadends *with and without* inhibitor

- Ambient
- Dead-end #1, with Inhibitor
- Dead-end #2, with Inhibitor
- Control Temperature
- Dead-end #3, no Inhibitor
- Dead-end #4, no Inhibitor

Thermal/Mechanical Test on Swage Technology: Single Stage ACSR
Resistance profile of Deadends with and without inhibitor
Temperature profile of Splices with inhibitor

Temperature (°C) vs Cycle Number

- Ambient
- Splice #1, North End, with Inhibitor
- Splice #1, South End, with Inhibitor
- Control Temperature
- Splice #2, North End, with Inhibitor
- Splice #2, South End, with Inhibitor

Thermal/Mechanical Test on Swage Technology: Single Stage ACSR
Resistance profile of Splices *with and without* inhibitor

![Graph showing resistance profile of splices with and without inhibitor](image)

Thermal/Mechanical Test on Swage Technology: Single Stage ACSR
Temperature profile of Splice *without* inhibitor

[Graph showing temperature profiles with different colors representing ambient, control temperature, and various splice conditions.]

Thermal/Mechanical Test on Swage Technology: Single Stage ACSR
Tension profile on Splice and Dead-end without inhibitor shows some creep and relaxation due to high temperature and tension.
Post thermal aging samples with inhibitor and samples without inhibitor were mechanically tensioned until failure.
Digital Radiography Imaging

Splice As New

Splice after Cycling, NO Inhibitor

Splice after Cycling, WITH Inhibitor

Core slippage

Thermal/Mechanical Test on Swage Technology: Single Stage ACSR
Inhibitor Compound
“DMC” DFTC-1LB for application on conductors rated at 93°C and below.

- Urethane Polymer Base
- Operating Range -40 F - +350 F
- Electrolytic Nickel-Aluminum Alloy
- Zinc Dust
Chemical analysis of Inhibitor Compound samples show significant decrease in base materials

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<thead>
<tr>
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<tbody>
<tr>
<td>⅛ Worked Penetration</td>
<td>293</td>
<td>279</td>
<td>-4.80%</td>
</tr>
<tr>
<td>Aluminum Content [ppm]</td>
<td>150,000</td>
<td>11,400</td>
<td>-92.40%</td>
</tr>
<tr>
<td>Nickel Content [ppm]</td>
<td>151,000</td>
<td>63.2</td>
<td>-99.90%</td>
</tr>
<tr>
<td>Silicon Content [ppm]</td>
<td>26,500</td>
<td>356</td>
<td>-98.70%</td>
</tr>
<tr>
<td>Iron Content [ppm]</td>
<td>169</td>
<td>1,280</td>
<td>657.40%</td>
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Corrosion Test Performed on Swage Technology SSC
Performed to ASTM B117 for 1000 hours

Table 1 Summary of DC Resistance Measurements

<table>
<thead>
<tr>
<th>Measurement Points</th>
<th>Hours Exposed to Salt Fog (hour)</th>
<th>Ambient (°C)</th>
<th>Group A: Without filler compound</th>
<th>Group B: With filler compound</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>AI-TT</td>
<td>A2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Micro Ohms</td>
<td>Micro Ohms</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>223</td>
<td>65.1</td>
<td>64.7</td>
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<tr>
<td>2</td>
<td>690</td>
<td>206</td>
<td>65.4</td>
<td>64.8</td>
</tr>
<tr>
<td>3</td>
<td>1000</td>
<td>236</td>
<td>65.7</td>
<td>64.9</td>
</tr>
<tr>
<td>Average Resistance</td>
<td></td>
<td></td>
<td>65.4</td>
<td>64.8</td>
</tr>
<tr>
<td>Resistance Increase</td>
<td></td>
<td></td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Resistance Increase (%)</td>
<td></td>
<td></td>
<td>0.9</td>
<td>0.2</td>
</tr>
</tbody>
</table>

One sample of each showed slight increase in resistance, however no discernable difference between samples with and without inhibitor could be drawn.
Conclusions:

- Single Stage Swaged connectors were subjected to 2,200 hours of emergency operating conditions (150°C)
- Single Stage Swaged connectors without inhibitor compound performed better
  - Thermally
  - Electrically
  - Mechanically
Based on the results of testing, DMC is rating Single Stage Full Tension Swage Connectors for 125°C continuous operating temperature!

Meets the highest NERC Reliability Standard FAC-008-3 - Facility Ratings