PG&E Covered Conductor Testing

Together, Building
a Better California

Energy Safety Directive

Purpose: Energy Safety directed utilities to collaborate on wildfire risk and effectiveness metrics Issues with progress updates required by **Nov. 1, 2021** and in the **2022 WMP Update**
Issue: Limited Evidence to Support the Effectiveness of Covered Conductor
Participating Organizations: SCE, SDG&E, PG&E, SCE, PacifiCorp, BVES, Liberty
Timeline: Ongoing

Issue Description:
The rationale to support the selection of covered conductor as a preferred initiative to mitigate wildfire risk lacks consistency among the utilities, leading some utilities to potentially expedite covered conductor deployment without first demonstrating a full understanding of its long-term risk reduction and cost-effectiveness. The utilities' current covered conductor pilot efforts are limited in scope[25] [100] and therefore fail to provide a full basis for understanding how covered conductor will perform in the field. Additionally, utilities justify covered conductor installation by alluding to reduced PSPS risk but fail to provide adequate comparison to other initiatives' ability to reduce PSPS risk.

Remedies required and alternative timeline if applicable:

The utilities must coordinate to **develop a consistent approach to evaluating the long-term risk reduction and cost-effectiveness of covered conductor deployment**, including:
1. The effectiveness of covered conductor in the field in comparison to alternative initiatives.
2. How covered conductor installation compares to other initiatives in its potential to reduce PSPS risk.

[25] Limited in terms of mileage installed, time elapsed since initial installation, or both. For example, SDG&E's pilot consisted of installing 1.9 miles of covered conductor, which has only been in place for one year.
[100] Limited in terms of mileage installed, time elapsed since initial installation, or both

2-Step Process

Phase 1 - Benchmark

- Develop IOU-agreed covered conductor FMEA
- Collect all previously performed covered conductor testing
- Map previous industry testing results to FMEA failure modes
- Identify testing gaps and provide recommendations

Phase 2 – Test Execution

- Develop test plans
- Map test plans to failure modes to ensure coverage based on Phase 1 report gaps
- Execute testing

Covered Conductor Effectiveness supplemental report to WMP finalized in Feb 2022

FMEA for CC

Table 3. Failure modes that affect bare conductors but are largely mitigated by covered conductors.

Hazard	#	Failure Mode
Extreme heat	4	Fault due to sag/clearance issues
Animal	14	Large bird contact of multiple conductors (phase-to-phase contact)
Moisture	15	Atmospheric corrosion of span leading to decreased mechanical strength or increased electrical resistance
	20	Stress corrosion cracking of span
Wind	26	Line slapping (intermittent conductor contact)
	27	Differential wind driven blowout leading to contact of distribution / transmission lines
Tree damage	29	Conductor failure/wire down resulting in loss of service, potential for ignition (along the entire length of bare conductor or exposed section of CC)
	31	Phase-to-phase fault. Potential ignition.
Public/worker impact	39	Potential for shock or electrocution
	40	Potential for guy wire whip to create contact to conductor
	41	Phase-to-phase contact (vehicle)
	42	Phase-to-ground contact (vehicle)
Third-party damage	44	Phase-to-phase contact (tarp)
	45	Phase-to-phase contact (balloon)
	46	Phase-to-phase contact (kite)
	47	Phase-to-phase contact (palm frond)
Maintenance/ Installation	52	Clearance issues due to increased sway

Table 4. Failure modes that affect *only* covered conductors.

Hazard	#	Failure Mode
Fire	1	Potential damage to sheath, reducing effectiveness
	2	Potential flammability of CC sheath
UV exposure / solar exposure	5	Embrittlement and/or cracking of conductor covering
Contamination	6	Tracking/insulation failure due to moisture/salt (corona)
	7	Tracking/insulation failure due to smoke/ash
Animal	12	Phase-to-phase fault due to animal-damaged sheath (chewing)
	13	Bird dropping degradation of polymer sheath
Ice/snow	17	Freeze/thaw cycles leading to sheath damage
	19	Migration of water within the sheath layer
Wind	28	Damage due to potential for increased loading when new covered conductors replace existing bare conductors on the same poles / crossarms / guys
Tree damage	33	Abrasion of sheath
	34	Cracking of CC sheaths
	35	Heating damage to sheath
	36	Corrosion of conductor due to compromised sheath
Maintenance / installation	48	Mechanical damage to sheath (dent/gouge)

SCE / Exponent Test Scope

Phase 1 Recommendations	Relevant Phase 2 Testing
Characterize CC susceptibility to certain mechanical failure modes (Aeolian vibration, galloping, etc.)	Tensile testing
Characterize key understudied contact-mediated fault scenarios (e.g., foreign object contact)	Arc testing, ignition testing
Characterize CC-specific failure modes	Moisture ingress testing, flammability testing, corrosion testing, tensile testing

- Exponent previously conducted a literature review for the California IOUs on the effectiveness of covered conductors (CCs) for wildfire mitigation ("Phase I"). This work identified selected areas for further study.
- The current scope is comprised of physical testing to address areas identified by the previously conducted literature study. These include:
  - Phase-to-phase contact testing: to understand the ability of CCs to prevent phase-to-phase arcing when in contact with foreign objects.
  - Simulated wire-down testing: to understand the ability of CCs to prevent ignition of dry fuel in the event of a wire-down event.
  - Fire risk: to understand the propensity for the polyethylene covering to ignite in the event of a nearby fire.
  - Corrosion susceptibility: to understand the corrosion susceptibility of CCs near stripped ends relative to bare conductors.
  - System strength: to understand the mechanical limits of CC systems.

PG&E Complimentary Test Scope

Hazard	Failure Mode	PGE Test	Output and Translation to Failure Mode
Fire	Potential flammability of CC sheath - cover conductor catches on fire	4.c: Flammability test per UL2556 - Self extinguishing - flame / molten drippage	UL rating - if the CC fire propagates vs. self extinguishes - UL rating for the relative performance - if CC drips molten material or not
UV exposure / solar exposure	Embrittlement and/or cracking of conductor covering	6.a.i: ASTM G154 UV Weathering or 6.a.ii: UV weathering per ICEA standard	approximation of expected useful life (visual or mechanical testing after UV exposure)
Contamination	Tracking insulation failure due moisture/salt (corona)	2.F Tracking resistance per ICEA	Baseline tracking resistance test. More tracking resistance means more resistance to contamination issues
Contamination	Tracking/insulation failure due to smoke/ash	2.F Tracking resistance per ICEA	Baseline tracking resistance test. More tracking resistance means more resistance to contamination issues
Moisture	Freeze/thaw cycles leading to sheath damage if CC is not co-extruded	2.B: Water Blocking Testing per ICEA standard - on every conductor type	Water tightness tests evaluates water tightness of covered conductors. We know that water getting into the conductor will degrade the steel
Moisture	Migration of water within the sheath layer	2.B: Proposed test – water immersion test for connection points	Water immersion test on splices with gel wraps to evaluate water ingress possibilities.
Moisture	Corrosion of conductor due to compromised sheath	6.B. environmental salt test for 500 - 1000hrs	Qualitative - compared to bare conductor
Design / Construction	Mechanical strength of conductors	3.A: Pull-out test	Vary the specs for installation and perform tensile tests to determine the impact of system strength.
Manufacturing Defect	CC is weaker mechanically than rating	1.A - E: Covering material tests	Material characterization tests that will be useful for baseline
Manufacturing Defect	Leakage current Baseline	2.D: Leakage current test	
Lightning	Lightning damages CC	2.H: Atmospheric impulse test	Measure conductor resistance to lightning and determining damage from large current/voltage
Multiple	Vegetation contact across various lines for an extended amount of time	3.A.v: Abraded insulation arcing and leakage current test	Expanding on the testing that SCE has already preformed. Making sure we can determine the threshold damage that would significantly reduce the CC insulating properties. Generate an output that can quantify condition in the field
Environmental	UV and humidity degradation of covering and conductor	6.a.i - samples will be exposed for periods 250, 500, 750 and 1000 hours to determine deterioration trends of the materials under test.	Utilize the standard's model for approximation of life relative to UV and humidity conditions
Manufacturing Defect	CC is less resilient to corrosion than manufacturing specifications	Material characterization via microscopy	Baseline thickness of various materials
Ambient temperature	covering shrinks and retracks back from connection points, exposing bare wire	4.E e. Shrink back Retraction Under Heat per EN 60811-502	Quantify the amount of shrinkage of covering

PG&E Complimentary Testing

- The purpose of this testing is to provide insight into the effectiveness of the proposed 397.5 AAC by [redacted] and 1/0 ACSR by [redacted] 15kV XLPE-covered conductor(s) for overhead distribution system hardening. Specifically, to address the following:
  - Qualitatively evaluate proposed covered conductor(s) against the bare conductor
  - Identify the presence of active degradation mechanisms pertaining to covered conductors.
  - Document the material, electrical, mechanical, and environmental properties.
- The results of this study will provide insights into the following:
  - The existence of any systemic degradation to the material properties of the proposed covered conductor.
  - Proposed inspection strategies.
- In some tests, alternative covered conductor(s) were also tested to assess specific properties (flammability, water ingress, etc)
- Majority of tests conducted per ANSI/ICEA S-121-733 unless otherwise specified. Some properties of interest not defined or required by ANSI/ICEA S-121-733 were determined by alternative methods.

PG&E

Covered Conductors Evaluated

[redacted] 397.5 AAC

15kV 3-Layer Tree Wire

AAC Conductor
Conductor Shield
XLPE Inner Layer
Track-Resistant XLHDPE Outer Layer

Cable image is for reference only and does not depict actual cable construction

Applications:

- Predominantly used for primary overhead distribution where limited space is available or desirable for rights-of-way.
- Installed as an uninsulated (covered) conductor; however, covering is effective in preventing short circuits and instantaneous flashovers should tree limbs or other grounded objects momentarily contact conductor in such close proximity.
- Used for spans where trees crowd the right-of-way, such as in wooded residential areas, when a minimum of interference with the environment is desired. Covering minimizes power outages due to conductor contact with tree limbs, reducing the need for frequent or severe trimming.
- Covering Rated 90°C Normal and 130°C Emergency Operation. Unless adequate knowledge of the thermal characteristics of the environment is known, the permissible conductor temperature should be reduced by 10°C or in accordance with available data.

Specifications:

Manufactured to the latest editions of the following standards:

- ASTM B231
- ICEA S-121-733

Construction:

Conductor

- AAC

Covering

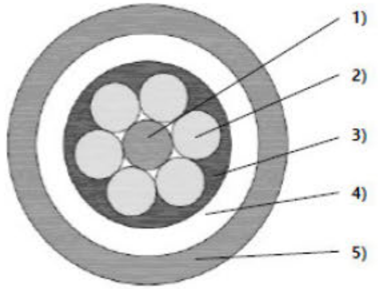
- Conductor Shield: Semi-Conducting Thermoset Polymer
- Inner Layer: Crosslinked Low Density Polyethylene
- Outer Layer: Gray, Track-Resistant Crosslinked High Density Polyethylene

[redacted] Part Number	Conductor			Covering Thickness			Cable Diameter	Rated Strength	Weight
	Type	Size-Strands (AWG)	Nom. Diameter (inches)	Conductor Shield Nom. (inches)	Inner Layer Nom. (inches)	Outer Layer Nom. (inches)	Nom. (inches)	Max. (lb.)	Nom. (lbs./1000ft)
66-24-00-xx	AAC	397.5-19	0.723	0.025	0.075	0.075	1.073	6754	578
66-24-01-xx	AAC	715.5-37	0.974	0.025	0.080	0.080	1.343	12160	951

[redacted] Part Number	Print	Length (feet)	Reel Type	Reel Flange OD (inches)	Reel Drum (inches)	Reel Traverse (inches)	Reel Weight
66-24-00-01	[redacted] C 397.5 KCMIL AL 25/75/75 MILS XLPE {MMM/DD/YYYY} {SEQUENTIAL FOOTAGE MARKS} SEQ FEET	3500 (+/- 10%)	N65	60	28	28	303
66-24-01-01	[redacted] C 715.5 KCMIL AL 25/80/80 MILS XLPE {MMM/DD/YYYY} {SEQUENTIAL FOOTAGE MARKS} SEQ FEET	2500 (+/- 10%)	N76	66	30	28	370

[redacted] 1/0 ACSR

CABLE SECTION DRAWING



CABLE CONSTRUCITON DATA

No.	DESCRIPTION		UNIT	PARTICULARS	
1	Basic standard		-	ICEA S-121-733, ASTM B 230, 232, 498	
2	Voltage rating (Phase to Phase)		kV	15	
3	1) Core (Steel)	Material	-	Galvanized steel wire	
		Strand	No./in	Nom.	1 / 0.1327
		Diameter	in	Nom.	0.1327
4	2) Conductor (Aluminum)	Material	-	Aluminum 1350-H19 wire	
		Strand	No./in	Nom.	6 / 0.1327
		Size	AWG	Nom.	1/0
		Diameter	in	Nom.	0.398
		Lay direction	-	Right hand(Z), Outer layer	
5	3) Conductor Shield	Material	-	Semiconducting thermoset polymer	
		Thickness	mils	Nom.	25
6	4) Inner Covering	Material	-	XL LDPE (Type I, Class A, Category 3, E5)	
		Thickness	mils	Nom.	75
7	5) Outer Covering	Material	-	XL HDPE (Type III, Class D, Category 4, E9) UV & Tracking Resistant	
		Color	-	Gray	
		Thickness	mils	Nom.	75
8	Overall diameter of completed cable		mils	Min.	738
				Nom.	748
				Max.	768
9	Weight of completed cable		lb/1000ft	Approx.	291
10	D.C Resistance at 25℃		Ω/1000ft	Nom.	0.163
11	Rated Strength of completed cable		lbs(kN)	Min.	4161 (18.51)
12	Material of Reel		-	Wood or Steel	

PG&E Complimentary Test Timeline

Jun-22 Week 1 2 3 4 5 | Jul-22 Week 1 2 3 4 5 | Aug-22 Week 1 2 3 4 | Sep-22 | Oct-22 | Nov-22 | Dec-22

		Status:
Covered Conductor Test Plan	Finalize PGE test plan	completed
Material Characterization	Filler content, water absorption analysis; DSC; FTIR; thickness measurement	completed
Enhanced Electrical Testing	Leakage current testing, and abraded insulation leakage current testing	completed
Flammability Testing	Flamibility Testing	completed
Moisture Testing	Water Ingress Testing	completed
Enhanced Mechanical Testing	Mechanical pull-out and slippage testing	completed
Corrosion Testing (at NTS)	Environment salt test	completed
Excess Heating (at NTS)	Shrink back retraction under heat	completed
UV Exposure Testing (at PowerTech)	UV weathering testing	completed
Tracking Testing (at PowerTech)	Tracking resistance testing	completed
Lightening Testing (at PowerTech)	Measure conductor resistance to lightning and determine damage from large current/voltage	completed
Reporting	Reporting	completed

Test Results Summary

Hazard	Test	Result
Manufacturing Defect	1. Dimensional Analysis	Cover conductors met dimensional requirements
Manufacturing Defect	2. Filler content analysis	[redacted] conductor outer layer had higher inorganic filler content than [redacted]
Manufacturing Defect	3. Water absorption test	Conductor insulation had no significant water absorption (< 0.01 wt.%)
Manufacturing Defect	4. Fourier-transform infrared spectroscopy	[redacted] and [redacted] inner and outer layers exhibit characteristic of XLPE
Ambient temperature	5. Heat shrinkage test	[redacted] exhibited higher heat shrinkage than [redacted] conductor at temp.
Fire	6. Differential scanning calorimetry	[redacted] shield layer exhibited some melting at emergency temp = 85°C.
Fire	7. Flammability test	Once insulation ignited, fire is self-sustaining and could drop molten droplets.
Overload	8. Tensile test	Conductors met rating. Strands of bare wire exposed at fracture after testing.
Moisture	9. Accelerated Corrosion test	Covered conductor corroded faster than bare. Gel splice wrap performed better than MVFT.
Moisture	10. Water ingress test	Moisture could travel internally unimpeded accelerating internal corrosion.
Moisture	11. Water immersion test	Splice gel wraps effective at inhibiting external water intrusion to splice.
UV exposure / solar exposure	12. UV weathering test	Per ANSI/ICEA S-121-733, both covers appeared not to meet sunlight resistant designation, and are anticipated to become more brittle over time.
Multiple	13. Leakage current and dielectric strength test	Conductors will still meet insulation rating with compromised outer layer. Splice covering maintain rating of conductor insulation
Contamination	14. Tracking resistance test	All samples passed the test criteria
Multiple	15. Tracking resistance with salt fog	Long term vegetation contact can cause damage and/or erosion on covered conductors
Lightning	16. Lightning test	Insulation could be damaged by lightning. Damaged expected to be localized.

Executive Summary (1/3)

Overall Takeaway: *Covered conductor(s) provide significantly improved short-term protection from vegetation and other hazards at the expense of an anticipated reduction in overall life attributed to an increased corrosion rate of the metallic conductor.*

Material Characterization

- Tensile Overload Testing
  - The tested covered conductors showed bare aluminum strands exposed after tensile overload testing.
  - The covered conductors pose the hazard of arcing during a wire-down event.
- Heat Shrinkage Testing
  - The [redacted] covered conductor exhibited cable insulation heat shrinkage of 1 %.
  - The heat shrinkage at the connectors and exposure of bare aluminum wire are ignition risks.
  - *ATS recommends performing additional heat shrinkage testing with full span length*
- Flammability Testing
  - The tested covered conductors showed that the cable insulation had no flame resistance and was dripping molten materials after ignition.
  - SCE study showed that probability for auto-ignition during surface or low-lying brush fire is low. Canopy fire may be sufficient to cause conductor sheath ignition
  - Faults on the covered conductor circuit could potentially ignite the cable insulations, however, the probability of ignition is low.

Executive Summary (2/3)

Environmental Resistance Characterization

- Corrosion and Water Ingress Testing
  - The tested covered conductors which had no water-blocking technology are more vulnerable to corrosion.
  - *ATS recommends assessing the covered conductors with water-blocking technology (for example [redacted] or ACSR-covered conductors with better galvanized layers.*
  - Dead-end connectors are exposed to the risk of water ingress.
  - *ATS recommends exploring methods to seal dead-ends to extend the lifetime of covered conductors.*
  - All covered conductors after 1000-hour atmospheric corrosion tests met the rated strength.
  - *ATS recommends conducting additional tests to measure the corrosion rate on the steel core to provide insights for conductor corrosion assessment in the future.*
- Immersion Testing
  - Gel wraps on splices provide sufficient protection to prevent water ingress during the immersion test.
- UV weathering Testing
  - The tested covered conductors show significant degradation in mechanical properties after UV exposure. The covered conductors' insulation materials became more brittle and had reduced toughness after the UV weathering test.
  - *ATS recommends establishing plans for enhanced visual inspection of the covered conductor at high UV exposed area*

Executive Summary (3/3)

Electrical Characterization

- Tracking Resistance Testing
  - Tracking could occur with phase-to-phase or phase-to-ground contact. This will degrade the cable insulation over time contributing to increased leakage current and potentially causing a fault.
  - Tracking is more likely to occur at the connection points with insulators. Tracking damage could completely compromise covering equating to performance similar of bare conductor.
  - After a certain amount of time, it is possible that the cable insulation will be compromised.
  - *ATS recommends Asset Strategy establishing plans for replacement once the tracking condition is found.*
- Lightning Testing
  - Both insulations could be damaged by lightning. Damaged expected to be localized and is not expected to propagate through continued auto-ignition.
- Damaged/Abraded Insulation Testing
  - Both conductors expected to meet leakage current per European Standard EN 50397-1:2020 and maintain a 2X insulation rating even with compromised outer layer exposing inner layer.
  - *ATS recommends future visual inspections to assess the cable insulation layer exposure. If the conductor inner insulating layer is exposed, the conductor should be scheduled for replacement.*

Additional Recommendation

- *ATS recommends performing freeze test of conductors with water ingress to determine mechanical effects of freeze cycle.*

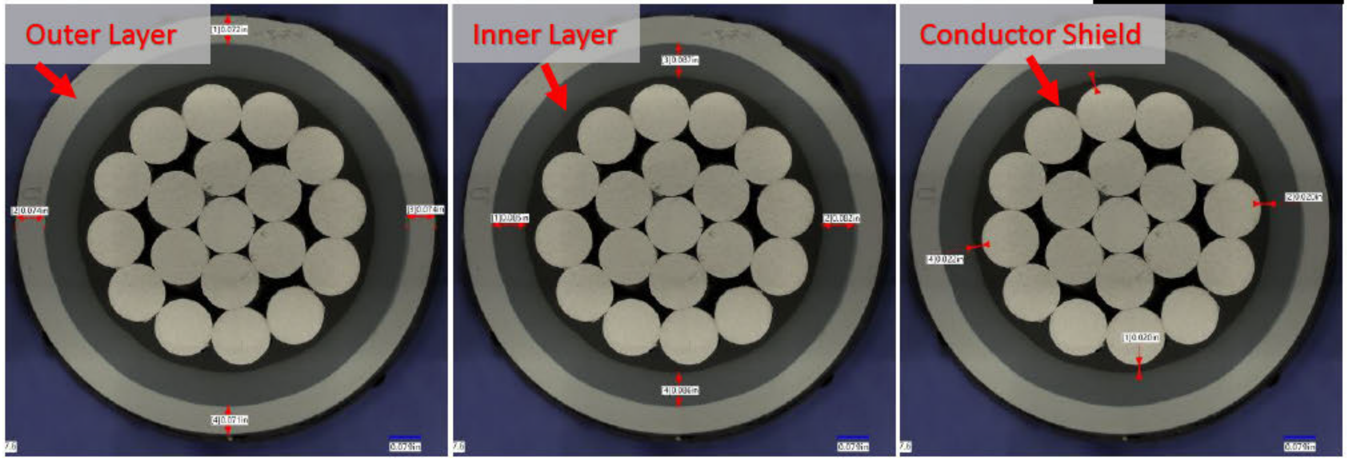
- *ATS recommends an update to EDPM response criteria for inspections specific to covered conductors based on the test results.*

Materials Characterization

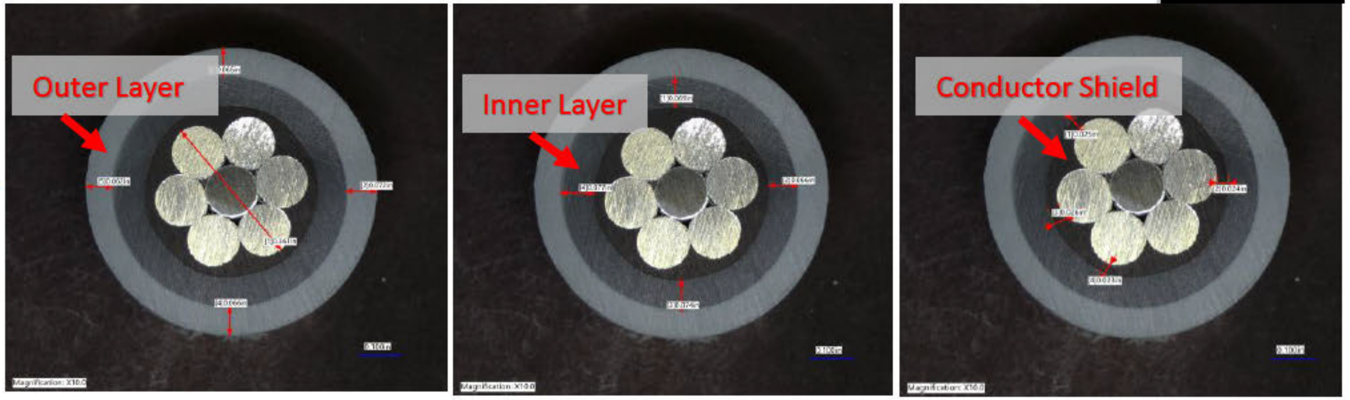
1. Dimensional Analysis (Required per ANSI/ICEA S-121-733)

- [redacted] 397 AAC
  - Outer layer thickness: 73 Mils
  - Inner layer thickness: 85 Mils
  - Total cover (insulation) thickness: 158 Mils
  - Conductor shield thickness: 21 Mils
- [redacted] 1/0 ACSR
  - Outer layer thickness: 67 Mils
  - Inner layer thickness: 72 Mils
  - Total cover thickness: 138 Mils
  - Conductor shield thickness: 26 Mils
- Per ANSI/ICEA S-121-733
  - Cover thickness Nom=150 Mils, Min=135 Mils
  - Shield thickness Nom=15 Mils, Min=12 Mils

[redacted]



[redacted]



The insulation thickness for both [redacted] and [redacted] covered conductors meets the requirements per ANSI/ICEA S-121-733 Table 4-1. The shield thicknesses exceeds the requirement per ANSI/ICEA S-121-733 Table 3-1.

Materials Characterization

2. Filler Content Analysis (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Fillers are used to improve flammability and/or weathering but can inversely affect tracking and/or embrittlement.
- The cable sections were dissected, and each polymer layer was analyzed for its inorganic filler content by weight difference before and after combustion at 550°C per Thermogravimetric Analysis (TGA).
- Results:

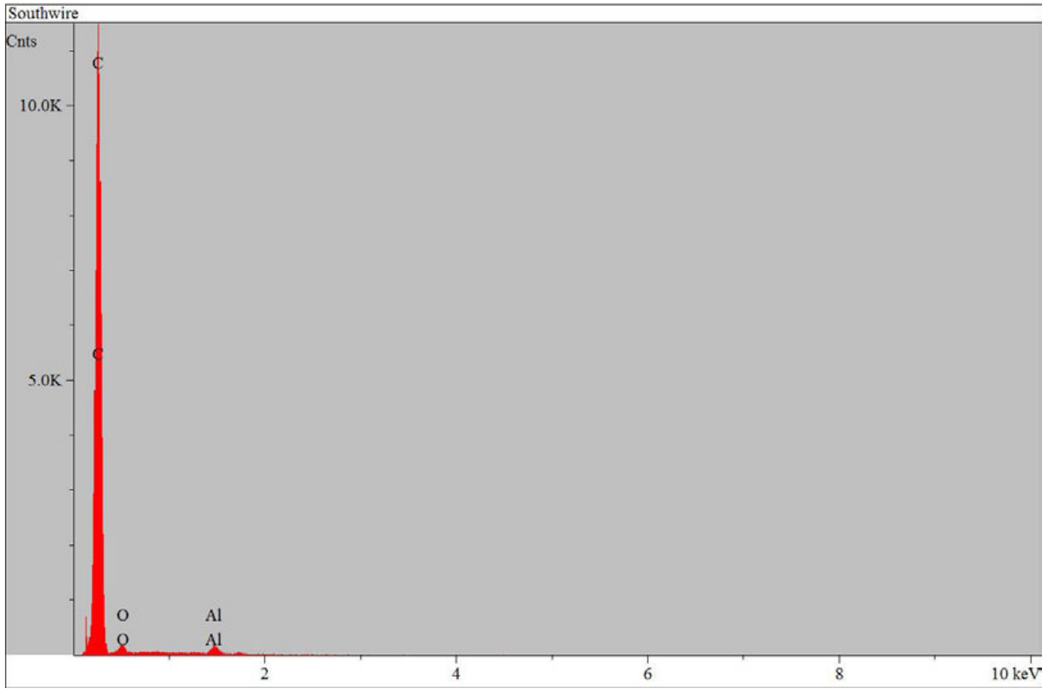
Sample	Inorganic filler content (wt.%)
[redacted] Outer Layer	1.6
[redacted] Inner Layer	< 0.1
[redacted] Conductor Shield Layer	< 0.1
[redacted] Outer Layer	5.5
[redacted] Inner Layer	< 0.1
[redacted] Conductor Shield Layer	< 0.1

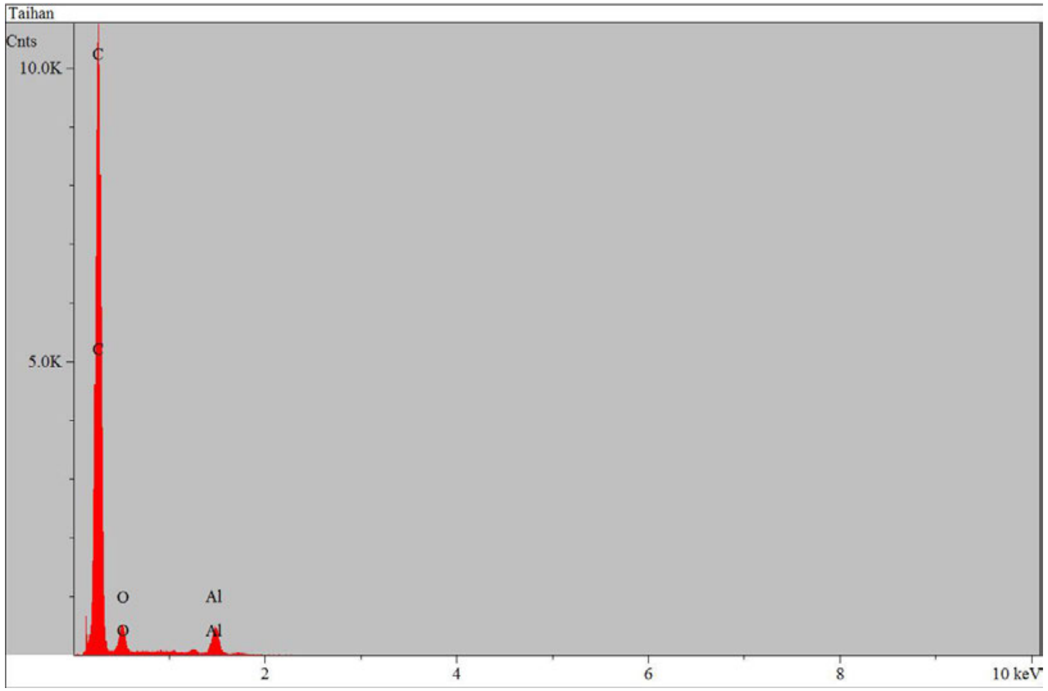
[redacted] covered conductor outer layer has higher inorganic filler content than [redacted]

Materials Characterization

2. Filler Content (cont'd)

- Scanning Electron Microscopy (SEM) / Energy Dispersive Spectroscopy (EDS) Analysis of outer layer





The inorganic filler content in the outer layer appears to be aluminum trihydrate (ATH), which is intended for flame retardancy and/or tracking resistance.

Materials Characterization

3. Water Absorption Test (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Understand water absorption over time. Water absorption increases conductivity of insulation. XLPE expected to have minimal water absorption
- Test guideline: modified ASTM D570-98
- Test setup: A section of each cable was conditioned for 24 hr at 50°C and then fully submerged for 24 hr in a container of distilled water at a temperature of 23°C.
- Results:

Sample	Weight increase during water immersion (wt.%)
[redacted]	< 0.01
[redacted]	< 0.01

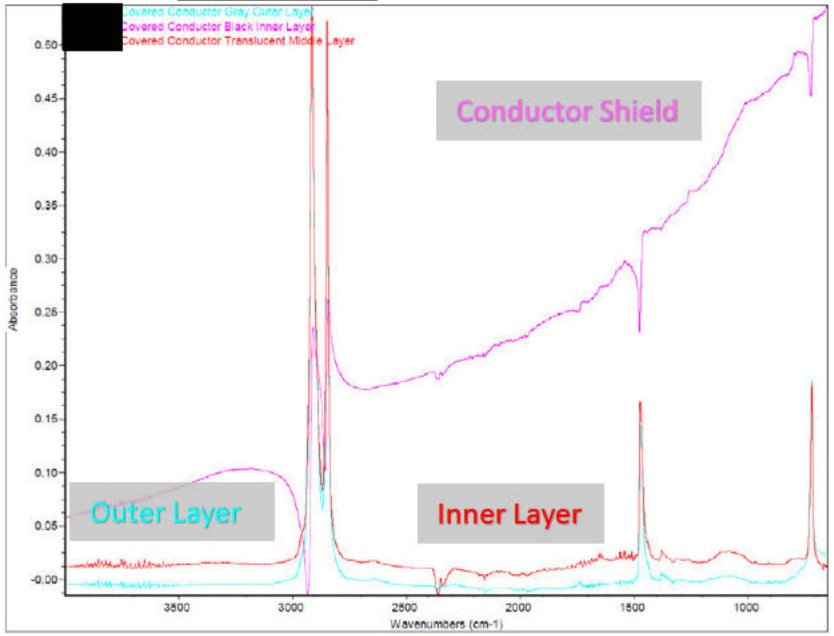
The [redacted] and [redacted] covered conductor layers absorbed little to no water consistent with XLPE.

Materials Characterization

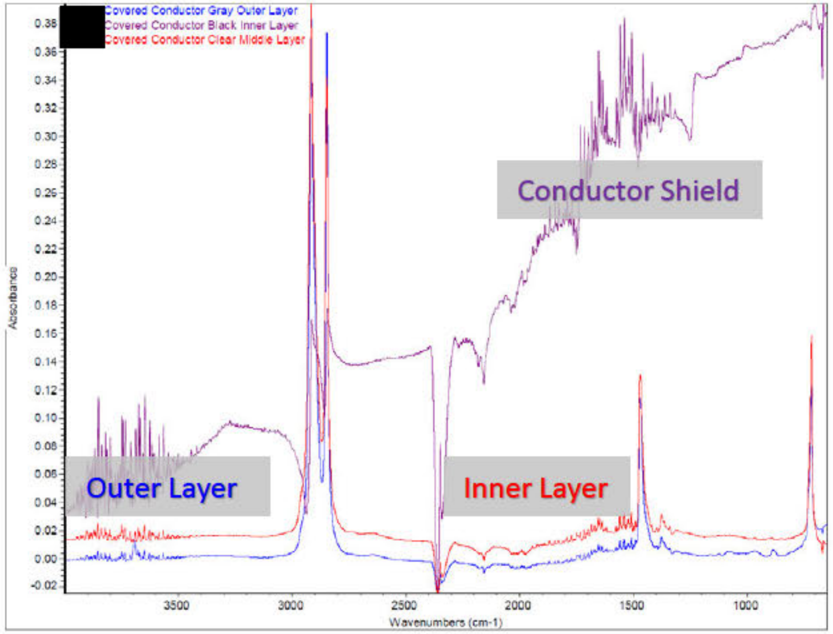
4. Layer Identification (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Characterize and baseline layer materials
- Test setup: The cable sections were dissected, and each polymer layer was tested with Fourier-transform infrared spectroscopy (FTIR)

[redacted] FTIR spectrums



[redacted] FTIR spectrums



[redacted] and [redacted] inner and outer layers exhibit characteristics of XLPE. Each shield layer was more complex and could not be determined.

Materials Characterization

5. Thermal Properties of Layers (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Understand thermal properties of layers versus operating temperatures of conductors
- Test guideline: ASTM D3418
  - "Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry"
- Thermal measurements were performed with Differential Scanning Calorimetry (DSC) on each layer

Sample	Test Values
[redacted] Outer Layer	Tg = 36° C Melt Onset = 117° C Melt Peak = 125° C Enthalpy = 130.3 J/g
[redacted] Inner Layer	Tg = 36° C Melt Onset = 87° C Melt Peak = 119° C Enthalpy = 102.0 J/g
[redacted] Conductor Shield Layer	Tg = 34° C Melt Onset = 87° C Melt Peak = 103° C Enthalpy = 38.07 J/g

Sample	Test Values
[redacted] Outer Layer	Tg = 49° C Melt Onset = 95° C Melt Peak = 104° C Enthalpy = 102 J/g
[redacted] Inner Layer	Tg = 48° C Melt Onset = 94° C Melt Peak = 104° C Enthalpy = 109 J/g
[redacted] Conductor Shield Layer	Tg = 42° C Melt Onset = 42° C Melt Peak = 85° C Enthalpy = 44 J/g

No degradation of [redacted] covered conductor is expected up to emergency operating temperatures. [redacted] shield layer may be prone to thermal degradation at repeated exposure to emergency temperatures.

Material Characterization

6. Heat Shrinkage Test (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Understand if conductor could become exposed at elevated temperatures.
- Test guideline: Required per EN 60811-502: Shrinkage Test for Cable Insulation at 130°C.
  - Also interested in % shrinkage at emergency operating temperatures
- Test setup: Cover conductors are conditioned at temp in air circulating chamber; measure final distance between separation marks and calculate % change.

Sample	Conditioning Temperature (°C)	Avg Initial Length (mm)	Avg. ΔL (%)	St. Dev.
[redacted] 397.5 AAC	130	200.0	1.1	0.15
	85	136.8	0.6	0.06
[redacted] 1/0 ACSR	130	200.0	0.0	0.25
	90	135.2	0.40	0.04

[redacted] covered conductors exhibited higher heat shrinkage than [redacted] covered conductor.

Flammability Test

7. Flammability Test (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Evaluates the flame resistance and self-extinguishing characteristics of the cover conductors
- Test guideline: per UL 2556 Section 9.1 FT2 (horizontal) and UL 2556 Section 9.3 FT1 (vertical).
  - The FT2 test involves flaming a horizontal section of the covered conductor for 30 seconds with some cotton wadding under the flamed area. Passing criterion includes flame propagation of less than 25mm/min, length of the carbonized region must not exceed 100mm, and the cotton wadding must not be ignited by dripping material.
  - The FT1 test involves flaming a vertical section of the covered conductor for 5 cycles of flame application for 15 seconds with a 15 second break. Passing criterion is that the sample must self-extinguish in less than 60 seconds after flame removal, and the cotton wadding underneath must not be ignited by dripping material.

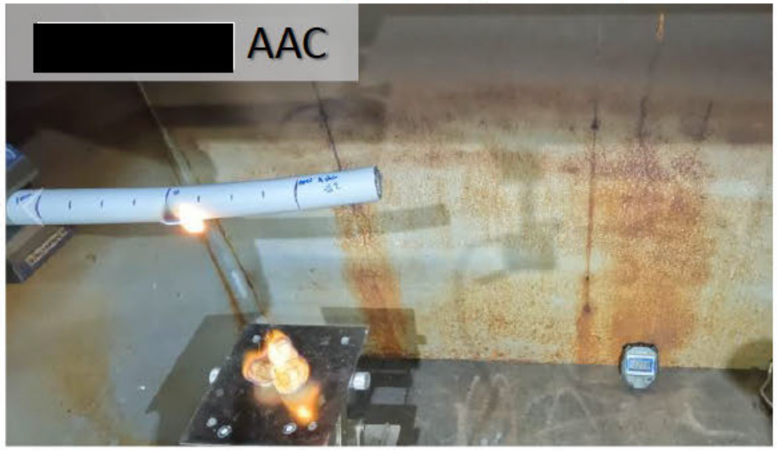
Test Sample Results	FT2	FT1
[redacted] AAC	Fail	N/A
[redacted] ACSR	Fail	N/A
[redacted] Grey CCSX Hybrid ACSR	Fail	N/A
[redacted] Grey CCSX Hybrid ACSR	Fail	N/A
[redacted] CCSX Black	Pass	Fail
[redacted] FRNP	Pass	Pass

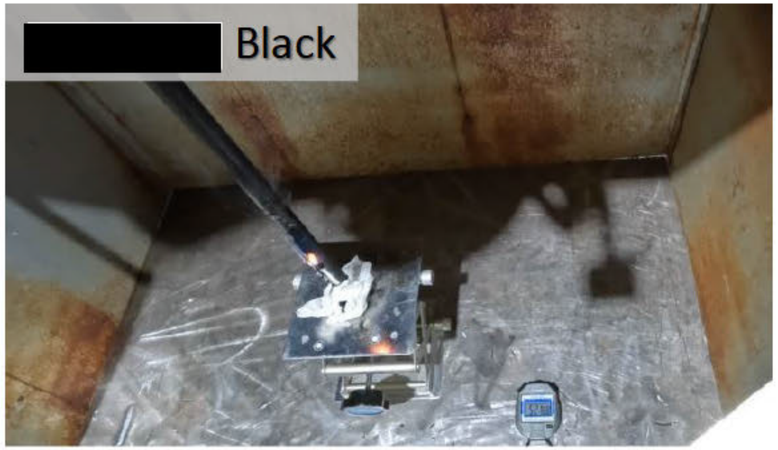
European Water Blocked Samples (Grey CCSX Hybrid ACSR, Grey CCSX Hybrid ACSR, CCSX Black)

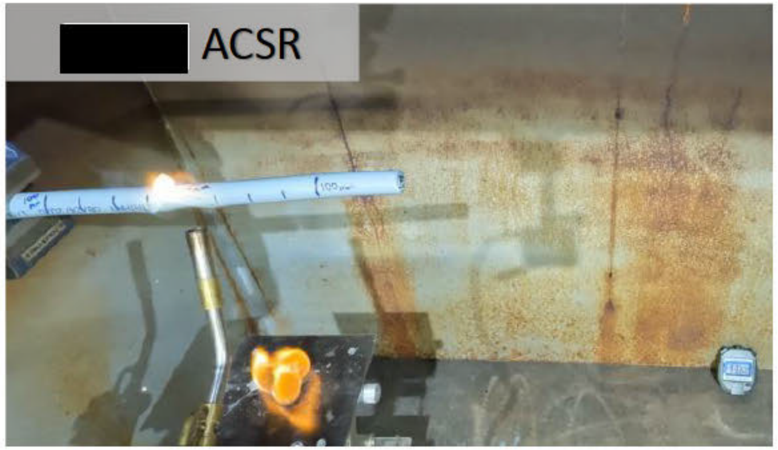
Self-Extinguishing (FRNP)

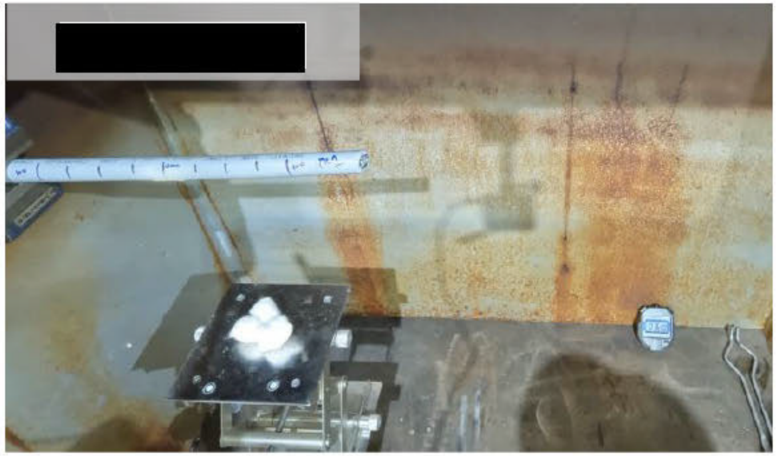
Materials Characterization

7. Flammability Test (cont'd)









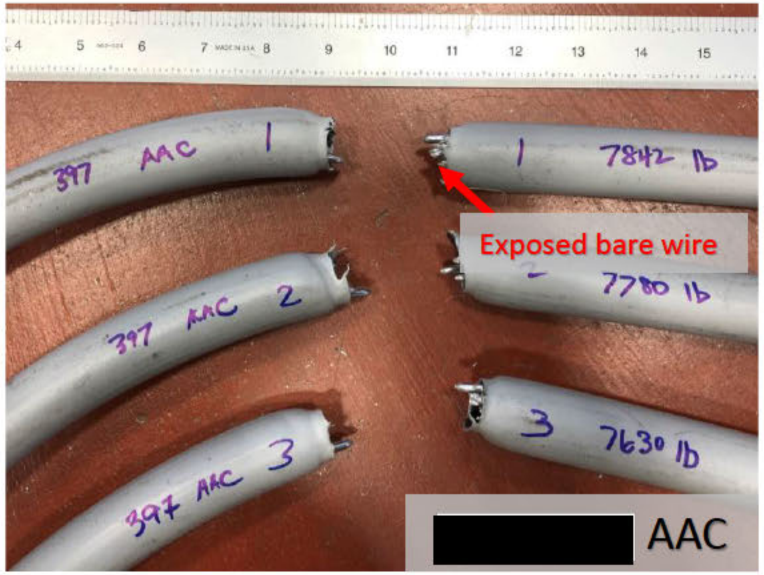
[redacted] and [redacted] covered conductors may be susceptible to catching on fire from fault(s) and/or lightning. The resulting droplets could catch vegetation on fire.

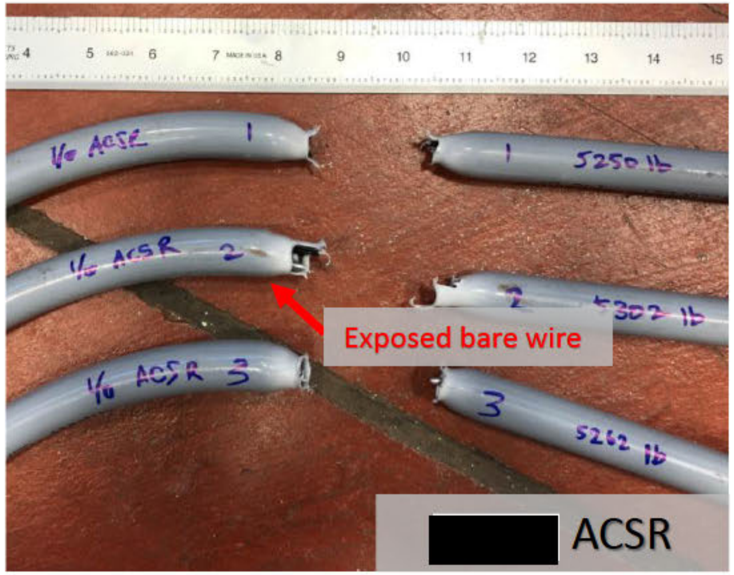
Materials Characterization

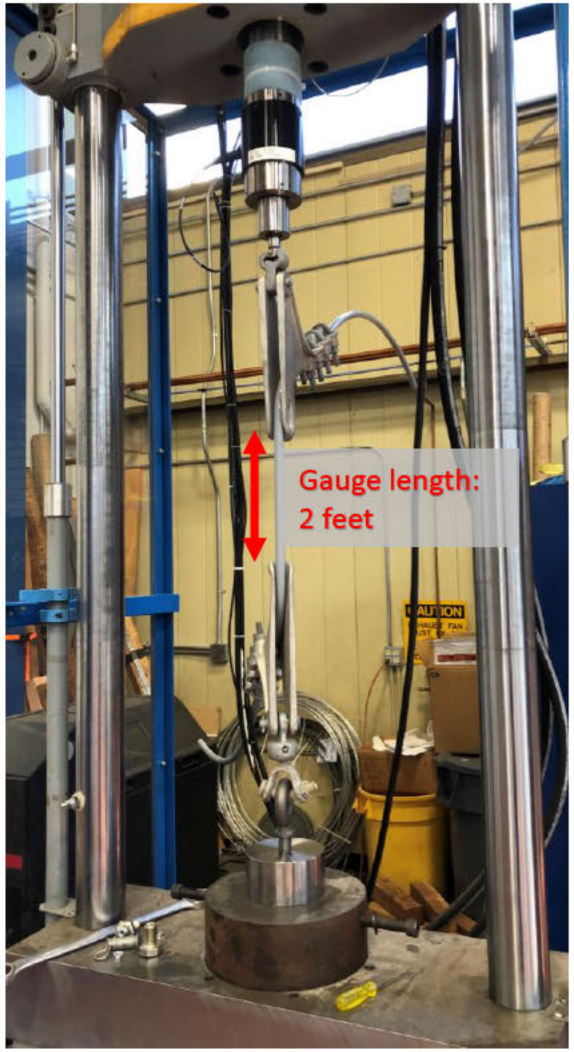
8. Tensile Strength (Required per ANSI/ICEA S-121-733)

- Intent of test: Confirm conductors meet rating and characterize fractures
- Test guideline: Test RBS per ASTM B231 & ASTM B232

	Avg Tensile Strength (lb)	St Dev (lb)	Min RBS (lb)
[redacted] 397 AAC	7751	109.0	7110
[redacted] 1/0 ACSR	5271	27.2	4380







Both [redacted] and [redacted] samples met the required RBS. Fractures are susceptible to exposing metallic conductor.

Environmental Resistance Characterization

9. Accelerated Atmospheric Corrosion Test (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Understand corrosion resistance of covered conductor + connectors relative to bare
- Test guideline: per ASTM B117: Atmospheric Corrosion for 1000 total hours of exposure at 35±2^{o}C chamber temperature continuous 5% neutral NaCl fog solution.
- Samples evaluated:
  - 397.5 AAC Bare (3)
  - 1/0 ACSR Bare (3)
  - [redacted] 1/0 ACSR Covered (3) + (3) MVFT (medium voltage fusion tape) + gel splice (3)
  - [redacted] 397.5 AAC Covered (3) + gel splice (3)
  - [redacted] 1/0 ACSR Covered: Added to test configuration to assess influence of water blocking agents
- Results
  - Gel splice prevented water intrusion; MVFT did not
  - Corrosion was elevated in covered conductors relative to bare
  - Water blocking agents are capable of preventing moisture ingress in covered conductors
  - All conductors still met RBS after 1000 hours of salt fog testing

Covered conductors (CC), in general, are expected to corrode at an accelerated rate relative to bare conductors. Spans with CC exposed at dead-ends are susceptible to faster corrosion rates due to water ingress. Water ingress may continue to the lowest point in line. Gel splices perform better than MVFT.

Environmental Resistance Characterization

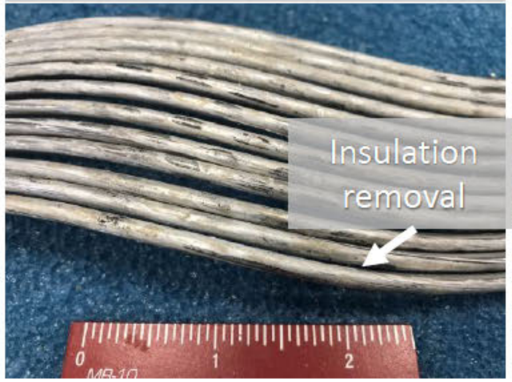
9. Atmospheric Corrosion Test (cont'd)

- Visual Results after 1000 hours (insulation removed)
  - Aluminum strands had more corrosion in covered conductors relative to bare
  - Steel strands had significant white rust present; had not progress to red rust
  - Water blocker inhibited moisture ingress

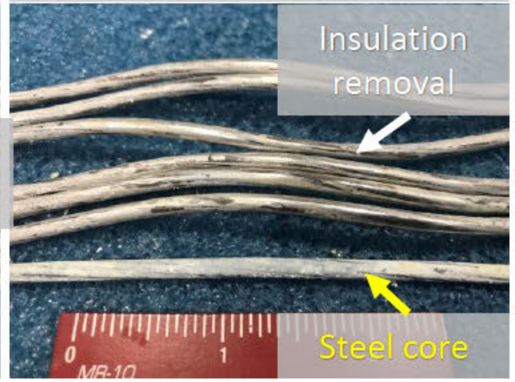
Bare AAC

Bare ACSR

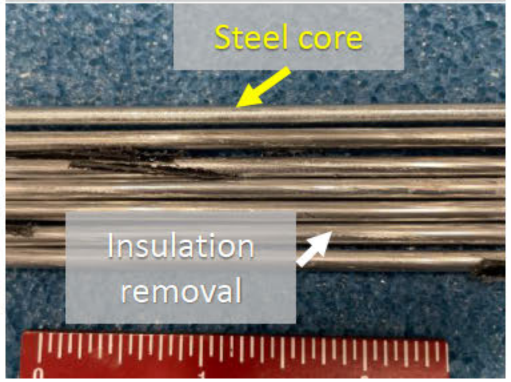
[redacted] AAC



[redacted] ACSR



[redacted] ACSR (Water Blocker)



- Tensile Results
  - All samples met RBS rating

Sample	Bare AAC	[redacted] CC AAC	ASTM B230 AAC Avg Min	Bare ACSR	[redacted] CC ACSR	[redacted] CC ACSR	ASTM B230 ACSR Avg min	ASTM B498 ACSR Avg min
Al (average)	26.4 ksi	24.8 ksi	24.5 ksi	26.4 ksi	25.4 ksi	24.6 ksi	25.0 ksi	
Steel core				230 ksi	232 ksi	218 ksi		205 ksi

Environmental Resistance Characterization

9. Atmospheric Corrosion Test (cont'd)

- Splice Results: Gel splice wraps performed better at inhibiting moisture ingress

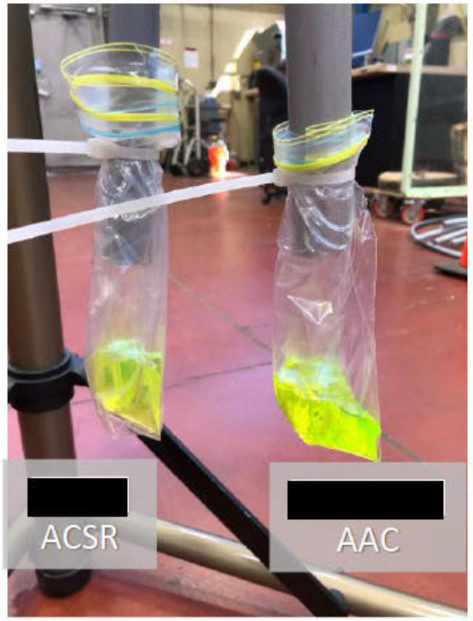
Splice cover removed after 1000 hrs

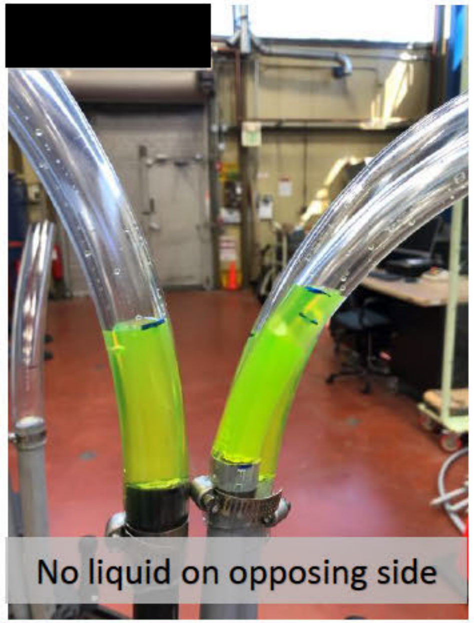
Ends at increased magnification

Environmental Resistance Characterization

10. Water Ingress Test (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Understand the role of water blocking
- Test guideline: ANSI/ICEA T-31-610-2018 Section 4.
  - Fluorescent water was introduced to the end of a vertically mounted 36in length covered and assess penetration after 2 hours.
  - Sample tested: [redacted] (No Water Blocking), [redacted] (No Water Blocking), and [redacted] (Water Blocked).
- Results:





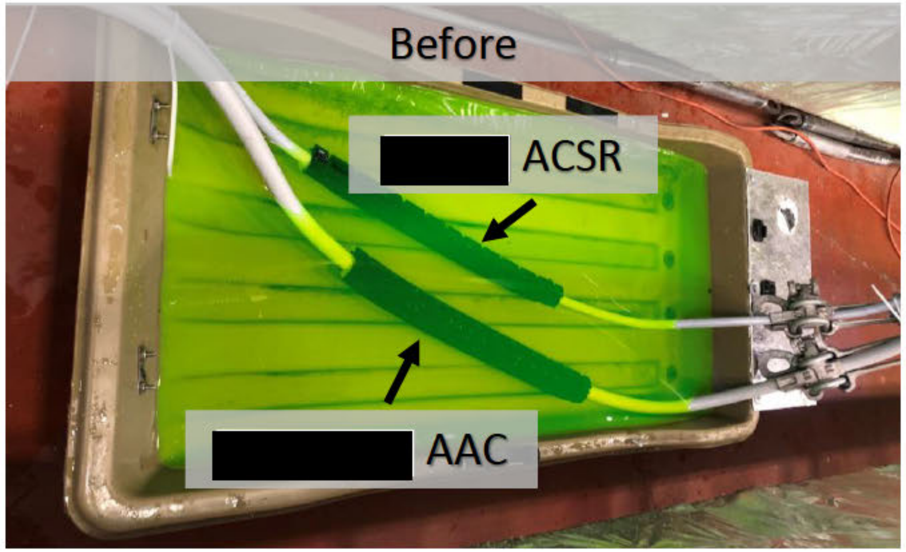
Test Setup

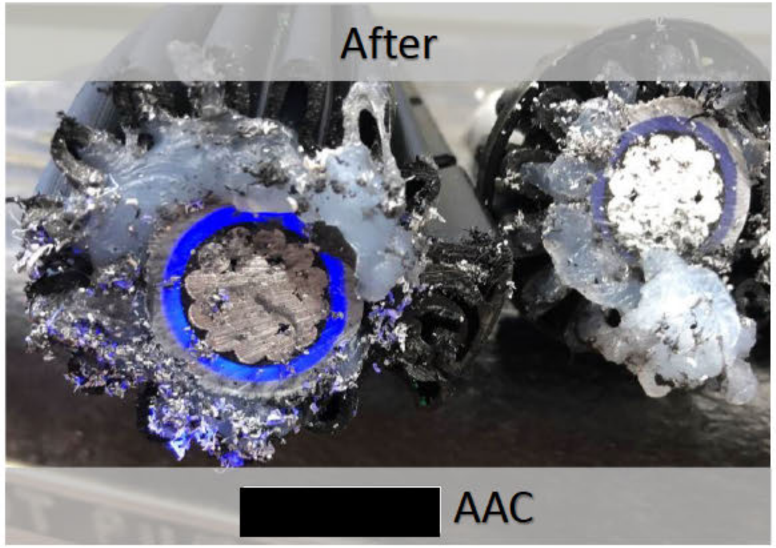
Water blocking agents can prevent moisture ingress in covered conductors, otherwise, moisture travels unimpeded accelerating internal corrosion.

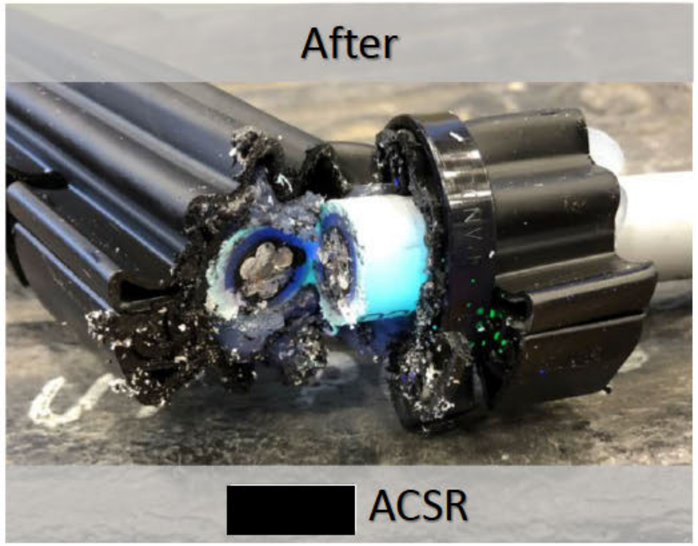
Environmental Resistance Characterization

11. Water Immersion Test

- Intent of test: Evaluate effectiveness of splice gel wraps
- Test setup (No relevant standard): Covered conductors with gel wraps fully submerged in fluorescent water for 2.5 hours. Then dissected and inspected with UV light for water intrusion
- Results: Both samples did not exhibit any signs of water intrusion.







[redacted] and [redacted] splice gel wraps effective at inhibiting external water intrusion to splice.

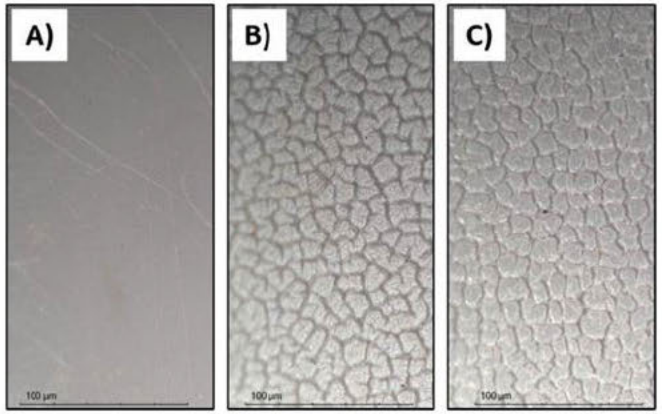
Environmental Resistance Characterization

12. UV Weathering Test

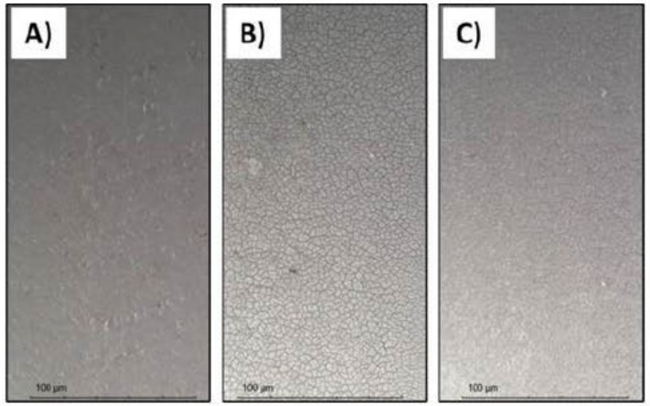
- Test guideline: Up to 1000hr Exposure to ASTM G155-21 (Table X3.1 Cycle 8)
- Test setup: 4hr @ 0.55 W/m²•nm light, 340nm λ, 50% relative humidity, 62°C chamber temp; 1hr dark, 95% humidity, 62°C temp (Sequentially).
- Requirements: Per ANSI/ICEA S-121-733, outer jacket considered sunlight resistant if ratio for original to aged tensile and elongation is >= 80% after 720h
- Results: Surface crazing occurred on both conductors by end of test*

*Mechanical testing occurred at 750 hr versus targeted 720 hr.

Sample	Average Tensile Property	As received	*750 hours	1000 hours	% change
[redacted] AAC	Stress at max force (MPa)	16.33	15.78	15.59	-4.57%
	Elongation at max force (%)	28.82	16.77	18.08	-37.25%
	Stress at break (MPa)	0.67	0.72	6.14	813.69%
	Elongation at break (%)	131.17	94.12	79.20	-39.62%
[redacted] ACSR	Stress at max force (MPa)	14.46	14.49	14.30	-1.11%
	Elongation at max force (%)	80.67	82.34	89.51	10.95%
	Stress at break (MPa)	1.44	9.86	12.32	757.80%
	Elongation at break (%)	146.94	97.81	105.66	-28.10



Microscope surface characterization of the [redacted]cable insulation at A) 0 hrs of weathering, B) 1000 hrs of weathering, and C) after 1000 hrs of weathering but wiped with a damp lab tissue.



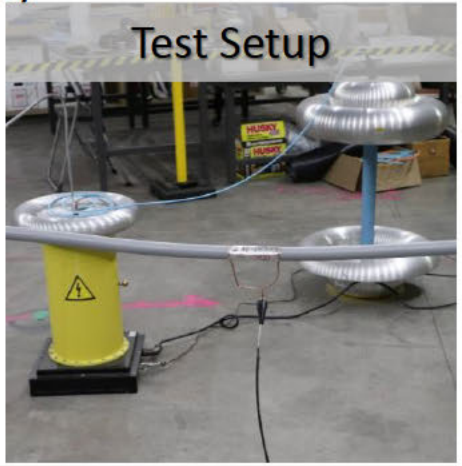
Microscope surface characterization of the [redacted]able insulation at A) 0 hrs of weathering, B) 1000 hrs of weathering, and C) after 1000 hrs of weathering but wiped with a damp lab tissue.

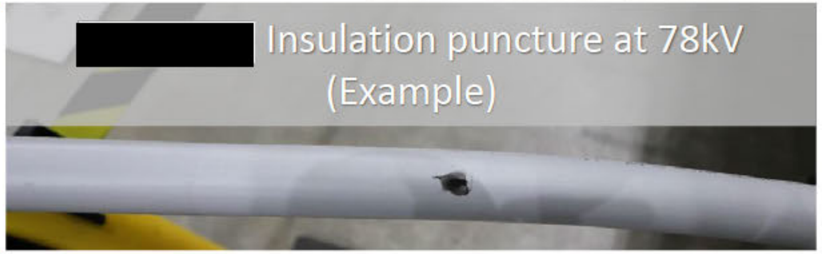
Per ANSI/ICEA S-121-733, both jackets appeared not to meet sunlight resistant designation, and are anticipated to become more brittle over time.

Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Understand replacement strategy for compromised jacket
- Test guideline: European Standard EN 50397-1:2020
- Test setup: Test at full insulation and 50% abraded insulation
- Requirements: Leakage current not to exceed 1mA at rated voltage.
- Results: All components tested exceeded the electrical specified dielectric rating.
  - [redacted] 15kV rated 397 AAC covered conductor
    - Insulation failed at 78kV. This calculates to 520% of the insulation rating.
    - For the 50% abraded insulation, the insulation failed at 68kV. This calculates to 453% of the insulation rating.
  - [redacted] 15kV rated 1/0 ACSR covered conductor
    - Insulation failed at 90kV. This calculates to 600% of the insulation rating.
    - For the 50% abraded insulation, the insulation failed at 40kV. This calculates to 266% of the insulation rating.





Both [redacted] and [redacted] covered conductors are expected to meet leakage current per European Standard EN 50397-1:2020, and maintain a 2X insulation rating even with compromised outer layer exposing inner layer.

Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Understand electrical insulating properties of splice coverings
- Test setup: Splice covering placed in 4" PVC conduit embedded in No 8 steel shot which served as the measuring electrode. Voltage applied to conductor and the return lead connected to the measuring electrode. Leakage current measured as voltage ramped up until dielectric breakdown.
- Results:
  - Compression splice with Gel Wrap: Withstood a minimum of 23kV between the splice and the outer electrode.
  - Compression splice with MVFT: Withstood a minimum of 19kV between the splice and the outer electrode.
  - Fired Wedge connector with cover: Withstood a minimum of 19kV between the wedge connector the electrode.

The splice covering maintains or exceeds the rating of the covered conductor insulation rating.

Electrical Testing Characterization

14. Tracking Resistance Test: Inclined Plane Tracking and Erosion (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Better understand susceptibility to tracking damage
- Test guideline: EN 50397-1:2020, Annex B.
- Test setup: Test voltage: 3.5 kV, Duration of the test: 6.0 h, Series resistor: 22 kΩ, Contaminant flow rate: 0.3 mL/min
- Requirements: The test is successful if the current in the high-voltage circuit does not exceed 60 mA for any of the 5 samples for 6 hours.
- Results: Both covered conductor types passed the test.
- Erosion depth (mm):

Sample	**1**	**2**	**3**	**4**	**5**
[redacted] AAC	0.33	0.81	0.53	0.90	0.31
[redacted] ACSR	0.22	0.23	0.26	0.41	0.24

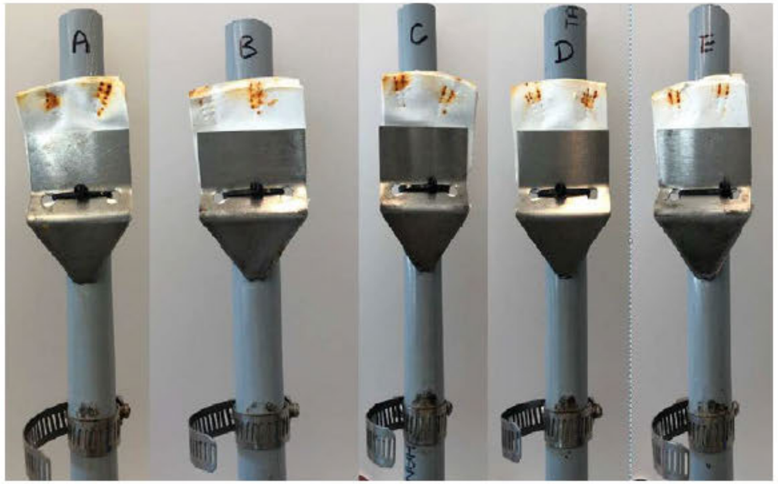
Both [redacted] and [redacted] passed the test criteria. [redacted] had a higher erosion depth than [redacted]

Electrical Testing Characterization

14. Tracking Resistance Test: Inclined Plane Tracking and Erosion (cont'd)

- [redacted] conductor after the test:

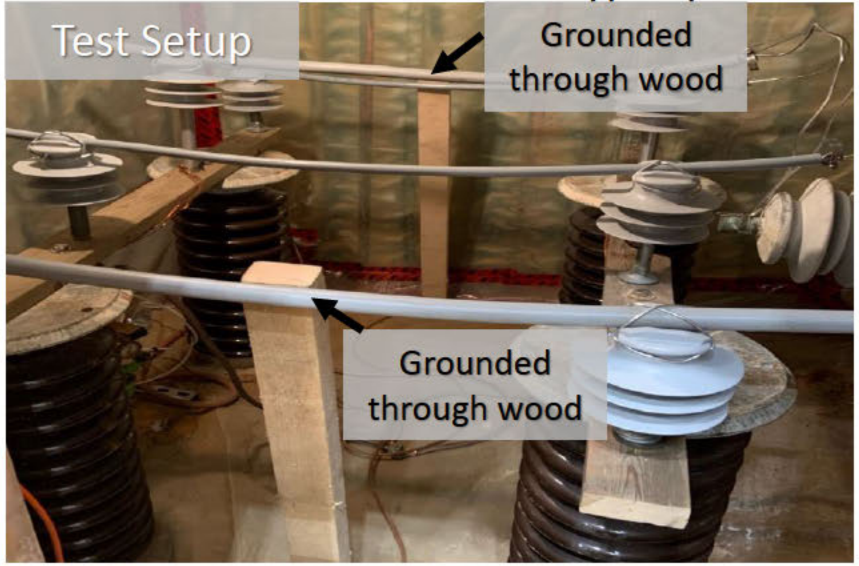
- [redacted] conductor after the test:



Electrical Testing Characterization

15. Tracking Resistance with Salt Fog (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Understand implications of long-term vegetation contact
- Test guideline: from IEC 62217:2012, Clause 9.3.3
- Test setup: Duration of the test: 1004.5 hours, Test voltage: 12.1kV_{rms}, Initial NaCl content of water: 8kg/m^3, Precipitation rate: 1.75 mL/hr
- Requirements: A sample passes the test if no tracking occurs; for composite insulators: erosion depth is less than 3 mm and does not reach the core (if applicable), and no shed, housing, or interface is punctured.
- Results: Both covered conductor types passed the test. [redacted] had a higher erosion depth than Taihan.



Wood Placement on [redacted]

Wood Placement on [redacted]

Long term vegetation contact can cause damage and/or erosion on both [redacted] and [redacted] covered conductors.

Electrical Testing Characterization

16. Lightning Impulse Test (Not Required per ANSI/ICEA S-121-733)

- Intent of test: Better understanding for how lightning could damage covering
- Test guideline: custom test with guidance from IEEE Std. 4 and IEC 60060-1
- Test Setup:
  - Three 3-ft long samples of each conductor were cut from their rolls, and the ends were stripped to reveal the bare stranded conductor. A section of aluminum mesh was wrapped around the center of each sample of the conductor.
  - The high-voltage lead was connected to the bare-stranded conductor, and the aluminum mesh was connected to ground. The samples were placed in insulating oil to prevent flashover from the ends.
  - The conductor samples were then subjected to lightning impulses of increasing voltage until a breakdown occurred. The voltage was started at 85 kV and then raised by approximately 5 kV on each successive impulse.
- Results - Breakdown voltage (kV):

Sample	1	2	3	kV_{peak}
[redacted] AAC	102.5	95.6	110.2	102.8
[redacted] ACSR	96.2	90.1	95.1	93.8

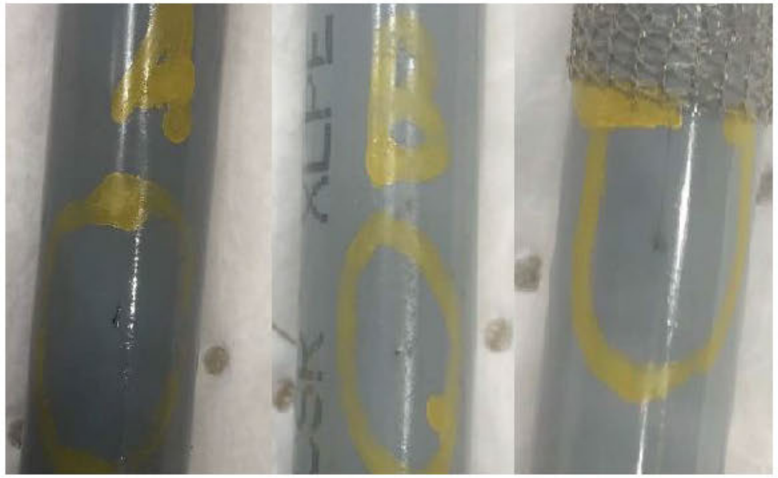
Both [redacted] and [redacted] covered conductors had similar performances under lightning. Insulation could be damaged by lightning. Damaged is expected to be localized.

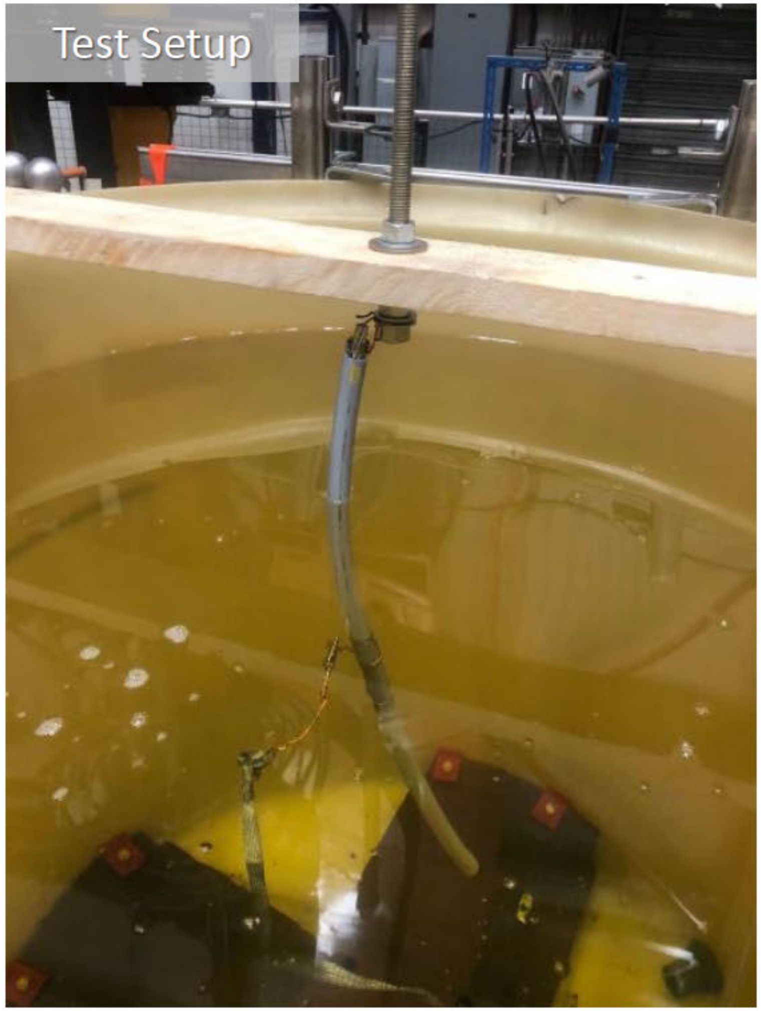
Electrical Testing Characterization

16. Lightning (Impulse Test, cont'd)

– Lightning impulse puncture locations - [redacted] conductor

– Lightning impulse puncture locations - [redacted] conductor





SCE Test Results (1/2)

Phase-to-Phase Contact Testing

- The tested CCs prevented arcing and limited current flow to <1 mA in all scenarios tested at rated voltages (17 kV and 35 kV).
- Phase-to-phase contact was created using various foreign objects including vegetation, wildlife, mylar balloons, and conductor slapping. Tests were performed with vegetation/soil properties representative of the SCE service territory.
- Both dry and wet environmental conditions were simulated, and various conductor conditions were analyzed including wildlife guards and simulated damage/abrasion to the conductor sheath.
- The only observed conductor insulation breakdown occurred for the 17 kV rated conductor at >3X the rated voltage and only when a half-thickness coating flaw was introduced.

Simulated Wire-Down Testing

- The tested CCs prevented arcing and fuel ignition in simulated wire-down events.
- Several tests performed with bare conductor under the same conditions resulted in ignition of the dry fuel bed.
- Full-thickness coating flaws also resulted in arcing and fuel ignition.
- Simulating a broken CC resulted in ignition.

SCE Test Results (2/2)

Fire Risk

- To understand the effects of a nearby wildland fire on CCs, tests were conducted to understand at what heat flux the polyethylene covering would auto-ignite.
- Results suggested that the heat fluxes and times required for auto-ignition of the polyethylene sheaths were unlikely to be encountered during a surface or low-lying brush fire; however, a canopy fire may be sufficient to cause conductor sheath ignition.

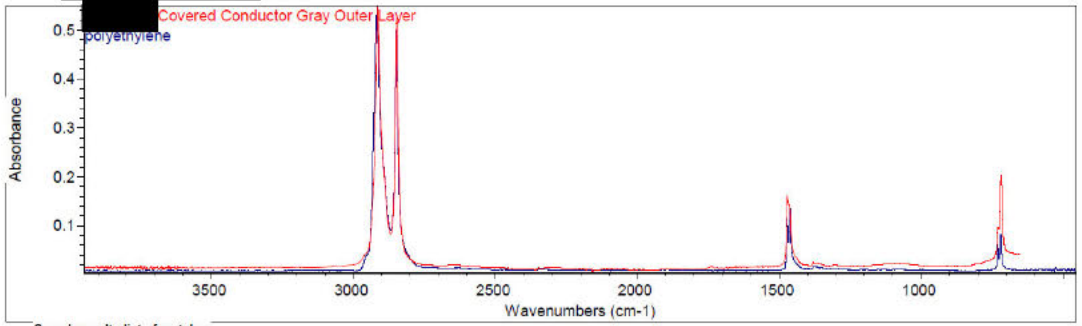
Corrosion Susceptibility

- Water ingress testing was performed to understand if implementation of CCs introduces a unique corrosion risk relative to bare conductors. Stripped ends of CCs were found to be susceptible to water ingress. While the test conditions were extreme relative to typical service conditions and did not account for potential heating/evaporation in service, water may percolate down the conductor length from a stripped end in some scenarios.
- Corrosion was observed under the CC sheath near the stripped ends following salt spray testing. While this indicates that subsurface corrosion is possible near a stripped CC end, subsequent tensile testing showed minimal reduction in total strength of the conductor. Potential water-ingress mitigation measures may be beneficial in areas where precipitation is likely to collect on the conductor.

Materials Characterization: FTIR Data

4. Fourier-transform infrared spectroscopy (FTIR)

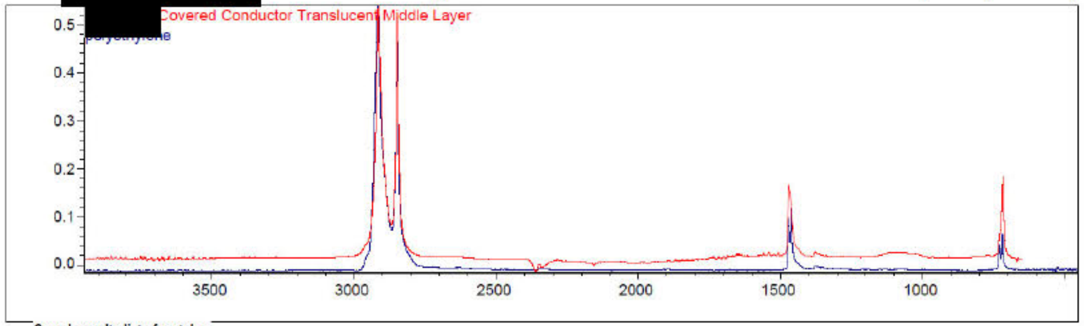
– [redacted] Outer Layer FTIR: consistent with polyethylene



Search results list of matches

	Index	Match	Compound Name	Library Name
1	625	91.06	polyethylene	HR Nicolet Sampler Library
2	768	80.58	NATURAL VEGETABLE WAX FROM MEXICAN SHRUB	HR Nicolet Sampler Library
3	769	77.26	Natural vegetable wax from Brazilian palm trees	HR Nicolet Sampler Library
4	604	76.15	oxidized polyethylene	HR Nicolet Sampler Library
5	32	73.72	POLY(ETHYLENE:PROPYLENE:DIENE)	Hummel Polymer Sample Library
6	7	73.06	POLY(ETHYLENE)	Hummel Polymer Sample Library

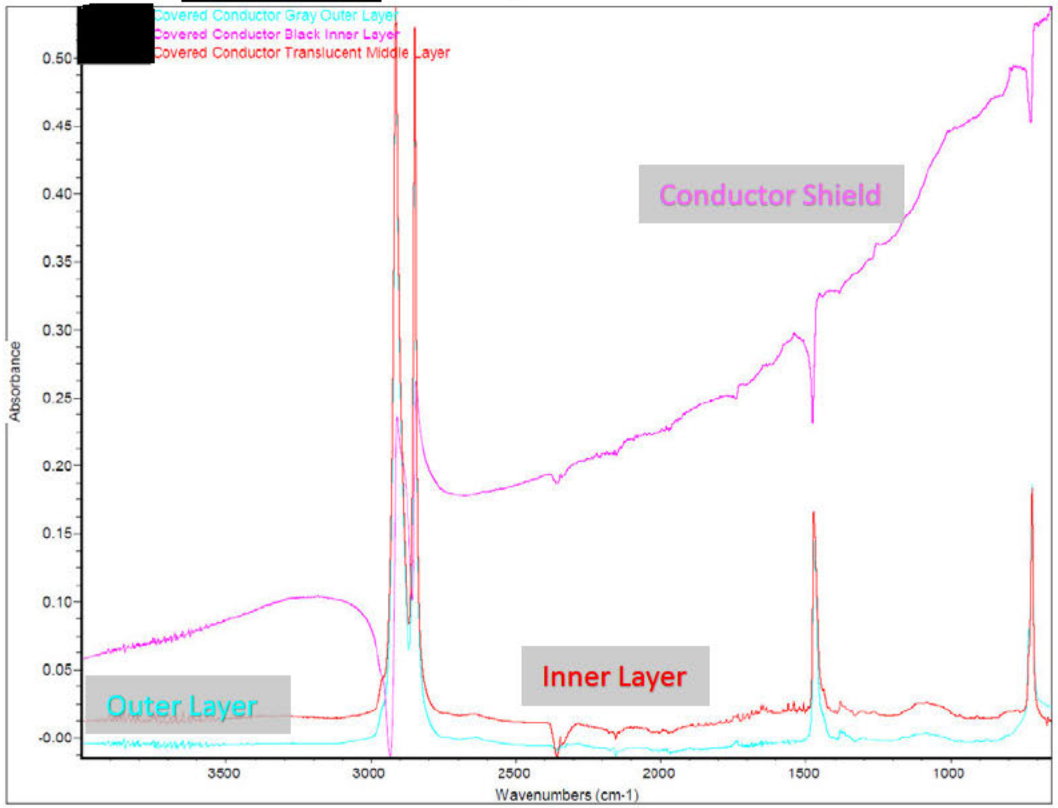
– [redacted] Inner Layer FTIR: consistent with polyethylene



Search results list of matches

	Index	Match	Compound Name	Library Name
1	625	89.46	polyethylene	HR Nicolet Sampler Library
2	768	78.30	NATURAL VEGETABLE WAX FROM MEXICAN SHRUB	HR Nicolet Sampler Library
3	769	74.93	Natural vegetable wax from Brazilian palm trees	HR Nicolet Sampler Library
4	32	74.35	POLY(ETHYLENE:PROPYLENE:DIENE)	Hummel Polymer Sample Library
5	7	73.70	POLY(ETHYLENE)	Hummel Polymer Sample Library
6	604	73.31	oxidized polyethylene	HR Nicolet Sampler Library

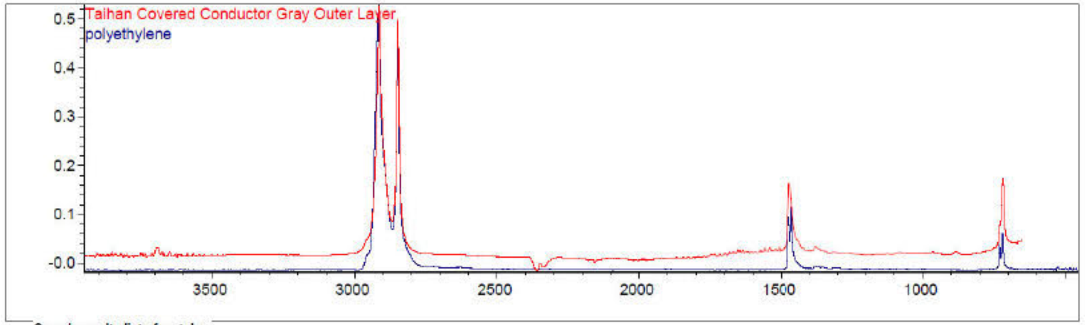
– [redacted] FTIR spectrum raw data



Materials Characterization: FTIR Data

4. Fourier-transform infrared spectroscopy (FTIR)

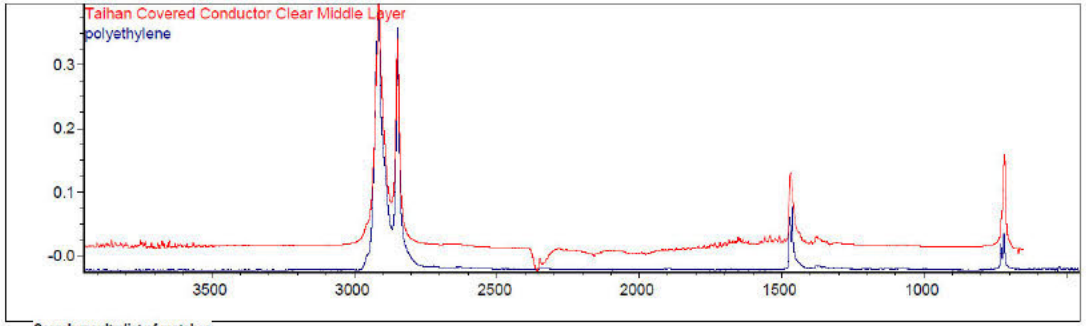
– [redacted] Outer Layer FTIR: consistent with polyethylene



Search results list of matches

	Index	Match	Compound Name	Library Name
1	625	90.44	polyethylene	HR Nicolet Sampler Library
2	768	79.23	NATURAL VEGETABLE WAX FROM MEXICAN SHRUB	HR Nicolet Sampler Library
3	32	76.55	POLY(ETHYLENE:PROPYLENE:DIENE)	Hummel Polymer Sample Library
4	769	75.94	Natural vegetable wax from Brazilian palm trees	HR Nicolet Sampler Library
5	7	74.59	POLY(ETHYLENE)	Hummel Polymer Sample Library
6	752	74.53	ETHOXYLATED STEARYL AMINE	HR Nicolet Sampler Library

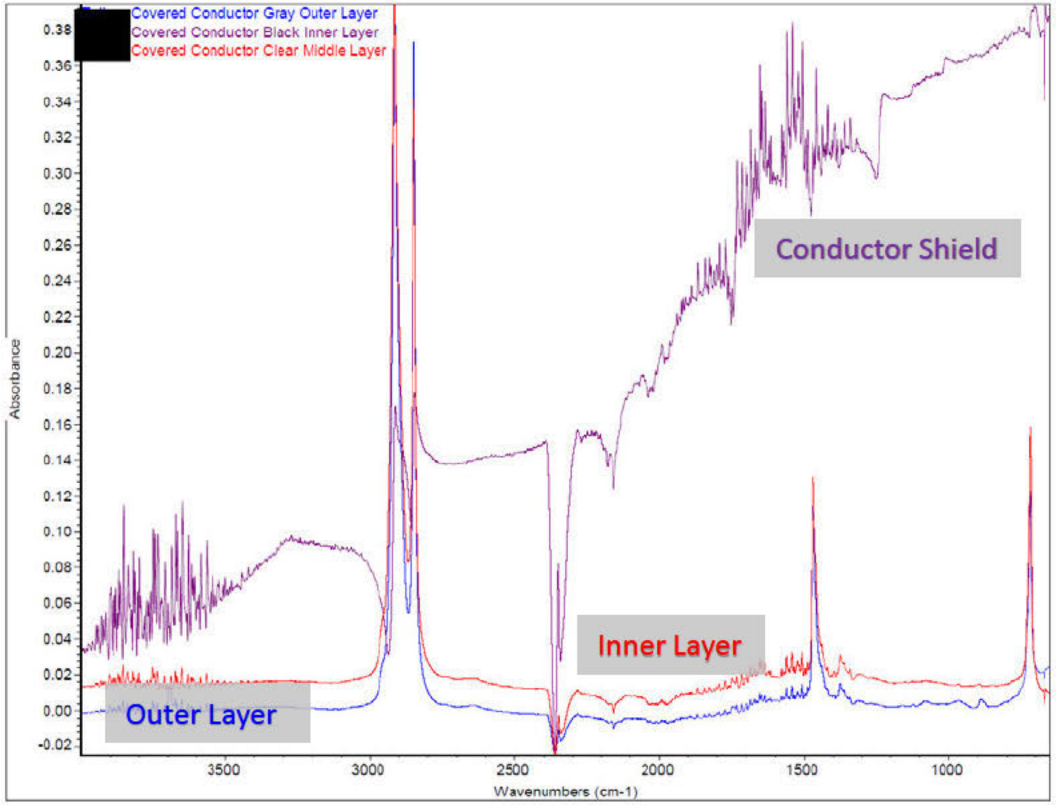
– [redacted] Inner Layer FTIR: consistent with polyethylene



Search results list of matches

	Index	Match	Compound Name	Library Name
1	625	86.63	polyethylene	HR Nicolet Sampler Library
2	32	82.45	POLY(ETHYLENE:PROPYLENE:DIENE)	Hummel Polymer Sample Library
3	752	81.28	ETHOXYLATED STEARYL AMINE	HR Nicolet Sampler Library
4	768	80.12	NATURAL VEGETABLE WAX FROM MEXICAN SHRUB	HR Nicolet Sampler Library
5	7	80.10	POLY(ETHYLENE)	Hummel Polymer Sample Library
6	769	78.78	Natural vegetable wax from Brazilian palm trees	HR Nicolet Sampler Library

– Taihan FTIR raw data

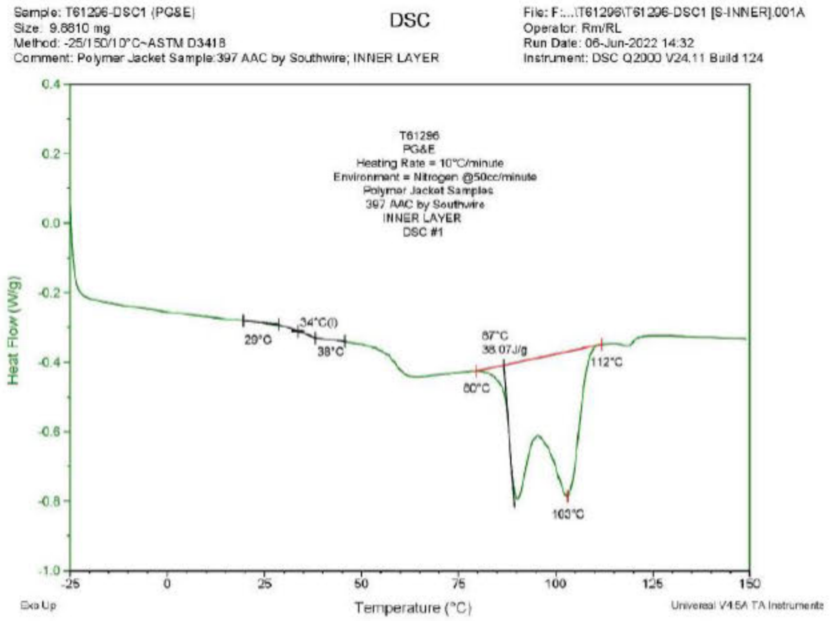


Materials Characterization

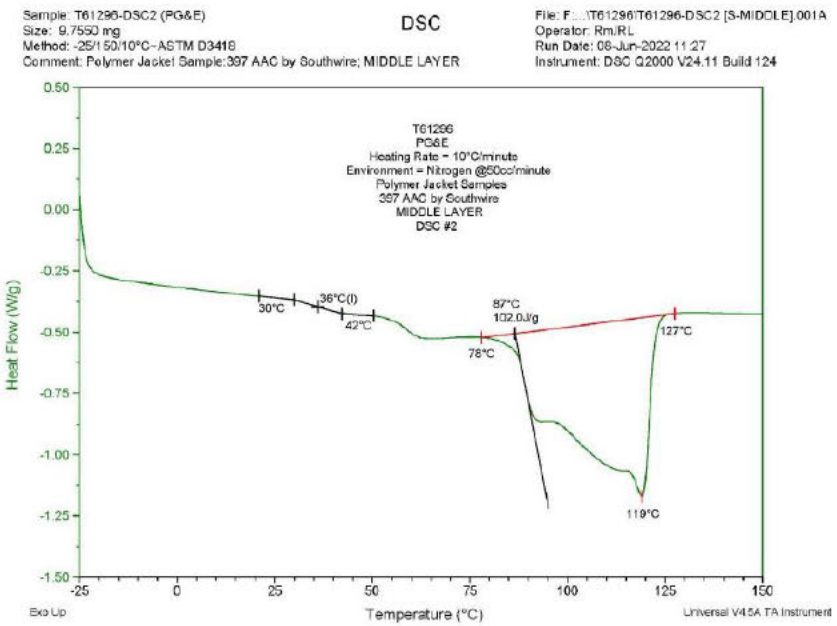
5. Thermal Properties of Layers (Not Required per ANSI/ICEA S-121-733)

- Thermal measurements were performed with Differential Scanning Calorimetry (DSC) on each layer

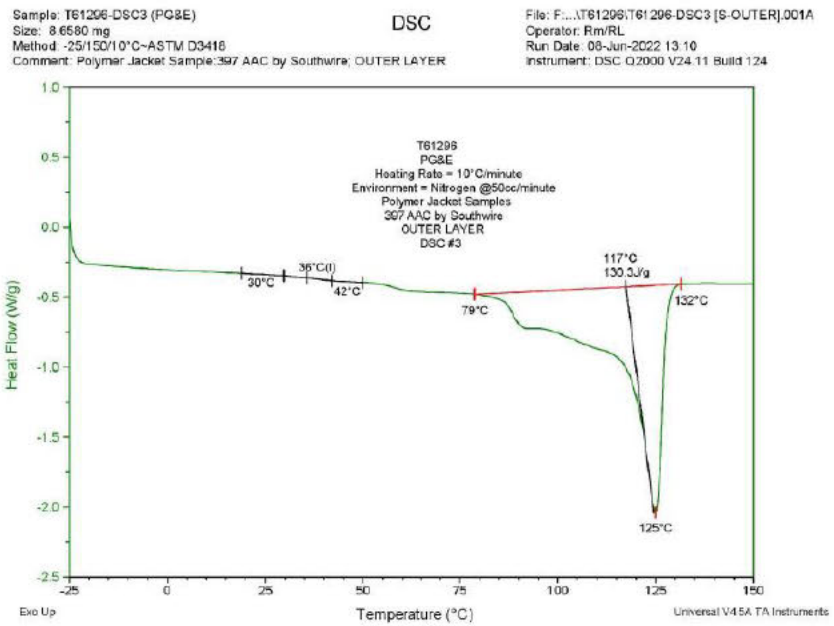
DSC Thermogram (DSC 1 ~ SOUTHWEST INNER LAYER)



DSC Thermogram (DSC 2 ~ SOUTHWEST MIDDLE LAYER)



DSC Thermogram (DSC 3 ~ SOUTHWEST OUTER LAYER)



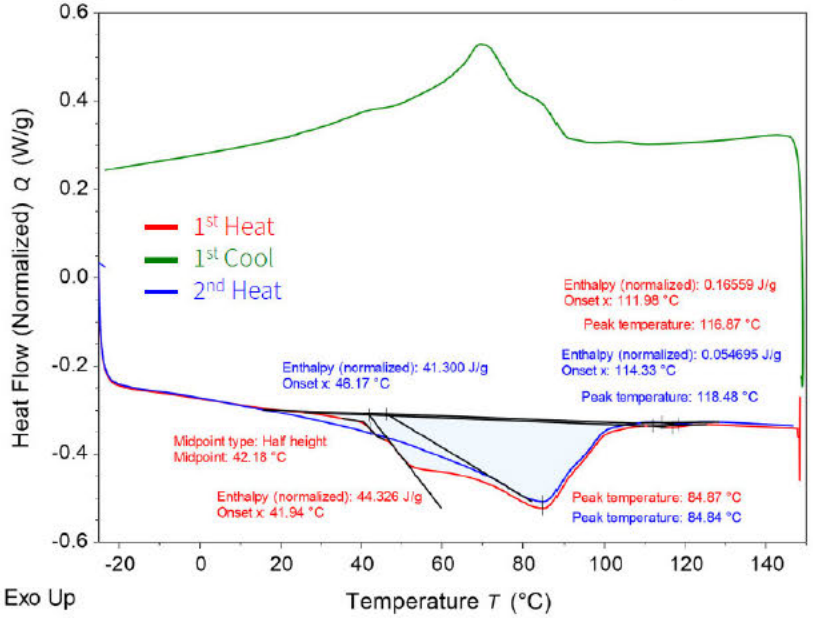
PG&E

Materials Characterization

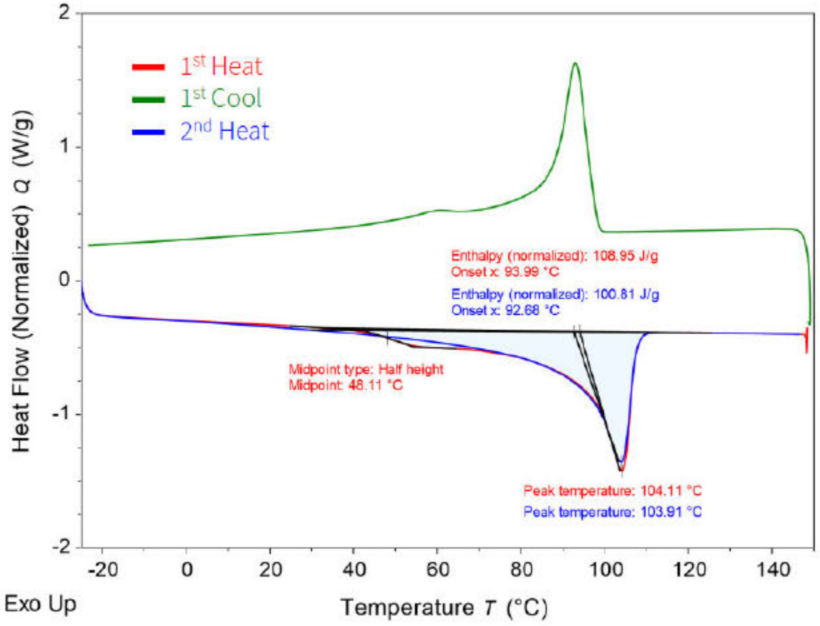
5. Thermal Properties of Layers (Not Required per ANSI/ICEA S-121-733)

- Thermal measurements were performed with Differential Scanning Calorimetry (DSC) on each layer

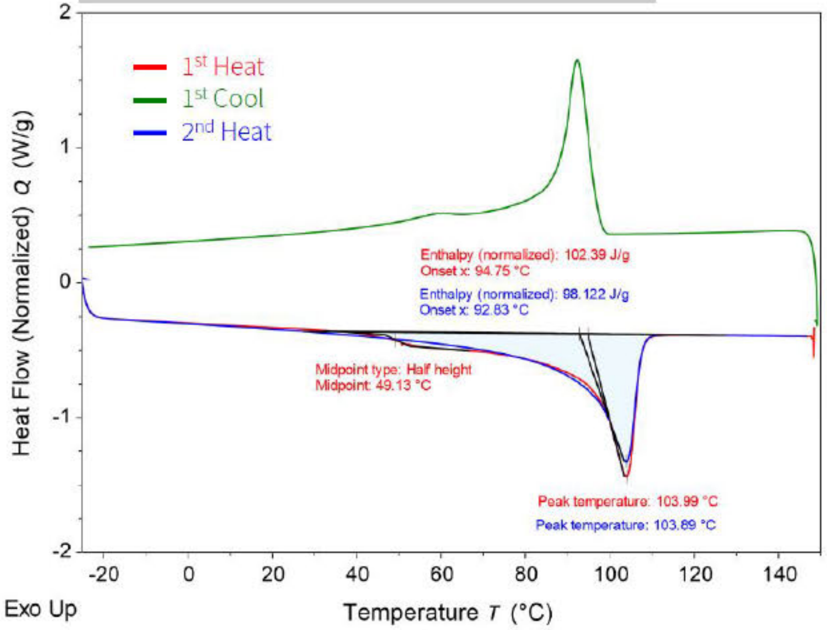
Taihan Inner Layer



Taihan Middle Layer



Taihan Outer Layer



Material Characterization

5. Heat Shrinkage Test (Not Required per ANSI/ICEA S-121-733)

- Intent of Test: Understand if conductor could become exposed at elevated temperatures
- Required per EN 60811-502: Shrinkage Test for Cable Insulation.
- Test: Cover conductors are conditioned at temp in air circulating chamber; measure final distance between separation marks and calculate % change

Sample	Conditioning Temperature (°C)	Initial Length (mm)	Final Length (mm)	Avg ΔL (%)
[redacted]	130	200.0	198.0	1
		200.0	198.0	1
		200.0	197.5	1.26
	85	136.78	136.07	0.52
		135.52	134.74	0.58
		135.33	134.47	0.64
[redacted]	130	200.0	200.5	-0.23
		190.0	189.5	0.26
		200.0	200.0	0.00
	90	135.16	134.61	0.41
		136.32	135.86	0.34
		135.00	134.50	0.37

[redacted] covered conductors exhibited higher heat shrinkage than [redacted] covered conductor.

Material Characterization: Tensile Test

8. Tensile Test

- An MTS 50kip vertical load frame was used to apply tensile loading for all samples.
- Samples were preloaded to 1,000lbf, then manually overloaded with displacement control until complete separation of the sample.
- All samples loaded from 1,000lbf to complete separation in approximately three seconds. All samples exceeded rated breaking strength, which indicates a successful tensile test without excessive stress concentrations.

Environmental Resistance Characterization

9. Accelerated Atmospheric Corrosion Test

ASTM B117: Atmospheric Corrosion for 1000 total hours of exposure at 35±2°C chamber temperature continuous 5% neutral NaCl fog solution.

- Samples tested: Bare AAC, bare ACSR, [redacted] AAC, [redacted] ACSR, [redacted], [redacted] ACSR +MVFT (medium voltage fusion tape), [redacted] AAC + gel splice, [redacted] ACSR + gel splice.

Bare AAC

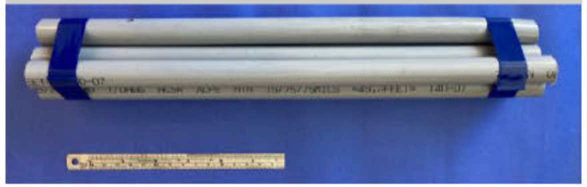
[redacted] AAC

[redacted]

[redacted] AAC + gel splice

Bare ACSR

[redacted] ACSR



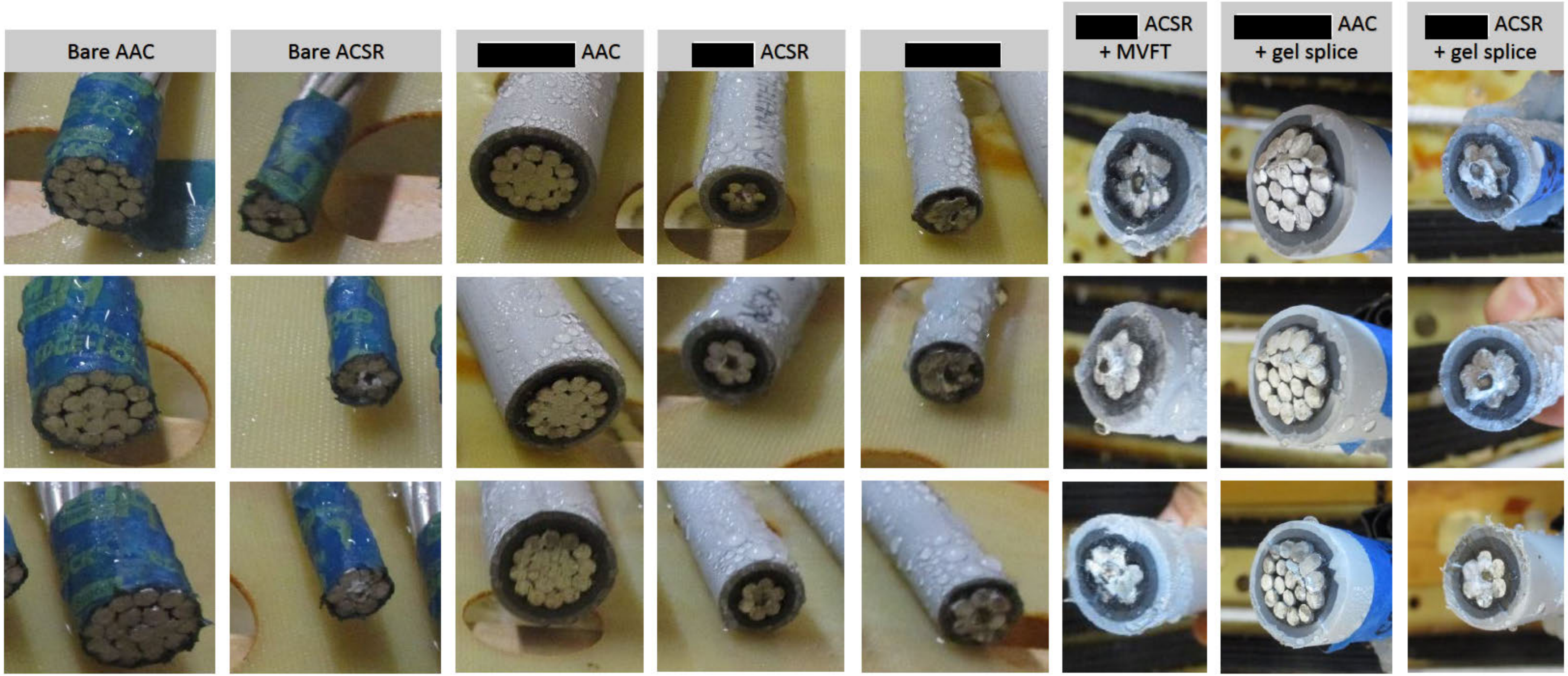
[redacted] ACSR + MVFT

[redacted] ACSR + gel splice

Environmental Resistance Characterization

9. Accelerated Atmospheric Corrosion Test (cont'd)

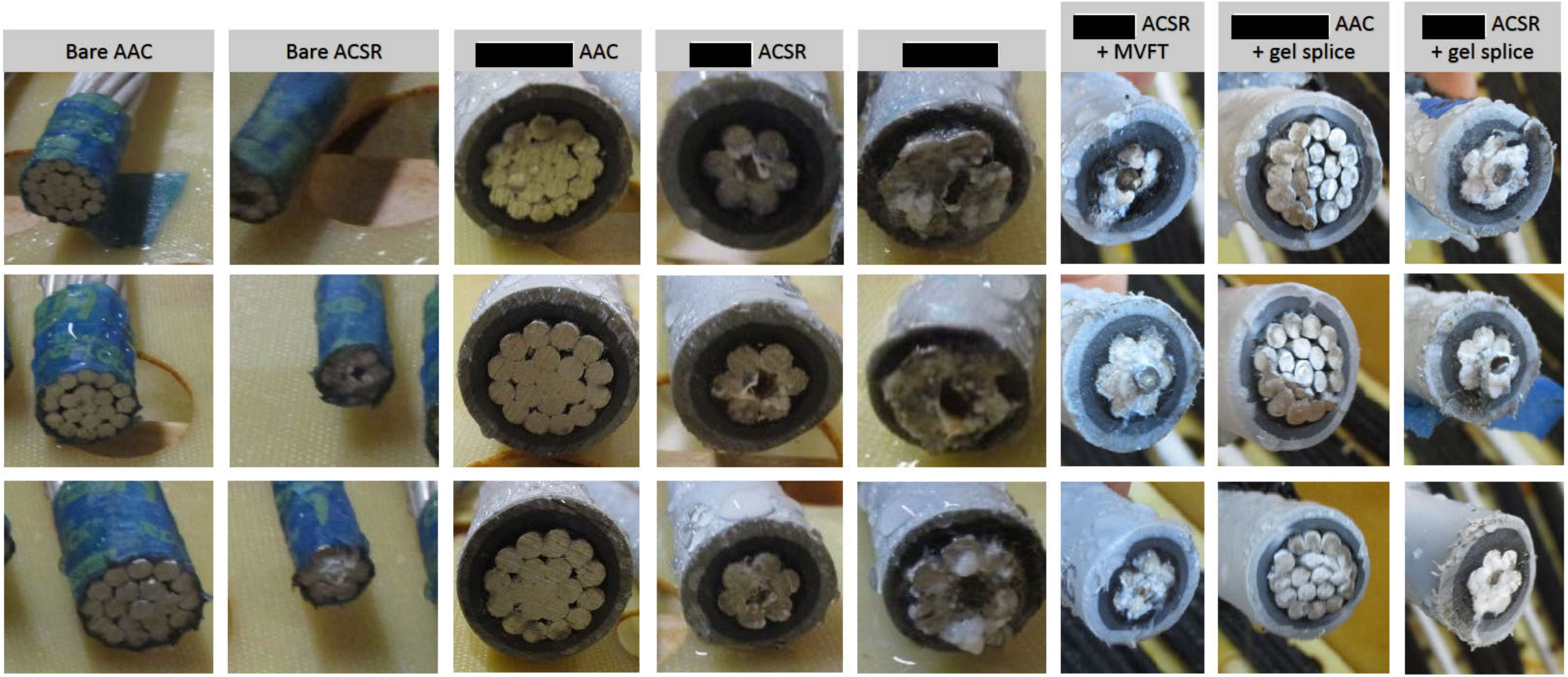
- 7-day exposure



Environmental Resistance Characterization

9. Accelerated Atmospheric Corrosion Test (cont'd)

- 14-day exposure

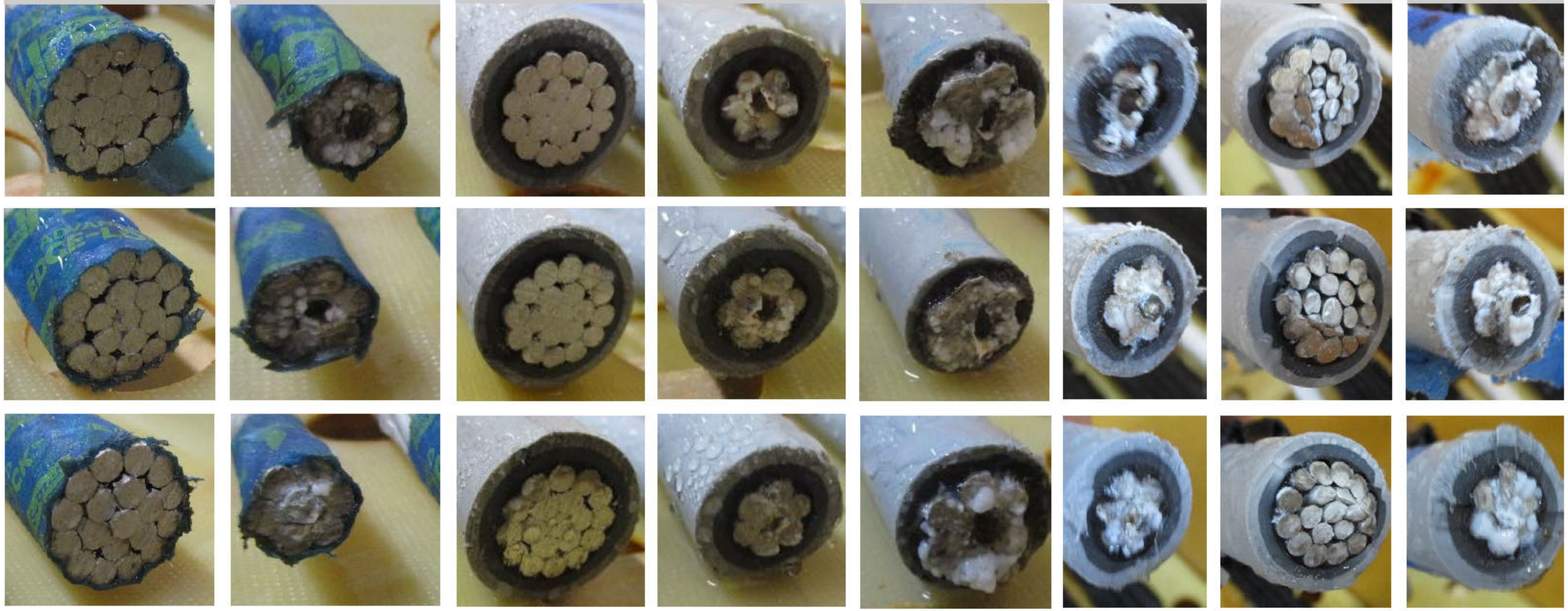


Environmental Resistance Characterization

9. Accelerated Atmospheric Corrosion Test (cont'd)

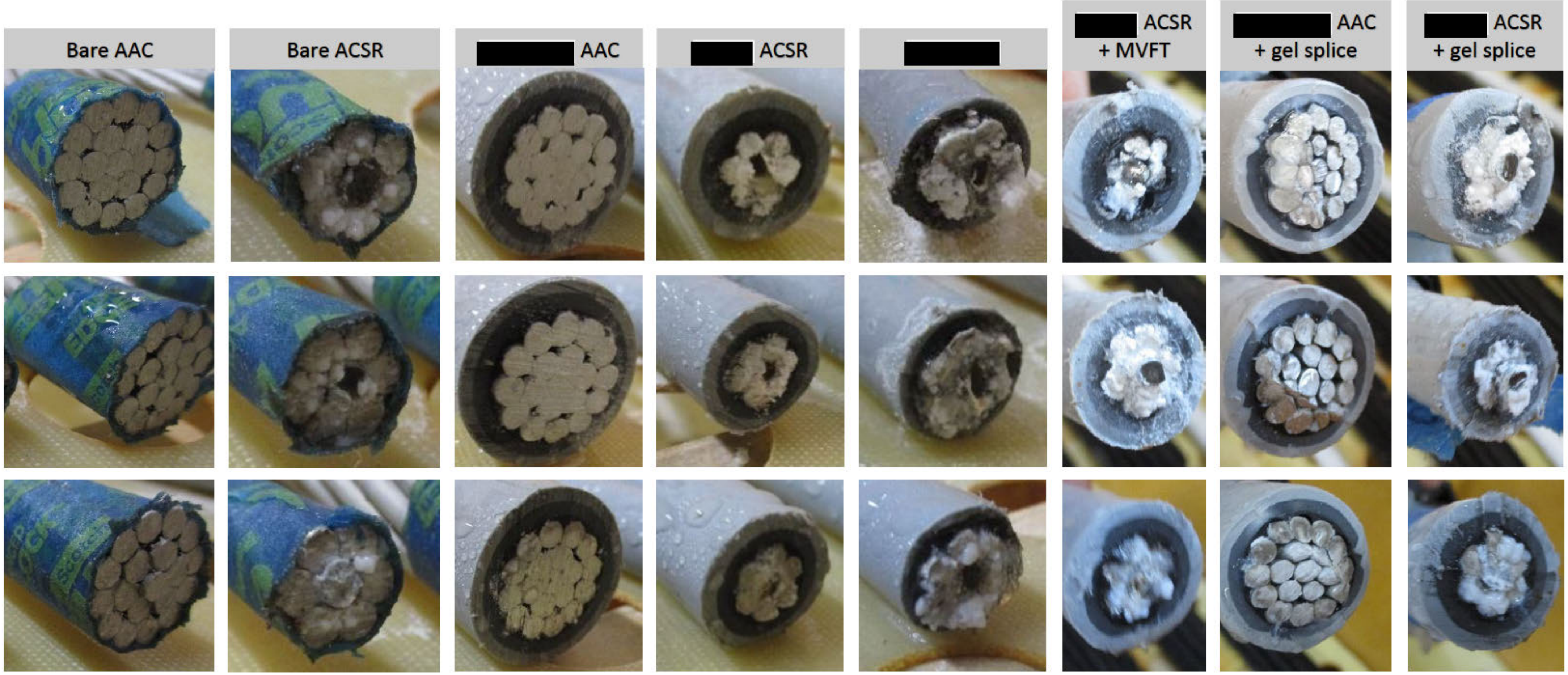
- 21-day exposure

Bare AAC	Bare ACSR	[redacted] AAC	[redacted] ACSR	[redacted]	[redacted] ACSR + MVFT	[redacted] AAC + gel splice	[redacted] ACSR + gel splice



Environmental Resistance Characterization

- Atmospheric Corrosion Test (cont'd)
  - 28-day exposure



Environmental Resistance Characterization

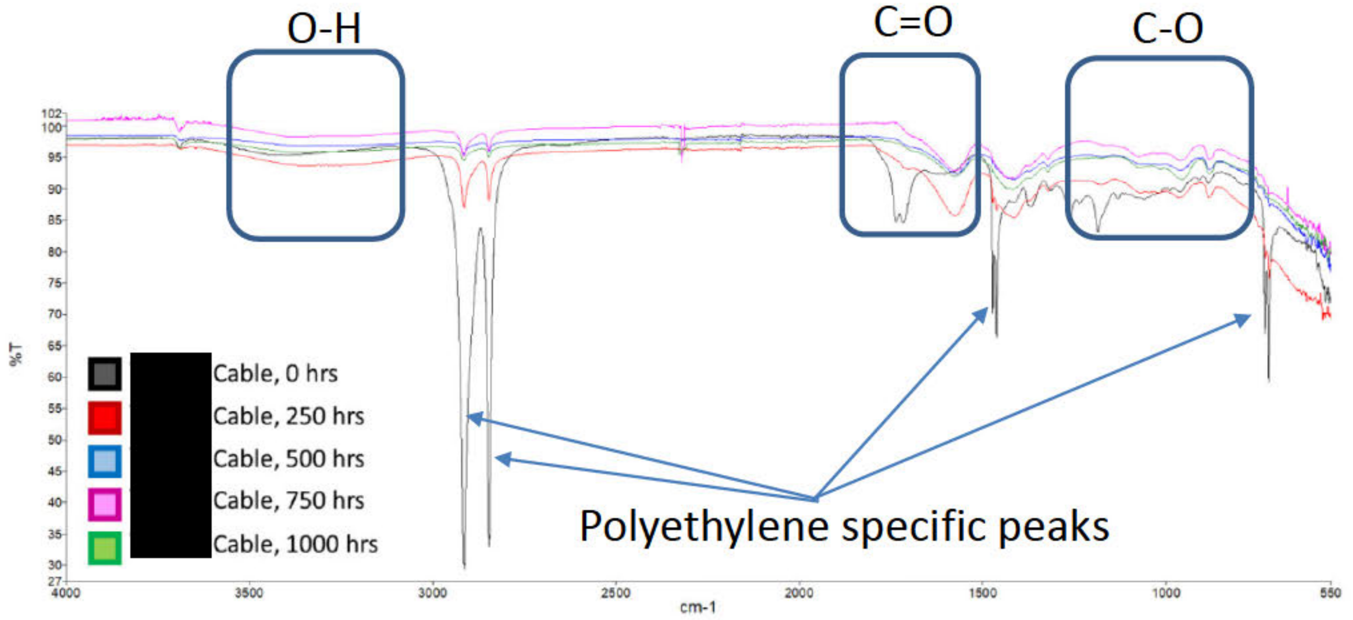
9. Accelerated Atmospheric Corrosion Test (cont'd)

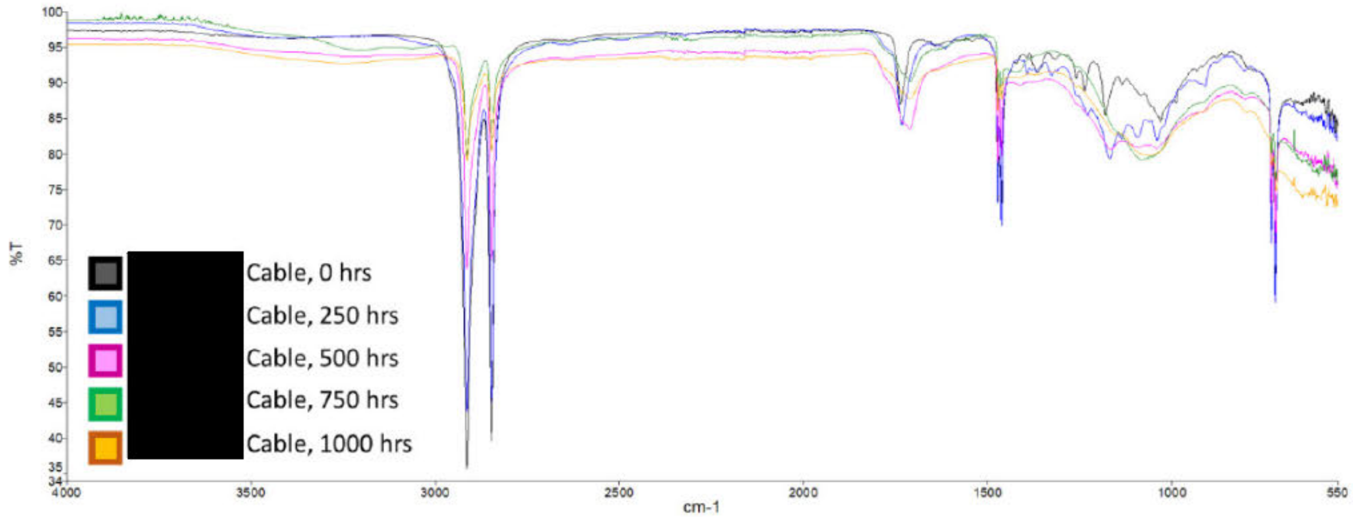
– Summary

Sample	Visual Observations
Bare AAC	Slight discoloration spots to the exterior cable bundles developed after (7) days of corrosion exposure. No further discoloration observed for the remainder of the exposure. No change observed to the cut ends.
Bare ACSR	Cut ends began to tarnish after (5) days, with no signs of red corrosion after the remainder of the exposure. Slight discoloration spots to the exterior cable bundles developed after (5) days for corrosion exposure. Slight discoloration developed after the remainder of the exposure.
[redacted] AAC	Cut ends began to tarnish after (5) days, with no signs of red corrosion after the remainder of the exposure.
[redacted] ACSR	Cut ends began to tarnish after (5) days, with no signs of red corrosion after the remainder of the exposure.
[redacted]	Cut ends began to tarnish after (5) days, with no signs of red corrosion after the remainder of the exposure.
[redacted] ACSR + MVFT	Cut ends began to tarnish after (5) days, with no signs of red corrosion after the remainder of the exposure.
[redacted] AAC + gel splice	No change observed to the cut ends.
[redacted] ACSR + gel splice	Cut ends began to tarnish after (5) days, with no signs of red corrosion after the remainder of the exposure.

12. UV Weathering test

- FTIR data

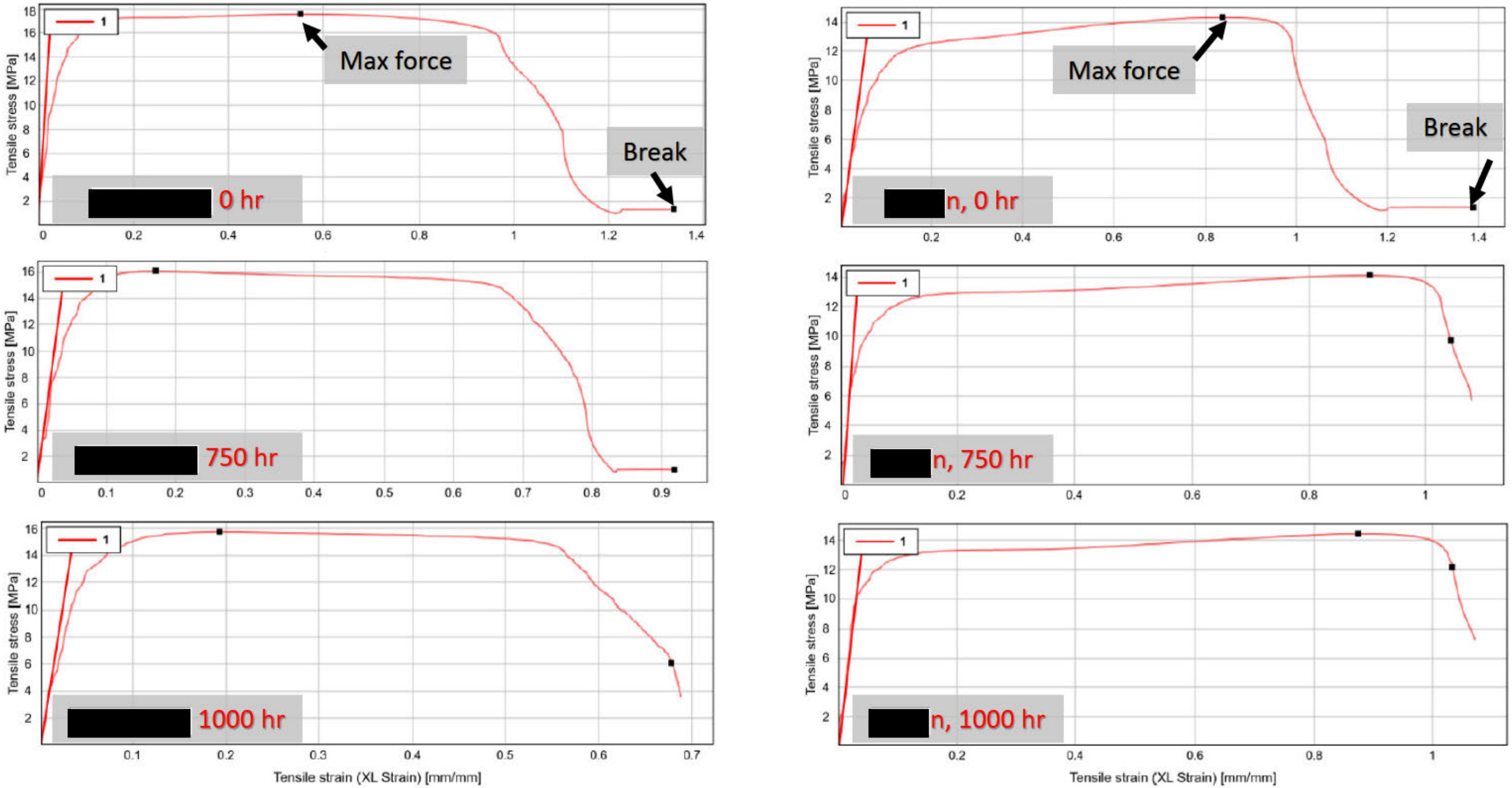




Environmental Resistance Characterization

12. UV Weathering test (cont'd)

- Tensile test data



Environmental Resistance Characterization

12. UV Weathering test (cont'd)

- Hardness (Shore D) Data

Sample	As received	250 hours	500 hours	750 hours	1000 hours	% change
[redacted]	56.3	55.2	59.1	58.3	57.8	2.66%
[redacted]	47.2	48.5	52.4	51.0	52.2	10.59%

Both [redacted] and [redacted] hardness increase after UV exposure.

Electrical Testing Characterization

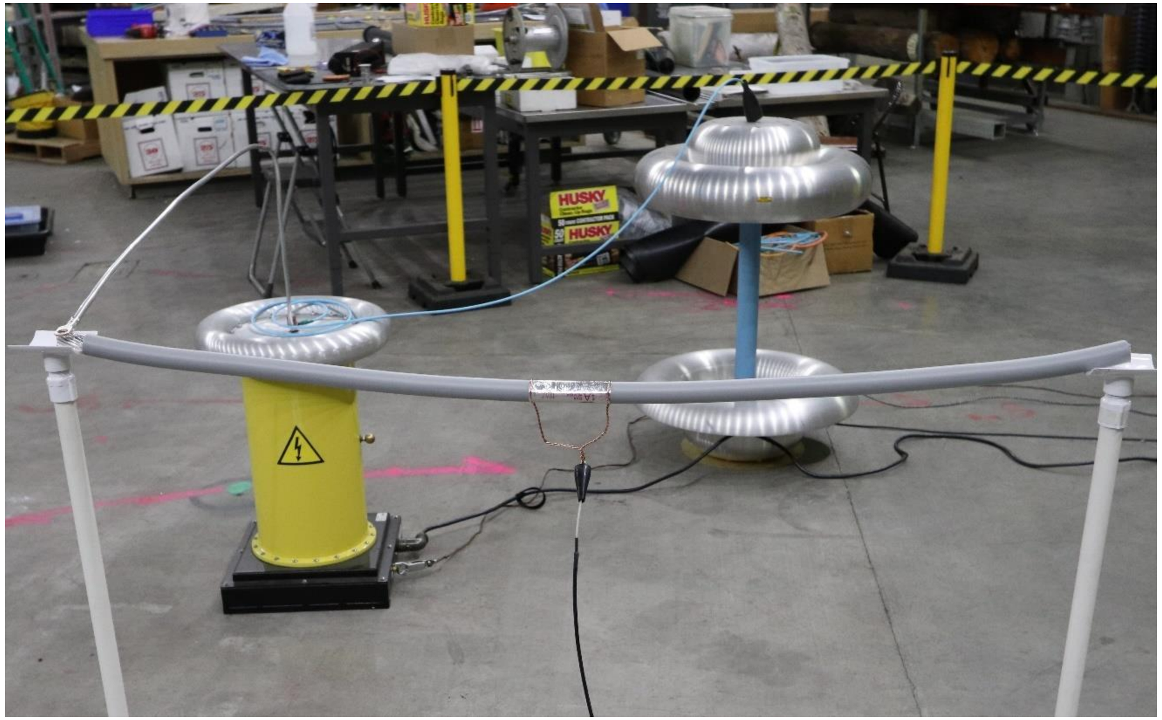
13. Leakage Current and Dielectric Withstand Test

- The leakage current and dielectric strength tests were performed on approved PG&E covered conductors, two methods of covering splices, and a fired wedge connector cover.
- Samples tested:
  - [redacted] 15kV rated 1/0 ACSR covered conductor
    - Full insulation
    - 50% insulation
  - [redacted] 15kV rated 397 AAC covered conductor
    - Full insulation
    - 50% insulation
  - 1/0 ACSR covered conductor compression splice with GelWrap covering sleeve
  - 397 AAC covered conductor compression splice with GelWrap covering sleeve
  - 1/0 ACSR covered conductor compression splice with Medium Voltage Fusion Tape covering sleeve
  - 1/0 to 1/0 fired wedge connector cover

Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

- Covered Conductor Test setup
  - Per European Standard EN 50397-1:2020, the setup for the leakage current test was followed. However, instead of using a wound copper conductor as the measuring electrode, an aluminum tape of the same 100mm diameter wrapped around the covered conductor was used. The European standard specified the leakage current must not exceed 1mA at U (rated voltage). Voltage was applied to the conductor and the return lead was connected to the measuring electrode. Leakage current was measured as the voltage ramped up until dielectric breakdown.

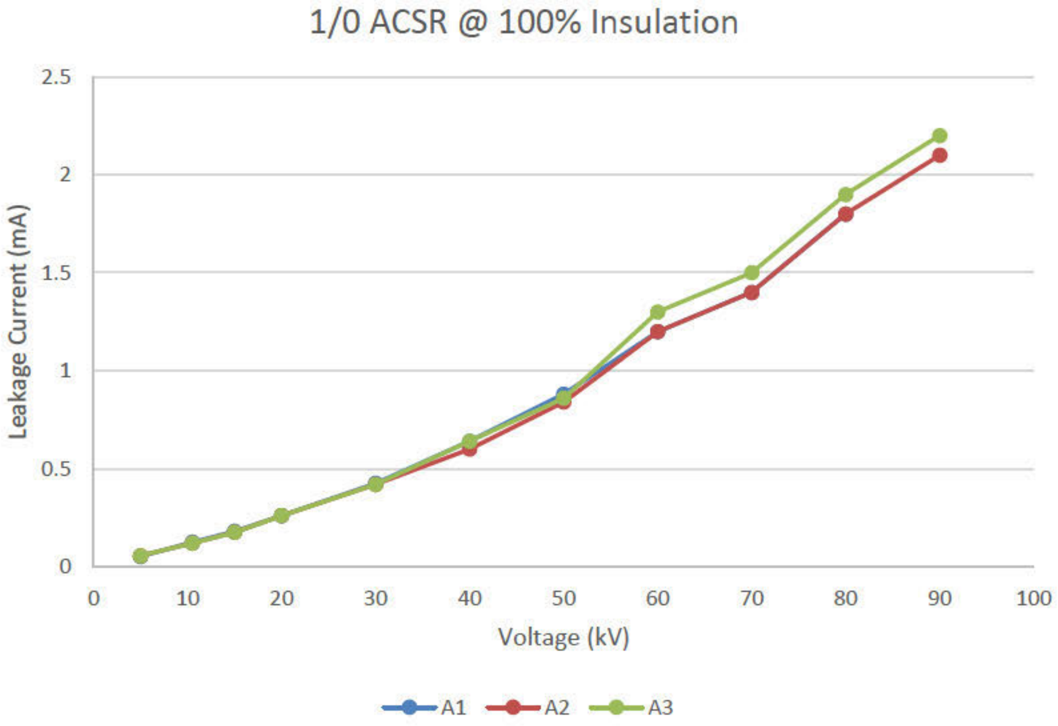


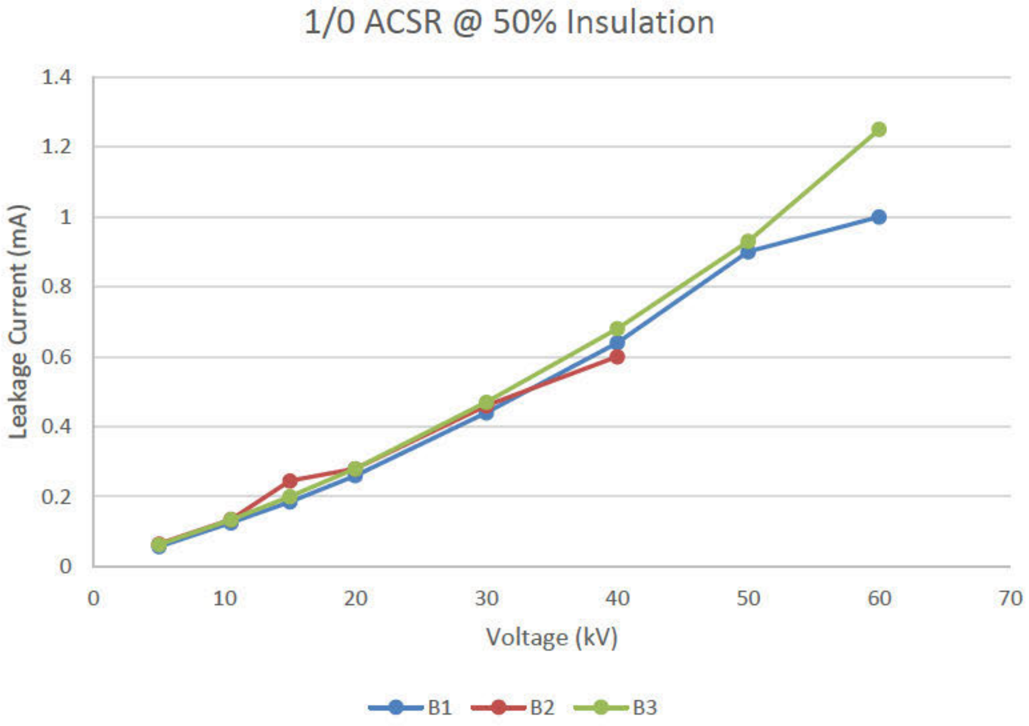
Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Covered Conductor Results

- [redacted] 1/0 ACSR Full and 50% Insulation- Voltage vs. Leakage Current Plot



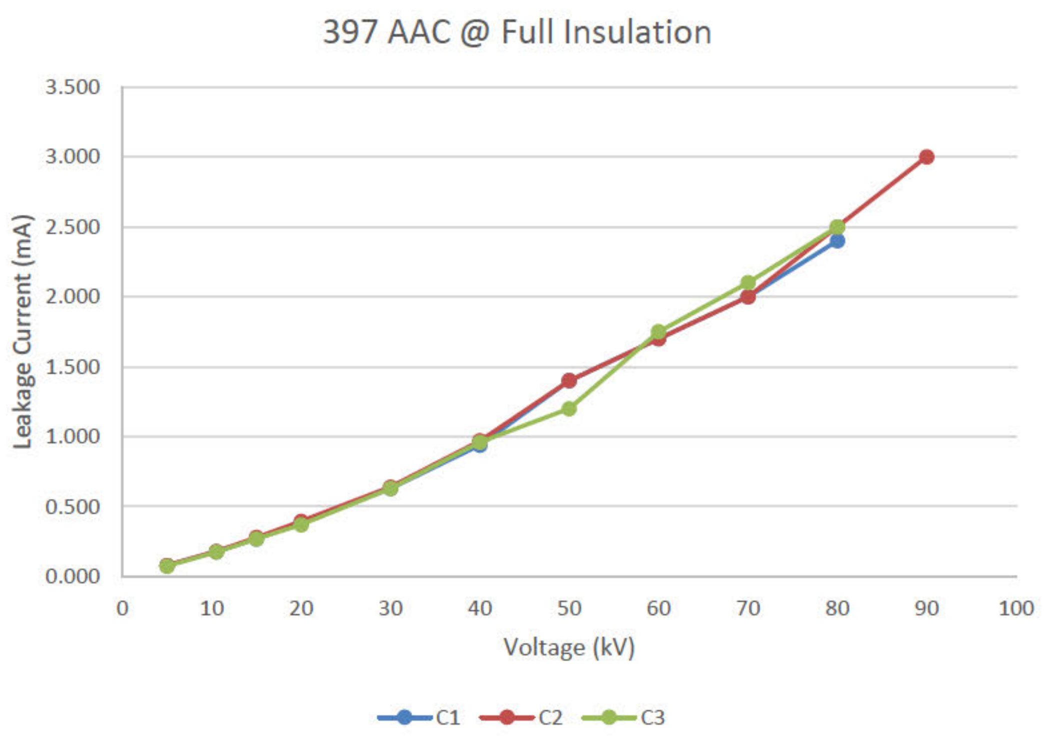


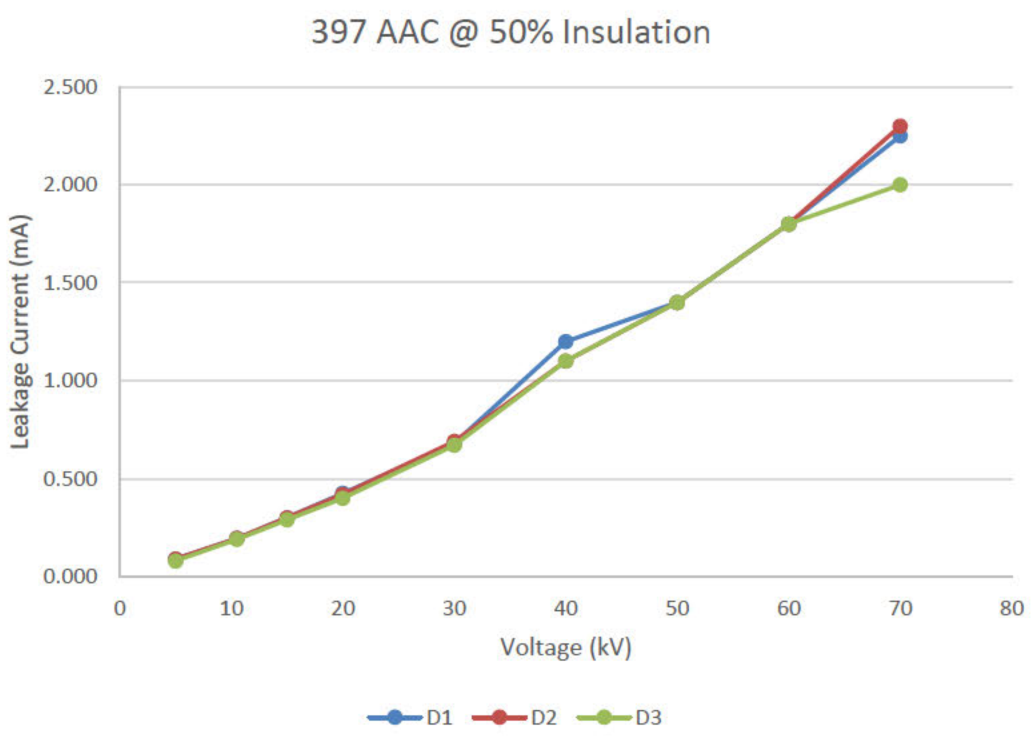
Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Covered Conductor Results

- [redacted] 397 AAC Full and 50% Insulation- Voltage vs. Leakage Current Plot





Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

- Covered Conductor Results
  - [redacted] 397 AAC Covered Conductor Leakage Current Measurements at Full and 50% Insulation

	Sample		kV											Comment
			5	10.5*	15	20	30	40	50	60	70	80	90	
397 AAC Full Insulation	C1	Leakage Current (mA)	0.080	0.178	0.270	0.380	0.630	0.940	1.40	1.70	2.00			Insulation punctured @ 78kV
397 AAC Full Insulation	C2	Leakage Current (mA)	0.080	0.180	0.280	0.395	0.640	0.970	1.40	1.70	2.00	2.50		flashover to cable ends @ 88kV
397 AAC Full Insulation	C3	Leakage Current (mA)	0.075	0.175	0.270	0.370	0.630	0.960	1.20	1.75	2.10			flashover to cable ends @ 80kV
397 AAC 50% Insulation	D1	Leakage Current (mA)	0.090	0.195	0.300	0.425	0.680	1.20	1.40	1.80				Insulation punctured @ 68kV
397 AAC 50% Insulation	D2	Leakage Current (mA)	0.090	0.195	0.300	0.420	0.690	1.10	1.40	1.80				Insulation punctured @ 70kV
397 AAC 50% Insulation	D3	Leakage Current (mA)	0.080	0.190	0.290	0.400	0.670	1.10	1.40	1.80				Insulation punctured @ 70kV

* At 0.7Uac, maximum current allowed is 1mA per EN 50397-1

Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Compression Splice Covering Test setup

- The compression splice was tested in a 4" PVC conduit embedded in No 8 steel shot which served as the measuring electrode. Voltage was applied to the conductor and the return lead was connected to the measuring electrode. Leakage current was measured as the voltage ramped up until dielectric breakdown.

Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Compression Splice Covering Results

- 1/0 ACSR Compression Splice with Gel Wrap Leakage Current Measurements

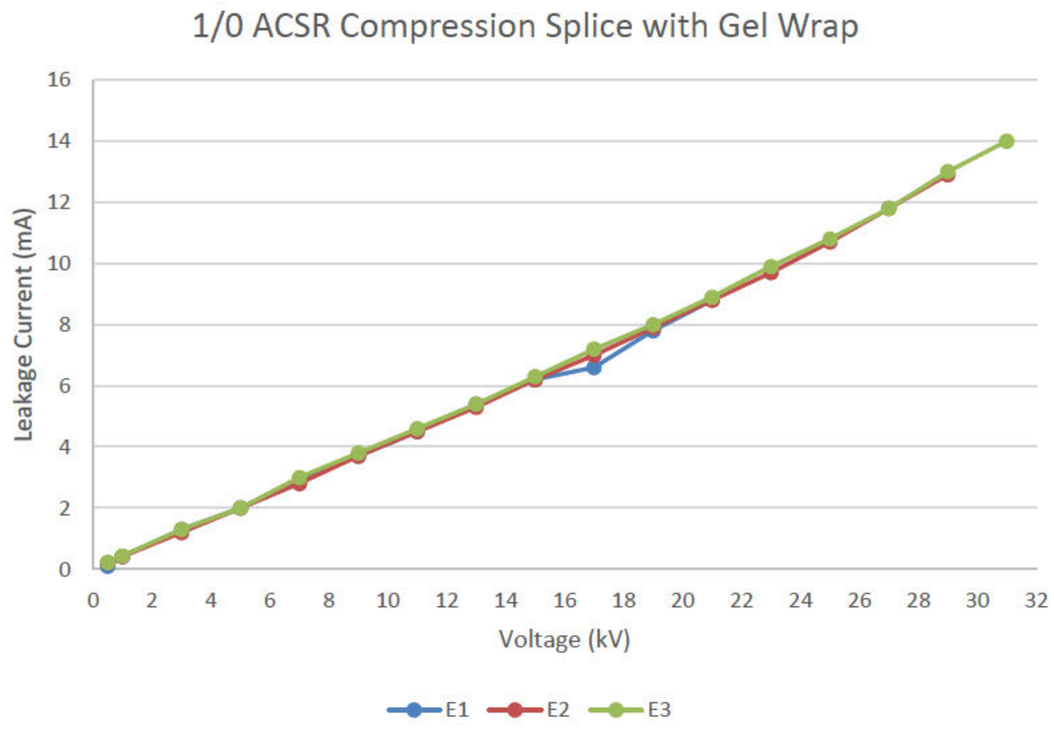
	Sample		Voltage (kV)																		Comments
			0.5	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	
1/0 ACSR Splice w/Gel Wrap	E1	Leakage Current (mA)	0.1	0.42	1.30	2.00	2.90	3.70	4.50	5.40	6.20	6.60	7.80	8.80							flashover @ 23kV
	E2		0.22	0.42	1.20	2.00	2.80	3.70	4.50	5.30	6.20	7.00	7.90	8.80	9.7	10.7	11.8	12.9			flashover @ 31kV
	E3		0.23	0.44	1.30	2.00	3.00	3.80	4.60	5.40	6.30	7.20	8.00	8.90	9.9	10.8	11.8	13	14		flashover @ 33kV

Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Compression Splice Covering Results

- 1/0 ACSR Compression Splice with Gel Wrap – Voltage vs. Leakage Current Plot



Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Compression Splice Covering Results

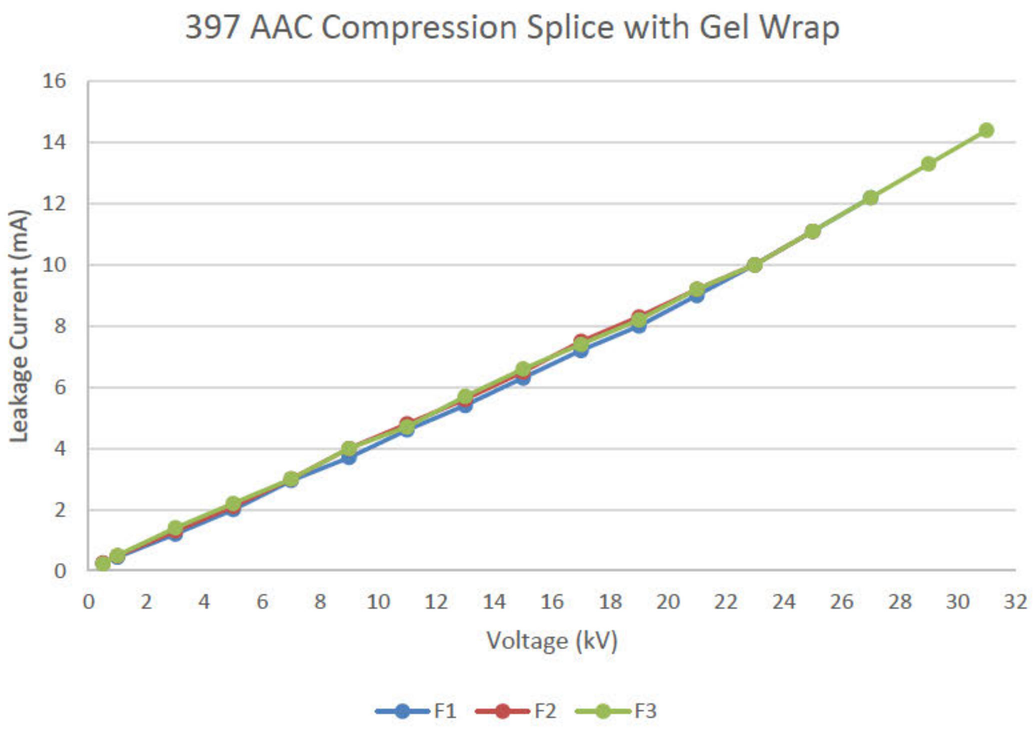
- 397 AAC Compression Splice with Gel Wrap Leakage Current Measurements

	Sample		Voltage (kV)																	Comments
			0.5	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	
397 AAC Splice w/Gel Wrap	F1	Leakage Current (mA)	0.23	0.44	1.20	2.00	2.95	3.70	4.60	5.40	6.30	7.20	8.00	9.00	10.0	11.1	12.2			flashover @ 29kV
	F2		0.25	0.48	1.30	2.10	3.00	4.00	4.80	5.60	6.50	7.50	8.30	9.20	10.0	11.1				flashover @ 27kV
	F3		0.22	0.50	1.40	2.20	3.00	4.00	4.70	5.70	6.60	7.40	8.20	9.20	10.0	11.1	12.2	13.3		flashover @ 31kV

Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

- Compression Splice Covering Results
  - 397 AAC Compression Splice with Gel Wrap – Voltage vs. Leakage Current Plot



Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

- Compression Splice Covering Results
  - 1/0 ACSR Compression Splice with Medium Voltage Fusion Tape Leakage Current Measurements

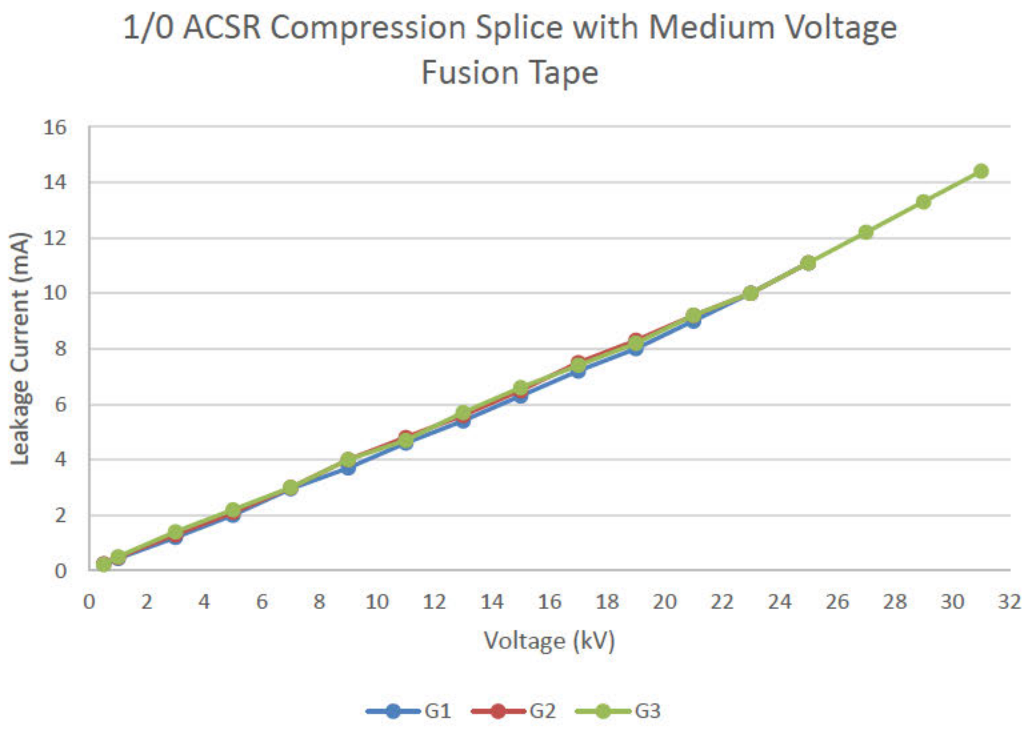
	Sample		Voltage (kV)														Comments
			0.5	1	3	5	7	9	11	13	15	17	19	21	23	25	
1/0 ACSR Splice w/MVFT	G1	Leakage Current (mA)	0.06	0.12	0.37	0.64	1.10	1.50	1.90	2.20	2.60	3.00					flashover @ 19kV
	G2		0.06	0.12	0.36	0.70	1.20	1.50	1.90	2.20	2.60	2.90	3.40				flashover @ 21kV
	G3		0.55	0.10	0.30	0.52	0.80	1.20	1.40	1.70	1.90	2.20	2.40	2.70	3.00		flashover @ 25kV

Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Compression Splice Covering Results

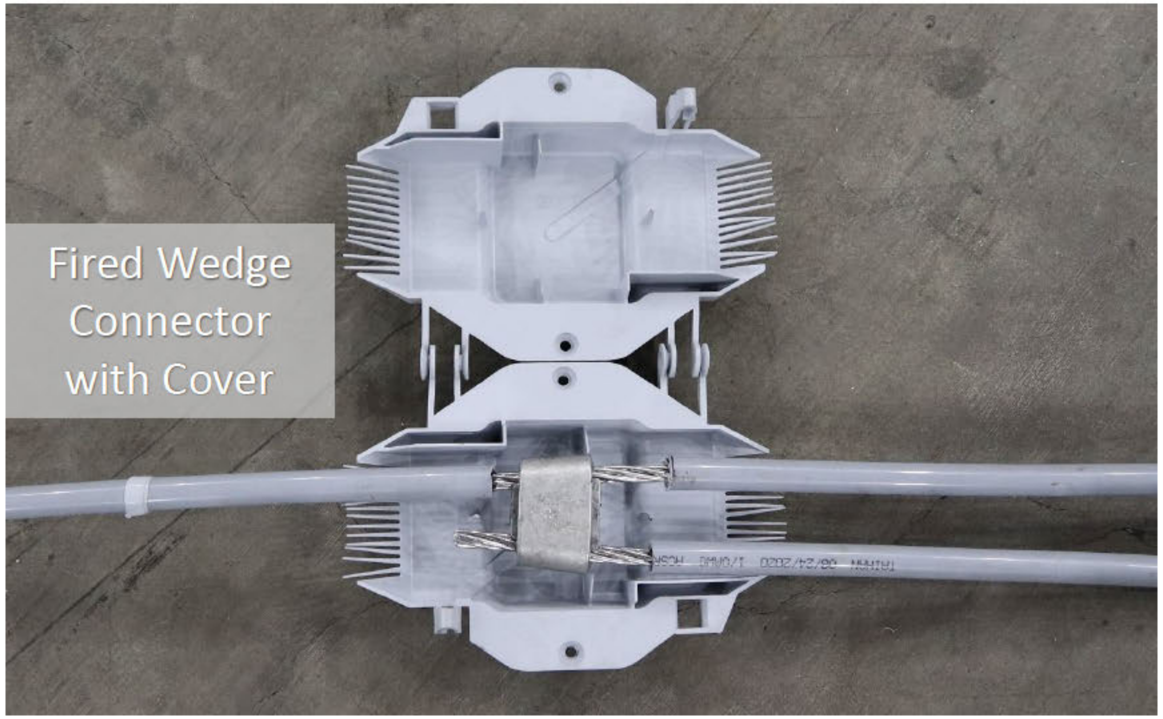
- 1/0 ACSR Compression Splice with MVFT – Voltage vs. Leakage Current Plot



Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

- Fired Wedge Connector Cover
  - Leakage current and dielectric strength tests were performed on a PG&E approved fired wedge connector cover. The wedge connector sized for a 1/0 to 1/0 connection was placed in the center of the cover.

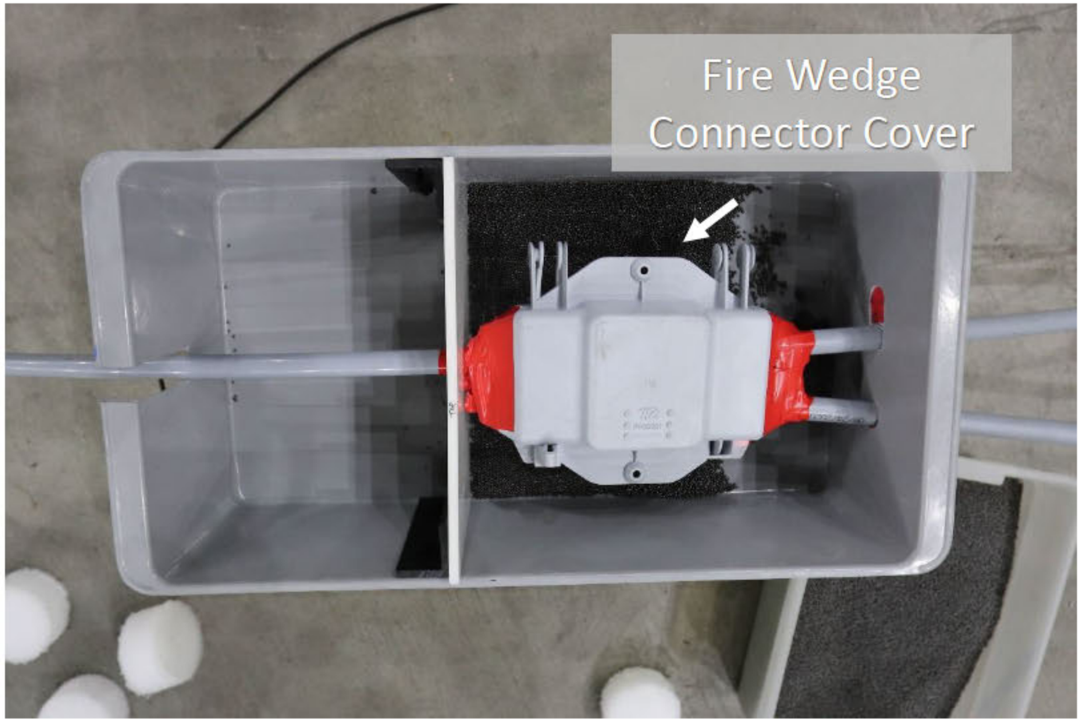


Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Fire Wedge Connector Cover Test setup

- The fire wedge connector with the cover was embedded in No 8 steel shot which served as the measuring electrode. Electrical tape was used to cover areas where shot was able to enter. Voltage was applied to the conductor and the return lead was connected to the measuring electrode. Leakage current was measured as the voltage ramped up until dielectric breakdown. .



Electrical Testing Characterization

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Fire Wedge Connector Cover Results

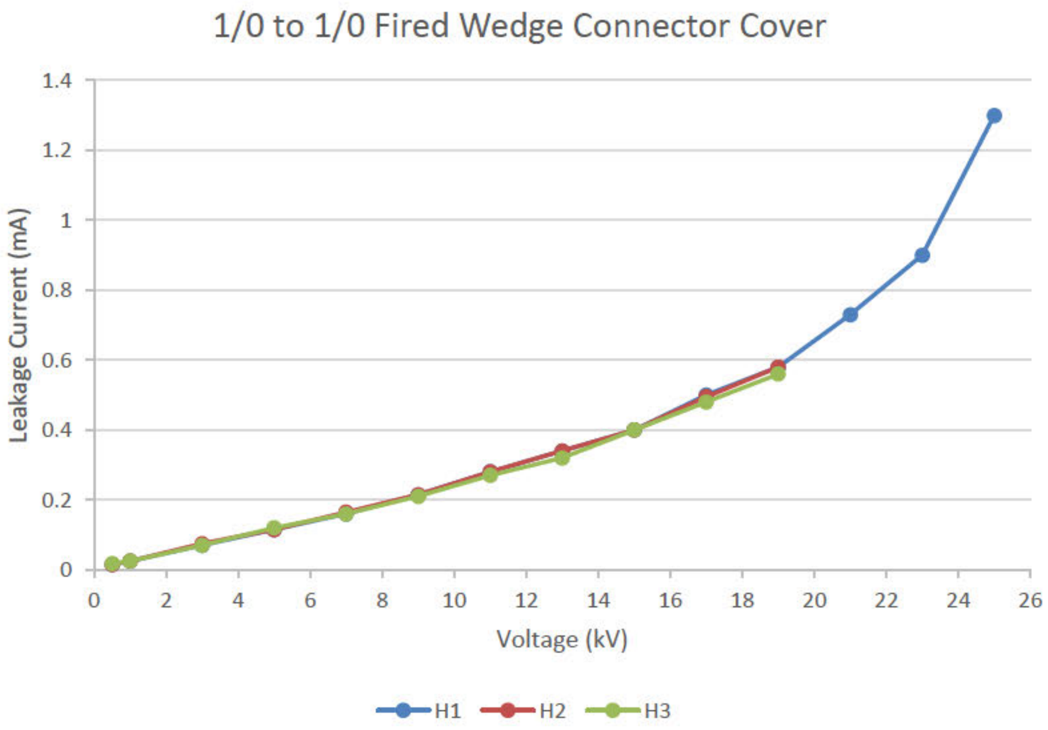
- 1/0 to 1/0 Fired Wedge Connector Cover Leakage Current Measurements

	Sample		kV														Comments
			0.5	1	3	5	7	9	11	13	15	17	19	21	23	25	
1/0 to 1/0 Fired Wedge Connector Cover	H1	Leakage Current (mA)	0.015	0.025	0.070	0.115	0.160	0.215	0.280	0.340	0.400	0.500	0.580	0.730	0.900	1.30	flashover @ 26kV
	H2		0.015	0.025	0.075	0.115	0.165	0.215	0.280	0.340	0.400	0.495	0.580				flashover @ 19kV
	H3		0.018	0.025	0.070	0.120	0.160	0.210	0.270	0.320	0.400	0.480	0.560				flashover @ 21kV

13. Leakage Current and Dielectric Withstand Test (Cont'd)

– Fire Wedge Connector Cover Results

- 1/0 to 1/0 Fired Wedge Connector Cover – Voltage vs. Leakage Current Plot



Splice Cover Evaluated

Gel Wrap

GELPACT COVERS
AMPACT TAPS

KEY FEATURES

- Provides corrosion protection for new Ampact installations
- Arrests progress of corrosion on existing Ampact connectors
- UV stable plastic
- GelPact covers can cover sizes from #6 to 1033 mcm with 5 part numbers
- PowerGel sealant provides an excellent moisture seal over a large temperature range (-40°C to 105°C)

TE Connectivity's (TE's) GelPact covers provide corrosion protection for AMPACT aluminum taps in severely corrosive environments such as coastal or heavily polluted areas. GelPact covers will prevent corrosion from forming on newly installed AMPACT taps in aerial applications. For previously installed AMPACT taps, installing a GelPact cover will help to arrest the progress of any corrosion that might be forming in the tap.

Made of sturdy, black, UV stable plastic. GelPact covers are provided in packs of 18 for white and blue and in packs of 12 for yellow. These covers are ready to snap on quickly and start providing corrosion protection for your electrical network.

Easy to Select
Just four sizes of GelPact covers accommodate the entire AMPACT tap product line. GelPact W-sized covers fit all white coded taps. GelPact B-sized fits all blue-coded AMPACT taps, while GelPact SMY-sized covers fit 336 up to 605 mcm. The XL yellow covers fits from 605 to 1033.

Customers can count on consistent, high quality products, driven by TE's proven innovation and backed by our extraordinary customer support.

ENERGY /// GELPACT COVERS

TE connectivity

MVTG

Tyco Electronics

MVFT
Medium Voltage Fusion Tape

ENERGY DIVISION

General Information

Surface should be free of sharp edges or burrs and thoroughly cleaned and degreased before applying.

Cleaning the Cable

Use an approved solvent, such as the one supplied in the P63 Cable Prep Kit, to clean the cable. Be sure to follow the manufacturer's instructions. Failure to follow these instructions could lead to product failure.

Some newer solvents do not evaporate quickly and need to be removed with a clean, lint-free cloth. Failure to do so could change the volume resistivity of the substrate or leave a residue on the surface.

Please follow the manufacturer's instructions carefully.

Safety Instructions

DANGER: When installing electrical power system accessories, failure to follow applicable personal safety requirements and written installation instructions could result in fire or explosion and serious or fatal injuries.

As Tyco Electronics has no control over field conditions which influence product installation, it is understood that the user must take this into account and apply his own experience and expertise

Customer Service

For 24 hour customer service, call 800-327-6996.