CABLE TECHNOLOGY LABORATORIES

CERTIFIED ENGINEERING

TEST REPORT

**CORE MATERIAL QUALIFICATION TESTS
AS PER AEIC CS8-13 AND ICEA S-94-649-2013
ON 15 KV, TR-XLPE INSULATED CABLE MADE
BY TAIHAN CABLE VINA CO., LTD.
WITH HFDA-0800 / HFDC-4202 EC / KW-3007ES COMPOUNDS**

FINAL REPORT

INVESTIGATION PERFORMED FOR

**TAIHAN CABLE VINA CO., LTD.
Long Thanh Industrial Zone, Dong Nai Province, Vietnam**

I hereby certify that this report is true and correct record of tests conducted under my direction.

Signed:..

Sworn and subscribed before me NOTARY PUBLIC

this: third day of August, 2018

Samantha Antonaccio, New Jersey

County: Middlesex

SAMANTHA D ANTONACCIO
Notary Public, State of New Jersey
My Commission Expires
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FINAL REPORT

1.0 PURPOSE

To report results of Core Material Qualification Tests performed on Tree Retardant Cross-Linked Polyethylene (TR-XLPE) insulated cable, rated 15 kV, manufactured by TAIHAN CABLE VINA CO., LTD., at their plant in Long Thanh Industrial Zone, Dong Nai Province, Vietnam. These tests were performed in accordance with "Specification for Extruded Dielectric Shielded Power Cables Rated 5 through 46 kV" (AEIC CS8-13, 4th Edition*) and "Standard for Concentric Neutral Cables Rated 5 through 46 kV" (ANSI/ICEA S-94-649-2013).

2.0 DESCRIPTION OF THE CABLE

The cable had the following construction:

CONDUCTOR: 1/0 AWG aluminum, 19 wires compressed, concentric lay stranding

CONDUCTOR SHIELD*:	0.012" minimum point thickness, semi-conductive shielding compound Compound identification: HFDA-0800 by Dow Chemical Co.
INSULATION*:	0.175" thick TR-XLPE Compound identification: HFDC-4202 EC by Dow Chemical Co.
INSULATION SHIELD*:	0.030" minimum point thickness, semi-conductive strippable shielding compound Compound identification: KW-3007ES Kyungwon New Materials
METALLIC SHIELDS	6 x 14 AWG bare copper concentric neutral wires

The cable was manufactured by TAIHAN CABLE VINA CO., LTD. at their plant in Long Thanh Industrial Zone, Dong Nai Province, Vietnam, using a triple extrusion cross head in a Catenary Continuous Vulcanizing Line (CCV) provided with dry curing and water cooling*.

* Compounds and manufacturing process as per information provided by the cable manufacturer.

3.0 TEST PERFORMANCE

3.1 Test Samples and Sequence of Tests

Core Material Qualification Tests were performed as per Section 15.0 of AEIC Specification CS8-13, in accordance with Section 10.1 of ICEA Specification S-94-649-2013. The sequence of tests is outlined in the “Cable Core Qualification Test Flow Chart”, which is attached to this report as Appendix 1.

Twenty one samples of the cable were prepared for tests. Each sample was 32 ft long –22 ft active length and 10 ft for terminations. Six of the samples were subjected to electrical and physical tests “as received” and the other fifteen samples were first subjected to cyclic heat aging in accordance with Section 10.1.5 of ICEA Specification S-94-649-2013.

After heat cycling six of the cable samples were electrically and physically tested. The other nine samples were used for accelerated water treeing tests.

3.2 Tests Performed

The following tests were completed:

- Partial discharge (PD) measurements at voltages up to 35 kV AC, 60 Hz (4.3.2.1, 9.13, 10.1.7)*. The tests were performed at room temperature on the cable as received, after heat cycling, and after aging for 120 days under AWTT conditions.
- Capacitance and dissipation factor measurements at room temperature and 8.7 kV ac voltage to ground, 60 Hz (4.3.2.5, 10.1.7)*. These measurements were performed during the same steps of the test program as those listed in the previous paragraph.
- Dissipation factor characterization test (10.5.7) *. Capacitance and dissipation factor measurements were performed at 130 ^{o}C conductor temperature on one of the load cycled cable sections.
- High voltage time tests on unaged and (10.1.3)* on three cable sections for each of the following conditions:
  - not aged,
  - load cycled,
  - aged under AWTT conditions during 120, 180, and 360 days.

* Paragraphs of the ICEA Specification S-94-649-2013 related to test procedures and performance requirements are shown in parenthesis

- Hot impulse tests (1.2 x 50 µsec wave) on unaged and on load cycled cable samples (4.3.2.3, 10.1.4)*. Subsequent to high voltage breakdown tests (both ac and impulse) breakdown sites were dissected and the breakdown origination point was established, whenever possible.
- The following measurements were performed on the cable samples as received, after load cycling, and after completing 120,180 and 360 days of AWTT aging:
  - Conductor shield thickness (3.2, 9.4.2.2, 10.1.8)*.
  - Insulation thickness (4.2, 9.4.2.2, 10.1.8)*.
  - Insulation shield thickness (5.2, 9.4.2.2, 10.1.8)*.
  - Insulation shield stripping tension (5.4.1.1, 9.9, 10.1.8)*.
- The pH level of the water in the conduits of the AWTT set-up was measured prior to aging and after 120, 180 and 360 days of aging (10.1.6.8)*.
- Tree count tests were performed according to section 15.2.1 of the AEIC Specification CS8-07, on each cable section subjected to aging under AWTT conditions.

* Paragraphs of the ICEA Specification S-94-649-2013 related to test procedures and performance requirements are shown in parenthesis

3.3 Tests at Elevated Temperature

In accordance with ANSI/ICEA Specification S-94-649-2013, heat cycling, hot impulse and dissipation factor characterization tests should be performed at the cable conductor maximum temperature of 130 ^{o}C.

For cyclic heat aging, cable samples were installed in a three-inch diameter polymeric conduit with sealed ends. Thermocouples were attached to the conductor and insulation shield, so that simultaneous temperature measurement of these two components could be performed. The load current was regulated to maintain the required conductor temperature of 130 ^{o}C during the last 4 hours of any load cycle. This temperature was reached at currents of 280-290 A, depending on ambient temperature. A relation between the conductor and insulation shield temperatures, in dependence to the load current, was derived from the experimental data, so that in all other tests the conductor temperature could be established by measuring the load current and insulation shield temperature.

For hot impulse tests, the active part of each cable sample was placed in a three-inch conduit, with sealed ends. Impulse tests were performed when the conductor temperature was between 125 and 130 ^{o}C. The dissipation factor characterization test was performed on a sample suspended freely in air. The temperature of 130 ^{o}C was stabilized within 1.5 hour.

3.4 Accelerated Water Treeing Tests

Each cable section subjected to AWTT had 14.5 feet of its length aged inside water-filled conduits. The sample ends were arranged with reservoirs to keep the conductor interstices filled with water. The samples were continuously under 26.3 kV, 60 Hz. During each of the five working days of a week the samples were heated with current during 8 hours. The level of current was set in such a way as to reach at the end of the heating period the required insulation shield surface temperature of 45 ^{o}C in water. The current magnitude (290 A) was established by heat cycling a dummy cable sample. Temperature profiles versus time for the cable conductor and insulation shield of the dummy, in air and in water, are shown in Figure 1. During the AWTT cycles, the current was regulated so as to reach the specified temperature of the insulation shield in water at the end of the current-on period.

4.0 TEST RESULTS

4.1 Partial Discharge

The apparent charge-transfer was less than 5 pC at all voltage stresses, at and below 200 V/mil (applied voltage 35 kV) for each cable section tested: one sample in the condition "as received", one other sample after heat cycling, and all three samples subjected to AWTT aging for 120 days. The test set-up is shown in Figure 2.

4.2 Capacitance and Dissipation Factor

To monitor changes in the electrical characteristics of the cable, capacitance and dissipation factor were measured at room temperature on one sample of unaged cable and on another after heat cycling. The latter was also used for the Dissipation Factor Characterization test. In addition, the same characteristics were measured at room temperature on all three samples tested after 120 days of AWTT aging. The results of these tests are given in Table No 1.

4.3 High Voltage Time Tests

Overall, fifteen samples of the cable were subjected to individual ac high voltage time tests, during the steps of the test program: three in each condition, as received, after heat cycling, and after 120, 180, and 360 days of AWTT aging. The results are given in Table Nos. 2 through 6. The test set-up was the same as for PD tests; see Figure 2.

All samples satisfied the test requirements. The weakest section, tested in the condition “as received”, withstood average stress of 820 V/mil; to be compared with the specification requirement to withstand 620 V/mil. This particular cable section exhibited a typical pattern of thermal runaway.

Heat cycling caused de-gassing of the insulation; therefore, sections tested after heat cycling had very high dielectric strength, to the extent they could not be broken with the test equipment employed. One of the sections failed in the test terminal; however, since it had withstood the stress of 1100 V/mil, no retesting was required (to be compared with the specification minimum limit is 660 V/mil).

Aging under AWTT conditions caused substantial reduction in the cable dielectric strength: the weakest sections tested after 120 and 180 days of aging could support voltage stresses of 700 and 620 V/mil, just one step above the respective minimums required (660 and 580 V/mil, respectively). Additional 180 days of aging caused further reduction in the dielectric strength (480 V/mil in the weakest section), while the minimum requirement to withstand dropped to 380 V/mil.

4.4 Hot Impulse Tests

Six samples of the cable were subjected to individual impulse tests, three of them before, and three after cyclic heat aging. The test set-up is shown in Figure 3. Figure 4 shows the impulse shape: front time of 0.97 μs (the tolerance is 0.84 to 1.56 μs) and tail time of 43 μs (tolerance 40 to 60 μs).

The results are given in Table No. 7 for the cable samples “as received” and in Table No. 8 for samples after cyclic aging. All cable sections had sufficiently high breakdown levels, to the extent that one of them could not be broken due to limitations in test terminals. The lowest breakdown stress was 1830 V/mil, way above the specification requirement to withstand 1200 V/mil. Since the cable dielectric strength under lightning impulse stresses had already been demonstrated to be very high, no effort was made to improve the terminations.

4.5 Dissection and Examination of Breakdown Sites

Subsequent to the voltage breakdown of the samples, cross-sectional slices of the insulation containing the breakdown paths were examined under a microscope to establish the insulation thickness at the location of each breakdown and the origin of the same. The results are shown in Table No. 9.

Considering the actual insulation thickness at the breakdown location, average voltage breakdown stresses were calculated. These data were then used to calculate the mean values for the ac and impulse tests, before and after heat cycling. The results are given in Table No.10 for the ac voltage stresses and in Table No.11 for the impulse voltage tests.

Mean ac breakdown voltages during the qualification tests are also shown in Figure 5. The same figure shows the maximum withstand stresses in the weakest cable section in each group of three samples, calculated using the nominal insulation thickness of 175 mils, versus the respective specification requirements.

4.6 Physical Measurements

To monitor changes in the physical characteristics of the cable during qualification tests, the conductor shield, insulation and insulation shield thicknesses and the insulation shield stripping tension were measured on one sample of the cable at each of the following conditions: unaged, heat cycled, and subjected to AWTT aging during 120, 180, and 360 days. The results of dimensional tests and stripping tensions are given in Table Nos. 12 and 13, respectively.

4.7 Water pH

This characteristic was measured in conduits of the AWTT set-up after 0, 120, 180, and 360 days of the cable aging. Three conduits were involved at each occasion. Variation of the results between conduits was minor (below 0.1), and in each case the average of the three readings was taken as the final result. The average pH was measured at 7.3, 7.6, 7.8, and 7.9 before aging, after 120, 180, and 360 days of aging, respectively.

4.8 Tree Count Test

Ten slices of insulation, each 25 mils average thickness, were cut from each cable sample subjected to the AWTT aging, close to the respective voltage failures. The slices were dyed with a methylene-blue solution and subjected to microscopic examination for the presence of water trees. All thirty slices (from each group of 3 specimens) were examined for the presence of vented and bowtie trees. Table 14 summarizes the test results.

A large number of dense bundles of discolored features, attached to the conductor shield, were noted in all samples subjected to wet aging. In the first batch of samples, tested after 120 days of aging, these formations were small in the radial direction, below the limit to be considered in the tree count tests; therefore they are not mentioned in Table 14. With the time of aging these features grew up, and after 360 days of aging they reached 20 mils in the radial direction.

These areas had shapes typical of water trees vented at the conductor shield; however, instead of absorbing the methylene blue dye and acquiring a bluish coloration, these formations repelled the dye (Figure 6). With aging, they absorbed some contaminants and became darker. It is remarkable that in all samples tested after 180 and 360 days of aging, laboratory breakdowns initiated at these “vented trees” (see Table 9).

In addition to the above described formations, there were several regular (commonly recognized) vented trees at the conductor shield. The largest one, 23 mils high, is shown in Figure 7. Furthermore, there were a few vented trees at the insulation shield, Figure 8.

A relatively high density of bow tie trees was present in the insulation, all of them below 15 mils in the greatest dimension. Density and sizes of these trees appeared to be randomly distributed and were not correlated with the aging time (see Table 14).

While examining the condition of different samples, a discolored band, attached to the insulation shield, was noted already at the early stages of wet aging, Figure 9. The discoloration did not propagate further with the time of aging; although its appearance somewhat depended on the aging conditions: It was very similar to that shown in Figure 9 in sections aged in air, while it became fuzzy, with a purely defined boundary, in sections aged in water, Figure 10.

5.0 DISCUSSION

Cable as received had relatively high dielectric strength at ac voltage stresses. Heat cycling allowed for release of volatile by-products of the cross-linking reaction and significantly improved the cable dielectric strength.

The first 120 days of wet aging caused a substantial drop in the cable dielectric strength, still remaining above the minimum requirement. Non-uniformities in the insulation developed in the area next to the conductor shield (Figure 6); similar in shape to vented water trees. Additionally, diffusion of impurities from the insulation shield was noted (Figure 9). There was also a relatively dense population of small bow tie trees (Table 14).

Additional aging of cable samples under AWTT conditions caused further growth of the whitish features and regular vented trees, conducive to continued drop in the insulation dielectric strength, still satisfying the qualification test requirements (Figure 5).

Dimensional characteristics of the components of the insulation system and adhesion between the insulation shield and insulation were well within the required limits. These characteristics were not affected by wet aging.

Overall, the performance of the cable subjected to the entire sequence of Core Material Qualification Tests, meets the requirements of the AEIC CS8-13 and ICEA S-94-649-2013 Specifications.

6.0 CONCLUSION

The cable made with the following compounds:

Conductor shield - HFDA-0800 by Dow Chemical Co.;

Insulation - HFDC -4202 EC by Dow Chemical Co.;

Insulation shield - KW-3007ES, by Kyungwon New Materials,

manufactured by TAIHAN CABLE VINA CO., LTD. at their plant in Long Thanh Industrial Zone, Dong Nai Province, Vietnam, meets and exceeds the requirements of the Cable Core Material Qualification Tests as outlined in the AEIC CS8-13 and ICEA S-94-649-2013 Specifications

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Stress Cones
Conditioning: See table

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: See table
Tested by: V. Yaroslavskiy

Table No. 1

DIELECTRIC CONSTANT AND DISSIPATION FACTOR

		Temperature, °C	Dielectric Constant	Dissipation Factor, %
As received Sample No. 1		18	2.4	0.03
After cyclic aging Sample No. 7		23	2.3	0.03
		130	2.3	0.12
After 120 days of AWTT aging	Sample No. 13	26	2.4	0.04
	Sample No. 14	21	2.4	0.05
	Sample No. 15	22	2.4	0.05
AEIC CS8-13 maximum limit		Ambient	3.5	0.5

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Water Terminals
Conditioning: None

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: Ambient
Tested by: V. Yaroslavskiy

Table No. 2

HIGH VOLTAGE TIME TEST
(on cable as received)

Applied Voltage* kV	Voltage Stress** V/mil	Sample No.		
		1	2	3
17.5	100	Passed	Passed	Passed
24.5	140	Passed	Passed	Passed
32	180	Passed	Passed	Passed
39	220	Passed	Passed	Passed
46	260	Passed	Passed	Passed
53	300	Passed	Passed	Passed
60	340	Passed	Passed	Passed
67	380	Passed	Passed	Passed
74	420	Passed	Passed	Passed
81	460	Passed	Passed	Passed
88	500	Passed	Passed	Passed
95	540	Passed	Passed	Passed
102	580	Passed	Passed	Passed
109	620	Passed	Passed	Passed
116	660	Passed	Passed	Passed
123	700	Passed	Passed	Passed
130	740	Passed	Passed	Passed
137	780	Passed	Passed	Passed
144	820	Passed	Passed	Passed
151	860	Passed	Passed	**Failed @ 4.3 min**
158	900	Passed	Passed	

Continues…

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage:	15 kV	**Conductor:**	1/0 AWG, Al
Insul. Material:	HFDC -4202 EC	**Ins. Thickness:**	175 mils
Cond. Shield:	HFDA-0800	**Test Length:**	22 feet
Insul. Shield:	KW-3007ES	**Test Temp:**	Ambient
Terminations:	Water Terminals	**Tested by:**	V. Yaroslavskiy
Conditioning:	None		

Table No. 2 (Continued)

HIGH VOLTAGE TIME TEST
(on cable as received)

Applied Voltage* kV	Voltage Stress** V/mil	Sample No.		
		1	2	3
165	940	Passed	Passed	
172	980	Passed	**Failed @ 0.5 min**	
179	1020	**Failed @ 3.4 min**		
Withstand Voltage Withstand Voltage Stress**		172 kV 980 V/mil	165 kV 940 V/mil	144 kV 820 V/mil

Min. Requirement to Pass = 620 V/mil** (failure on test section)
* 5 minute voltage steps
** Based on nominal insulation thickness of 175 mils

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Water Terminals
Conditioning: Cyclic Aging

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: Ambient
Tested by: V. Yaroslavskiy

Table No. 3

HIGH VOLTAGE TIME TEST
(on cable after heat cycling)

Applied Voltage* kV	Voltage Stress** V/mil	Sample No. 7	Sample No. 8	Sample No. 9
17.5	100	Passed	Passed	Passed
25	140	Passed	Passed	Passed
32	180	Passed	Passed	Passed
39	220	Passed	Passed	Passed
46	260	Passed	Passed	Passed
53	300	Passed	Passed	Passed
60	340	Passed	Passed	Passed
67	380	Passed	Passed	Passed
74	420	Passed	Passed	Passed
81	460	Passed	Passed	Passed
88	500	Passed	Passed	Passed
95	540	Passed	Passed	Passed
102	580	Passed	Passed	Passed
109	620	Passed	Passed	Passed
116	660	Passed	Passed	Passed
123	700	Passed	Passed	Passed
130	740	Passed	Passed	Passed
137	780	Passed	Passed	Passed
144	820	Passed	Passed	Passed
151	860	Passed	Passed	Passed
158	900	Passed	Passed	Passed

Continues…

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage:	15 kV	**Conductor:**	1/0 AWG, Al
Insul. Material:	HFDC -4202 EC	**Ins. Thickness:**	175 mils
Cond. Shield:	HFDA-0800	**Test Length:**	22 feet
Insul. Shield:	KW-3007ES	**Test Temp:**	Ambient
Terminations:	Water Terminals	**Tested by:**	V. Yaroslavskiy
Conditioning:	Cyclic Aging		

Table No. 3 (Continued)

HIGH VOLTAGE TIME TEST
(on cable after heat cycling)

Applied Voltage* kV	Voltage Stress** V/mil	Sample No.		
		7	8	9
165	940	Passed	Passed	Passed
172	980	Passed	Passed	Passed
179	1020	Passed	Passed	Passed
186	1060	Passed	Passed	Passed
193	1100	Passed	Passed	Passed
200	1140	Passed	Passed	Passed
207	1180	**Termination failure**	Passed	Passed
214	1220		Passed	Passed
221	1260		Passed	Passed
228	1300		Passed	Passed
235	1340		Passed	Passed
242	1380		Passed	Passed
249	1420		Passed	Passed
256	1460		**Discontinued*** **	Passed
263	1500			Passed
270	1540			Passed
277	1580			Passed
283	1620			Passed
290	1660			**Discontinued*** **
Withstand Voltage Withstand Voltage Stress**		>200 kV >1140 V/mil	>249 kV >1420 V/mil	>283 kV >1620 V/mil

Min. Requirement to Pass = 660 V/mil** (failure on test section)
* 5 minute voltage steps
** Based on nominal insulation thickness of 175 mils
*** Discontinued due to test system limitations

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Water Terminals
Conditioning: 120 days AWTT
Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: Ambient
Tested by: V. Yaroslavskiy

Table No. 4

HIGH VOLTAGE TIME TEST
(on cable after 120 days of AWTT aging)

Applied Voltage* kV	Voltage Stress** V/mil	Sample No.		
		13	14	15
17.5	100	Passed	Passed	Passed
24.5	140	Passed	Passed	Passed
32	180	Passed	Passed	Passed
39	220	Passed	Passed	Passed
46	260	Passed	Passed	Passed
53	300	Passed	Passed	Passed
60	340	Passed	Passed	Passed
67	380	Passed	Passed	Passed
74	420	Passed	Passed	Passed
81	460	Passed	Passed	Passed
88	500	Passed	Passed	Passed
95	540	Passed	Passed	Passed
102	580	Passed	Passed	Passed
109	620	Passed	Passed	Passed
116	660	Passed	Passed	Passed
123	700	Passed	Passed	Passed
130	740	Passed	**Failed @ 2.6 min**	Passed
137	780	Passed		**Failed @ 3.3 min**
144	820	Passed		
151	860	Passed		
158	900	Passed		

Continues…

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Water Terminals
Conditioning: 120 days AWTT

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: Ambient
Tested by: V. Yaroslavskiy

Table No. 4 (Continued)

HIGH VOLTAGE TIME TEST
(on cable after 120 days of AWTT aging)

Applied Voltage* kV	Voltage Stress** V/mil	Sample No.		
		13	14	15
165	940	Passed		
172	980	Passed		
179	1020	Passed		
186	1060	**Failed @ 4.1 min**		
Withstand Voltage Withstand Voltage Stress**		179 kV 1020 V/mil	123 kV 700 V/mil	130 kV 740 V/mil

Min. Requirement to Pass = 660 V/mil** (failure on test section)
* 5 minute voltage steps
** Based on nominal insulation thickness of 175 mils

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Water Terminals
Conditioning: 180 days AWTT

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: Ambient
Tested by: V. Yaroslavskiy

Table No. 5

HIGH VOLTAGE TIME TEST
(on cable after 180 days of AWTT aging)

Applied Voltage* kV	Voltage Stress** V/mil	Sample No. 16	Sample No. 17	Sample No. 18
17.5	100	Passed	Passed	Passed
24.5	140	Passed	Passed	Passed
32	180	Passed	Passed	Passed
39	220	Passed	Passed	Passed
46	260	Passed	Passed	Passed
53	300	Passed	Passed	Passed
60	340	Passed	Passed	Passed
67	380	Passed	Passed	Passed
74	420	Passed	Passed	Passed
81	460	Passed	Passed	Passed
88	500	Passed	Passed	Passed
95	540	Passed	Passed	Passed
102	580	Passed	Passed	Passed
109	620	Passed	Passed	Passed
116	660	Passed	**Failed @ 0.5 min**	**Failed @ 1.3 min**
123	700	Passed		
130	740	Passed		
137	780	Passed		
144	820	**Failed @ 4.0 min**		
Withstand Voltage Withstand Voltage Stress**		137 kV 780 V/mil	109 kV 620 V/mil	109 kV 620 V/mil

Min. Requirement to Pass = 580 V/mil** (failure on test section)
* 5 minute voltage steps
** Based on nominal insulation thickness of 175 mils

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Water Terminals
Conditioning: 360 days AWTT

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: Ambient
Tested by: V. Yaroslavskiy

Table No. 6

HIGH VOLTAGE TIME TEST
(on cable after 360 days of AWTT aging)

Applied Voltage* kV	Voltage Stress** V/mil	Sample No.		
		19	20	21
17.5	100	Passed	Passed	Passed
24.5	140	Passed	Passed	Passed
32	180	Passed	Passed	Passed
39	220	Passed	Passed	Passed
46	260	Passed	Passed	Passed
53	300	Passed	Passed	Passed
60	340	Passed	Passed	Passed
67	380	Passed	Passed	Passed
74	420	Passed	Passed	Passed
81	460	Passed	Passed	Passed
88	500	**Failed @ 3.0 min**	Passed	Passed
95	540		**Failed @ 0.1 min**	**Failed @ 1.1 min**
Withstand Voltage Withstand Voltage Stress**		81 kV 460 V/mil	88 kV 500 V/mil	88 kV 500 V/mil

Min. Requirement to Pass = 380 V/mil** (failure on test section)
* 5 minute voltage steps
** Based on nominal insulation thickness of 175 mils

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Resistive
Conditioning: None

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: 130^{o}C
Tested by: V. Yaroslavskiy

Table No. 7

HOT IMPULSE TEST
(on cable as received)

Number of Pulses	Polarity	Applied Voltage kV	Voltage Stress* V/mil	Sample No.		
				4	5	6
10	Positive	110	630	Passed	Passed	Passed
10	Negative	110	630	Passed	Passed	Passed
3	Negative	140	800	Passed	Passed	Passed
3	Negative	170	980	Passed	Passed	Passed
3	Negative	200	1150	Passed	Passed	Passed
3	Negative	230	1320	Passed	Passed	Passed
3	Negative	260	1490	Passed	Passed	Passed
3	Negative	290	1660	Passed	Passed	Passed
3	Negative	320	1830	Passed	Passed	Passed
3	Negative	350	2000	Passed	Passed	Passed
3	Negative	380	2170	Passed	Passed	**Failed @ 3rd impulse**
3	Negative	410	2340	Passed	**Failed @ 3rd impulse**	
3	Negative	440	2510	Passed		
3	Negative	470	2690	**Termination flashover**		
Withstand Voltage Withstand Voltage Stress*				>440 kV >2510 V/mil	380 kV 2170 V/mil	350 kV 2000 V/mil
Min. Requirement to Pass = 1200 V/mil* (failure on test section) * Based on nominal insulation thickness of 175 mils						

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Resistive
Conditioning: Cyclic Aging

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: 130^{o}C
Tested by: V. Yaroslavskiy

Table No. 8

HOT IMPULSE TEST
(on cable after heat cycling)

Number of Pulses	Polarity	Applied Voltage kV	Voltage Stress* V/mil	Sample No.		
				10	11	12
10	Positive	110	630	Passed	Passed	Passed
10	Negative	110	630	Passed	Passed	Passed
3	Negative	140	800	Passed	Passed	Passed
3	Negative	170	980	Passed	Passed	Passed
3	Negative	200	1150	Passed	Passed	Passed
3	Negative	230	1320	Passed	Passed	Passed
3	Negative	260	1490	Passed	Passed	Passed
3	Negative	290	1660	Passed	Passed	Passed
3	Negative	320	1830	Passed	Passed	Passed
3	Negative	350	2000	**Failed @ 2nd impulse**	Passed	Passed
3	Negative	380	2170		Passed	Passed
3	Negative	410	2340		**Failed @ 1st impulse**	**Failed @ 1st impulse**
Withstand Voltage Withstand Voltage Stress*				320 kV 1830 V/mil	380 kV 2170 V/mil	380 kV 2170 V/mil
Min. Requirement to Pass = 1200 V/mil* (failure on test section) * Based on nominal insulation thickness of 175 mils						

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: None
Conditioning: See table

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length:
Test Temp: See table
Tested by: V. Yaroslavskiy

Table No. 9
FAILURE EXAMINATION

Sample No.	Type of Test	Test Temp. °C	Conditioning	Thickness at Breakdown mils	Breakdown Origin
1	AC	Ambient	None	187	Outer third of insulation wall
2	AC	Ambient	None	186	Inner third of insulation wall
3	AC	Ambient	None	188	Inner third of insulation wall
4	Impulse	130	None	198*	N/A
5	Impulse	130	None	183	Central third of insulation wall
6	Impulse	130	None	192	Central third of insulation wall
7	AC	Ambient	Cyclic Aging	198*	N/A
8	AC	Ambient	Cyclic Aging	198*	N/A
9	AC	Ambient	Cyclic Aging	198*	N/A
10	Impulse	130	Cyclic Aging	194	Inner third of insulation wall
11	Impulse	130	Cyclic Aging	198	Central third of insulation wall
12	Impulse	130	Cyclic Aging	194	Inner third of insulation wall
13	AC	Ambient	120 days AWTT	189	Outer third of insulation wall
14	AC	Ambient	120 days AWTT	184	Inner third of insulation wall
15	AC	Ambient	120 days AWTT	190	Could not be established
16	AC	Ambient	180 days AWTT	191	Conductor shield
17	AC	Ambient	180 days AWTT	192	Conductor shield
18	AC	Ambient	180 days AWTT	192	Conductor shield
19	AC	Ambient	360 days AWTT	180	Conductor shield
20	AC	Ambient	360 days AWTT	184	Conductor shield
21	AC	Ambient	360 days AWTT	188	Conductor shield

* The maximum measured insulation thickness is assumed

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Water Terminals
Conditioning: See table

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: Ambient
Tested by: V. Yaroslavskiy

Table No. 10

SUMMARY OF AC VOLTAGE BREAKDOWN STRESSES

Sample No.	Condition	Breakdown Voltage, kV	Thickness at Breakdown, mils	Average Stress, V/mil	Mean Value, V/mil
1	As received	179	187	960	890
2		172	186	920	
3		151	188	800	
7	After load cycling	>193	198*	>970	>1240
8		>256	198*	>1290	
9		>290	198*	>1460	
13	After 120 days AWTT	186	189	980	800
14		130	184	710	
15		137	190	720	
16	After 180 days AWTT	144	191	750	650
17		116	192	600	
18		116	192	600	
19	After 360 days AWTT	88	180	490	510
20		95	184	520	
21		95	188	510	

* The maximum measured insulation thickness is assumed

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: Resistive
Conditioning: See table

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 22 feet
Test Temp: 130 °C
Tested by: V. Yaroslavskiy

Table No. 11

SUMMARY OF IMPULSE VOLTAGE BREAKDOWN STRESSES

Sample No.	Condition	Breakdown Voltage, kV	Thickness at Breakdown, mils	Average Stress, V/mil	Mean Value, V/mil
4	As received	>440	198*	>2220	>2150
5		410	183	2240	
6		380	192	1980	
10	After load cycling	350	194	1800	1990
11		410	198	2070	
12		410	194	2110	

* The maximum measured insulation thickness is assumed

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: None
Conditioning: See table

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length:
Test Temp: Ambient
Tested by: V. Yaroslavskiy

Table No. 12
DIMENSIONAL CHARACTERISTICS

Sample No.	Thickness - mils	Min.	Max.	Avg.
	Conductor Shield			
1	Before heat cycling	25	33	28
7	After heat cycling	26	34	30
13	After 120 days AWTT	26	32	29
16	After 180 days AWTT	25	32	28
19	After 360 days AWTT	27	35	31
	AEIC Limits	12	--	--
	Insulation			
1	Before heat cycling	184	194	188
7	After heat cycling	182	193	188
13	After 120 days AWTT	182	190	188
16	After 180 days AWTT	184	194	189
19	After 360 days AWTT	178	190	184
	AEIC Limits	165	205	--
	Insulation Shield			
1	Before heat cycling	38	45	41
7	After heat cycling	38	43	41
13	After 120 days AWTT	39	44	41
16	After 180 days AWTT	39	44	41
19	After 360 days AWTT	38	42	40
	AEIC Limits	30	60	--

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage: 15 kV
Insul. Material: HFDC -4202 EC
Cond. Shield: HFDA-0800
Insul. Shield: KW-3007ES
Terminations: None
Conditioning: See table

Conductor: 1/0 AWG, Al
Ins. Thickness: 175 mils
Test Length: 2 feet
Test Temp: Ambient
Tested by: V. Yaroslavskiy

Table No. 13

STRIPPING TENSION

		Pulling Tension – lbf	
		Minimum	**Maximum**
Before heat cycling	Pull 1	7	7½
(Sample No. 1)	Pull 2	6½	7¼
AEIC Limits		3	24
After heat cycling	Pull 1	5	7½
(Sample No. 7)	Pull 2	5	5¾
AEIC Limits		3	-
After 120 days AWTT	Pull 1	5	5¼
(Sample No.13)	Pull 2	5	5½
AEIC Limits		-	-
After 180 days AWTT	Pull 1	4½	5
(Sample No.16)	Pull 2	4½	5½
AEIC Limits		-	-
After 360 days AWTT	Pull 1	4	5½
(Sample No.19)	Pull 2	3½	4½
AEIC Limits		-	-

CUSTOMER: TAIHAN CABLE VINA CO., LTD.

Rated Voltage:	15 kV	**Conductor:**	1/0 AWG, Al
Insul. Material:	HFDC -4202 EC	**Ins. Thickness:**	175 mils
Cond. Shield:	HFDA-0800	**Test Length:**	
Insul. Shield:	KW-3007ES	**Test Temp:**	Ambient
Terminations:	N/A	**Tested by:**	V. Yaroslavskiy
Conditioning:	See Table		

Table No. 14
RESULTS OF TREE COUNT TEST

			6-10 mils (30 wafers)	11-20 mils (30 wafers)	21-30 mils (30 wafers)
Bowtie trees	Volume examined, in^3		0.25	0.25	0.25
	120 days AWTT	Number	35	3	0
		Tree density, N/in^3	140	12	0
	180 days AWTT	Number	0	20	0
		Tree density, N/in^3	0	80	0
	360 days AWTT	Number	10	6	0
		Tree density, N/in^3	40	24	0
			10-15 mils (30 wafers)	**16-20 mils (30 wafers)**	**21-25 mils (30 wafers)**
Vented trees at conductor shield surface*	Surface examined, in^2		0.9	0.9	0.9
	120 days AWTT	Number	0	0	0
		Tree density, N/in^2	0	0	0
	180 days AWTT	Number	Numerous*	0	0
		Tree density, N/in^2	N/A	0	0
	360 days AWTT	Number	Numerous*		2
		Tree density, N/in^2	N/A		2.2
Vented trees at insulation shield surface	Surface examined, in^2		1.8	1.8	1.8
	120 days AWTT	Number	0	0	0
		Tree density, N/in^2	0	0	0
	180 days AWTT	Number	0	1	0
		Tree density, N/in^2	0	0.6	0
	360 days AWTT	Number	3	0	0
		Tree density, N/in^2	1.7	0	0

* Whitish formations resembling water trees (see section 4.8 and Figure 6). There were dense agglomerates of these features preventing their counting.

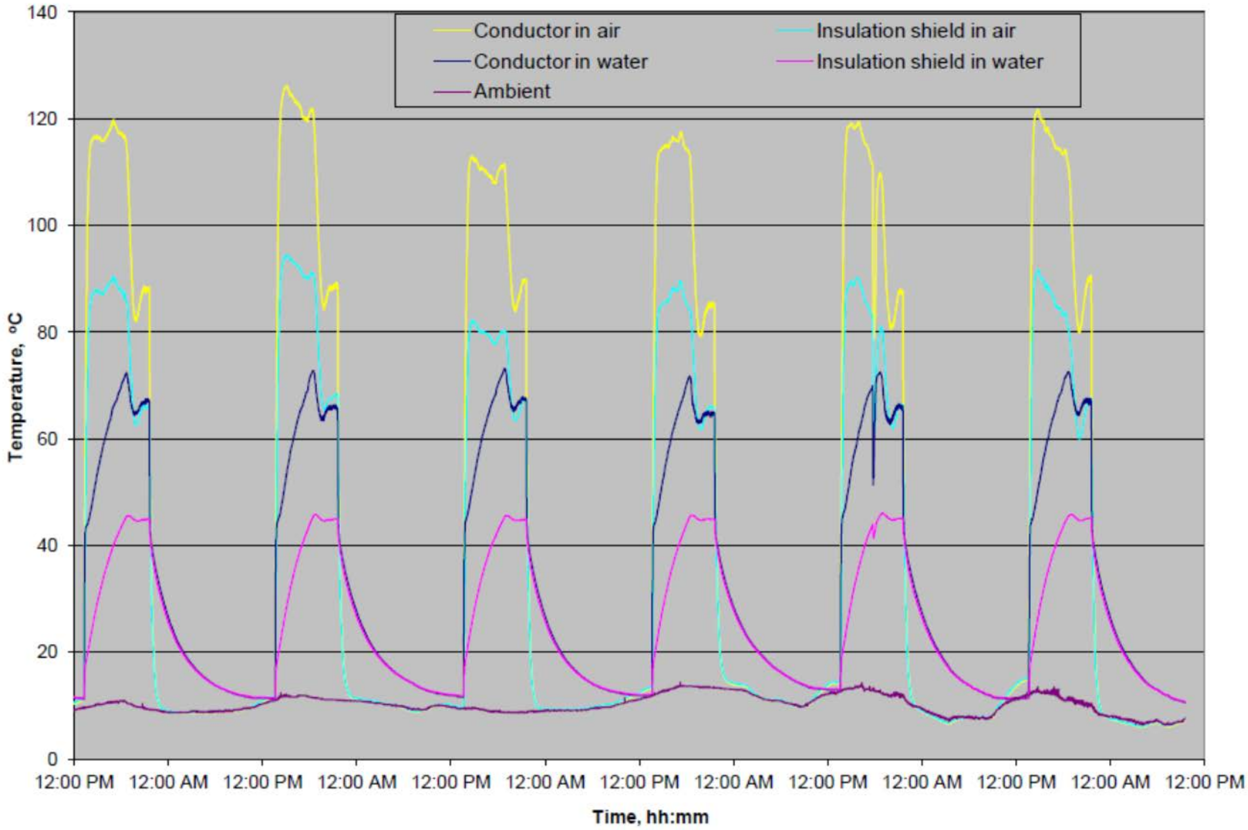


Figure 1: AWTT temperature profiles registered on the dummy

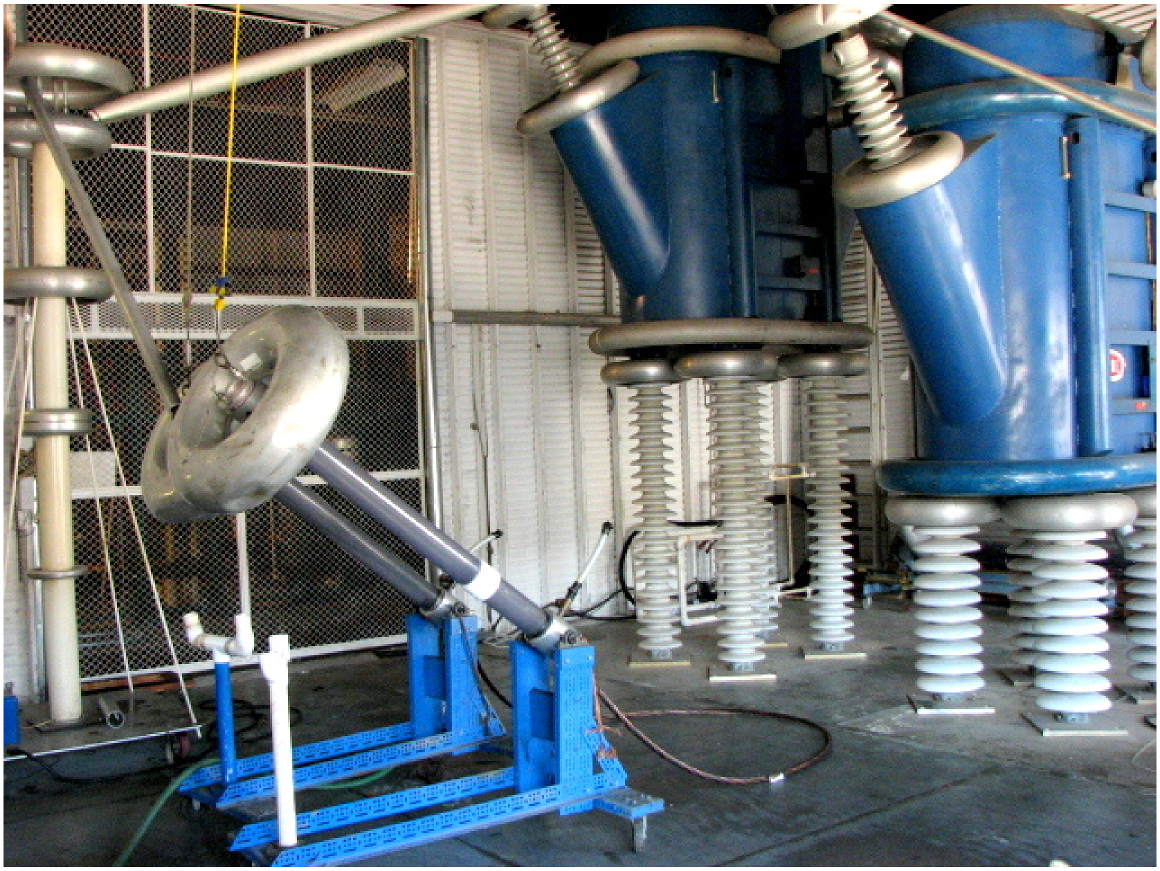
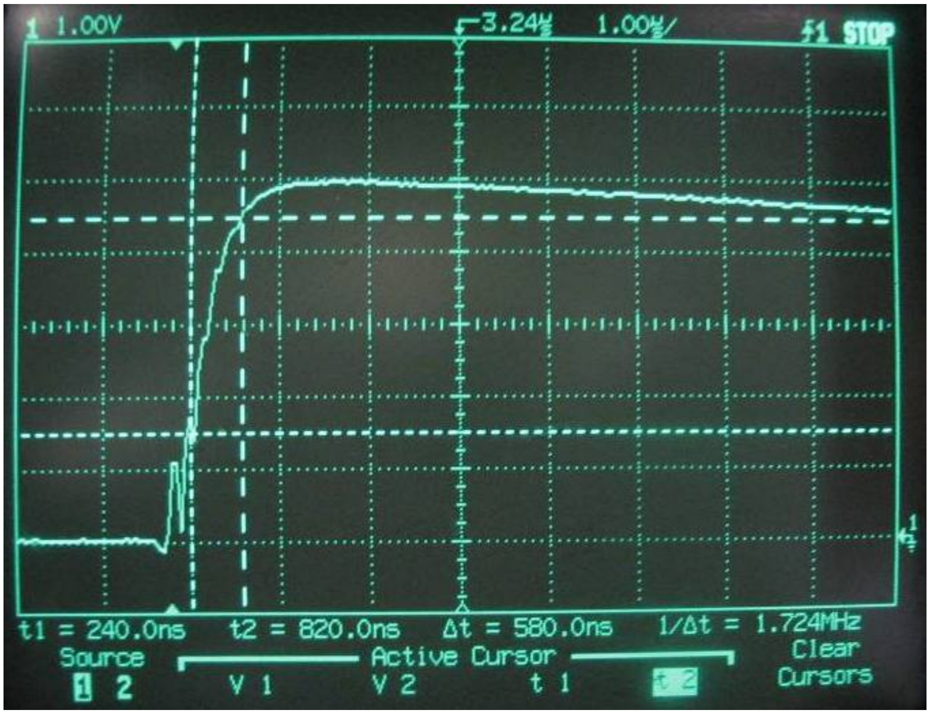


Figure 2: Set-up for partial discharge and ac high voltage time tests

Figure 3: Set-up for impulse voltage tests at high temperature.



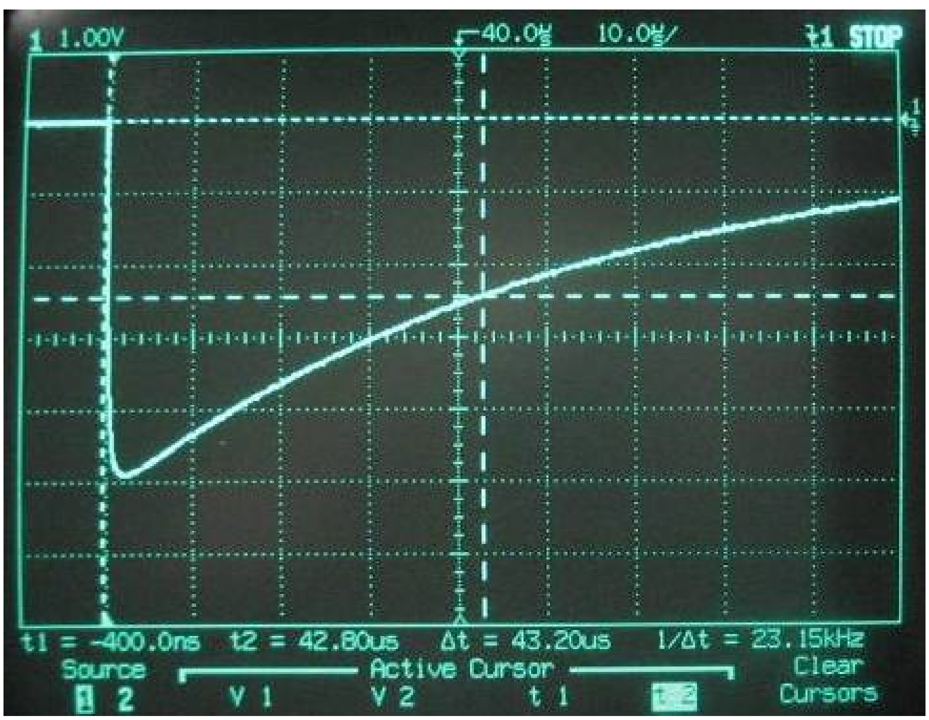


Figure 4: Impulse front (upper picture) and tail (lower picture).

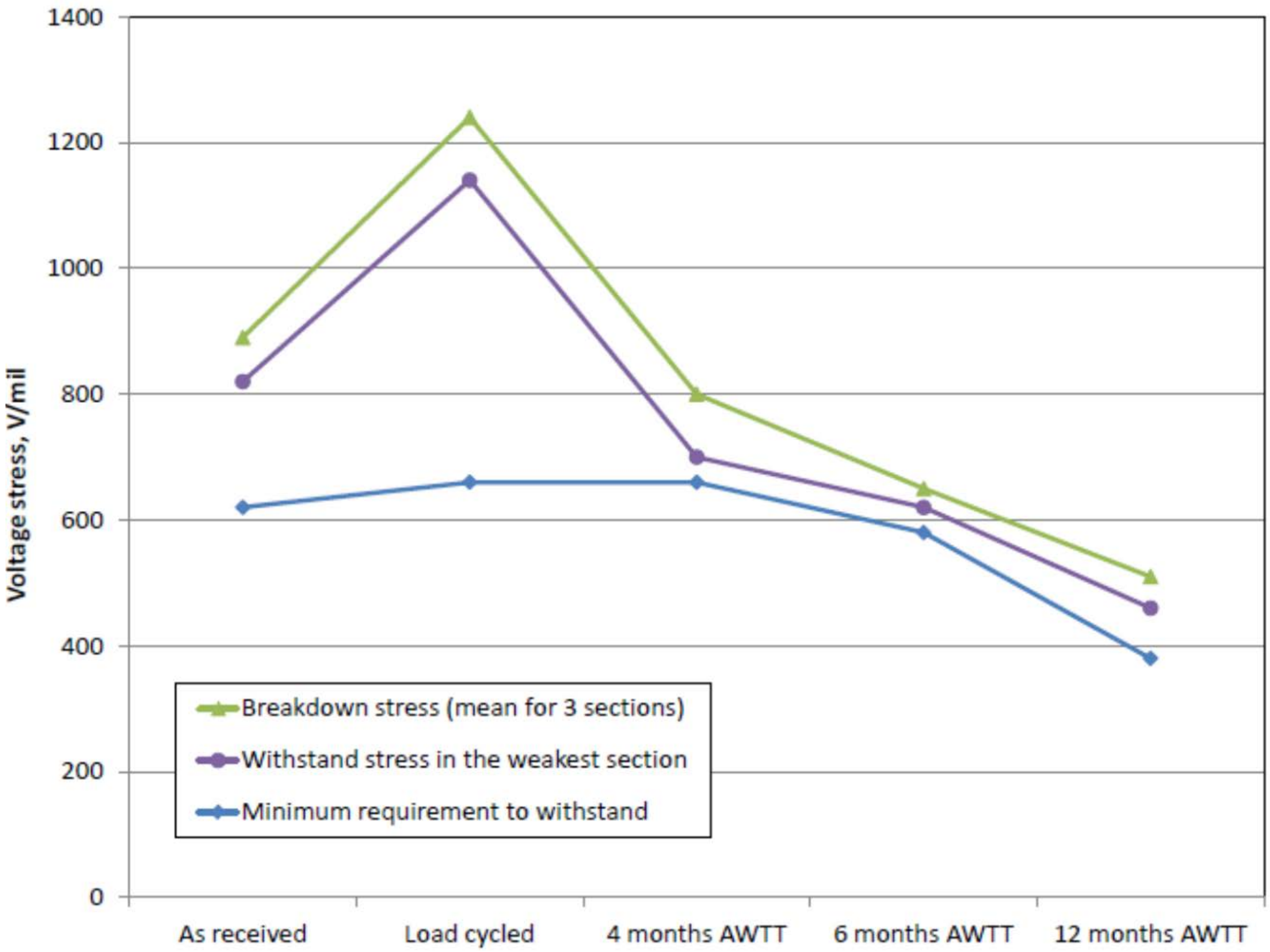


Figure 5: Change in cable ac dielectric strength during the test program.

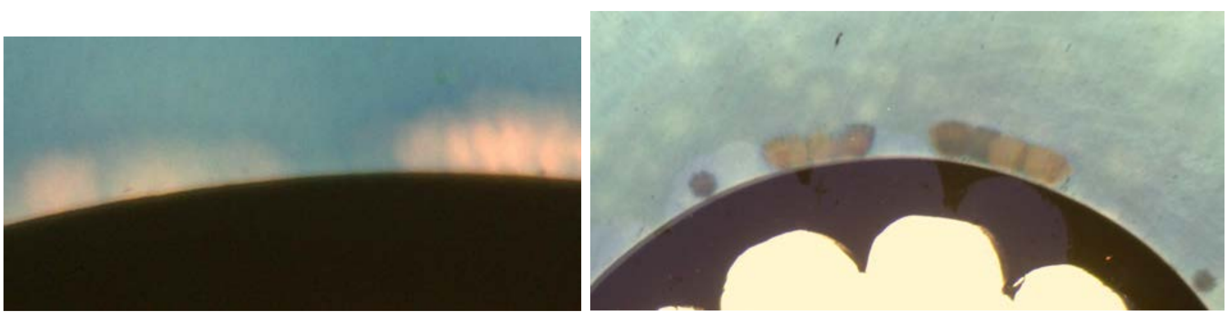


Figure 6: Typical appearance of features resembling water trees vented at the conductor shield (in sample tested after 120 days of AWTT aging, left picture, and after 360 days of aging, right picture).

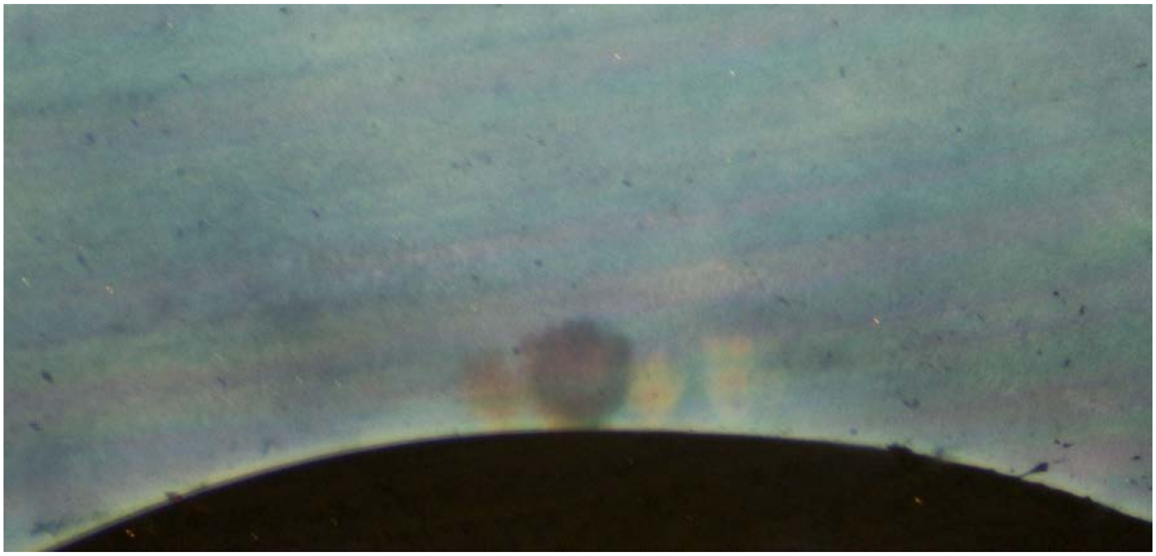


Figure 7: Vented tree at the conductor shield.

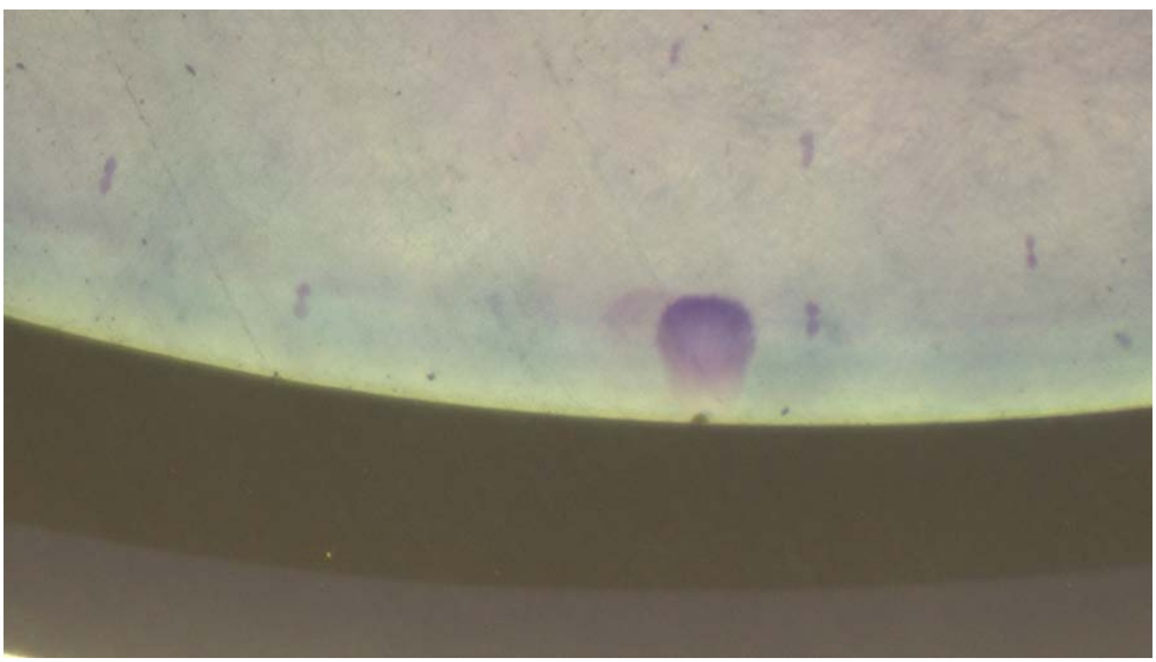


Figure 8: Vented tree at the insulation shield. Note small, densely populated bow tie trees.

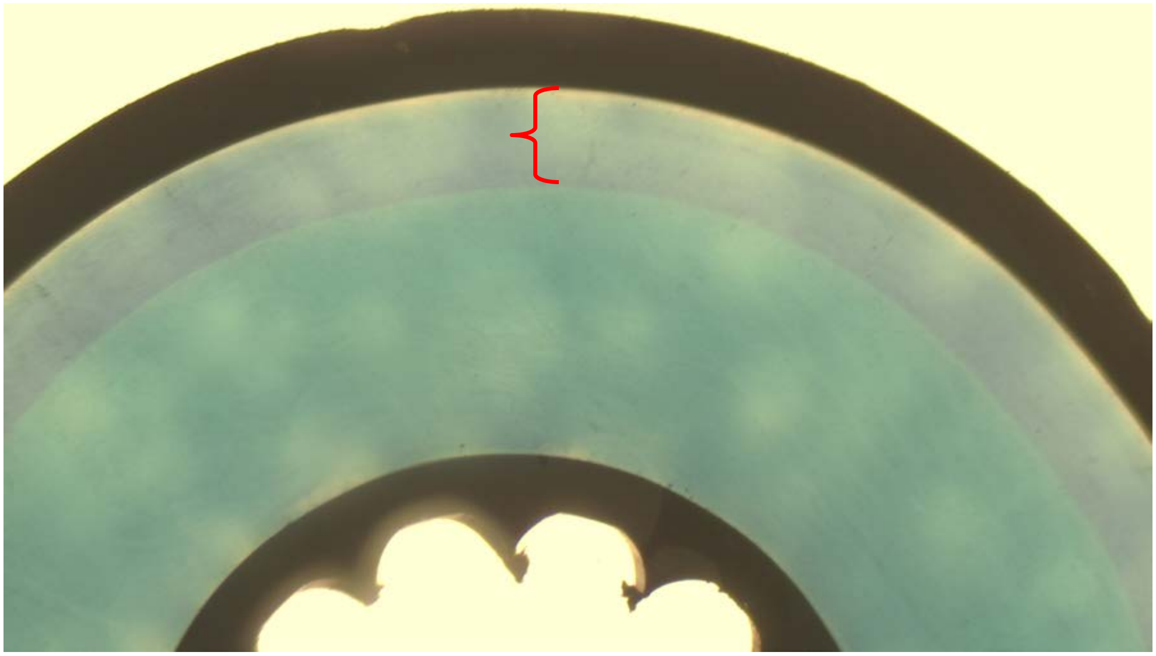


Figure 9: Discolored band attached to the insulation shield (120 days of AWTT aging).

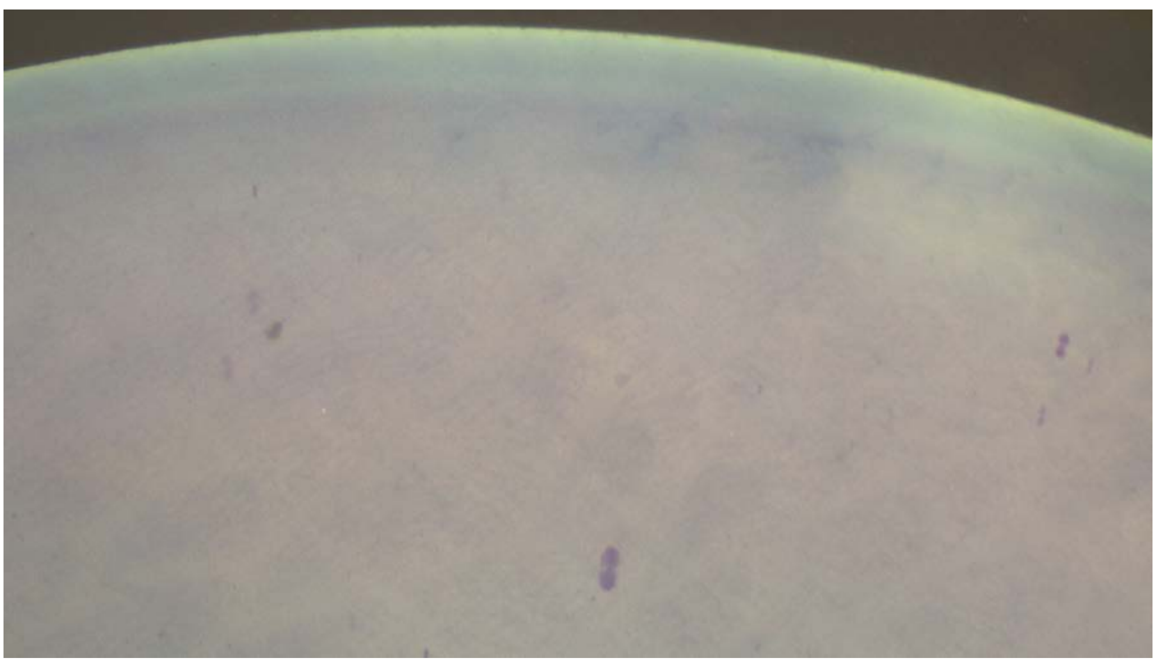


Figure 10: Diffused color band in sample 16 and one of the largest bow tie trees.

APPENDIX 1

FLOW CHART FOR CORE QUALIFICATION TESTS