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BCIC PRODUCT FIELD SAMPLE CASE STUDY REPORT

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Summary

TE Connectivity (Raychem) BCIC bushing connection insulation cover was removed from its substation in Durban for investigation into the products degradation and material performance assessment after 12 years in service. Summary of testing evaluating the materials visual, mechanical and electrical performance after its successful operational service life in comparison to a new product. Correlating the current material qualification and performance including a predicted service life performance against a real in-service product which has been exposed to 12 years of high temperatures, high UV and day to day airborne pollutants situated by the coast.

The insulation and structural integrity of the material is inline with predicted service performance values exceeding 25 years active service, remaining products installed will perform to function as expected for at least a further 13 years.

Revision History

Issue	Changes
1	Original Issue
2	Addition of Product Performance Evaluation IEEE std. 4-2001

1 Objective

To characterise the material and product performance of a bushing connection insulation cover which has been in field service for 12 years compared to new product to align natural degradation with the accelerated ageing which qualifies the material.

1.1 Product Performance Assessment Objective

Evaluate the AC withstand performance of a BCIC-5.5D/11 bushing protection cover that had been installed in the field for 12 years compared to a new cover.

2 Material

In Field Service Product

	Product 1	Product 2
Product Description	BCIC-5.5D/11-HO	BCIC-5.5D/11-HO
Manufacturing Number	A6AA205	A6HH016
Material	BCIS	BCIS
Years of Service	12	12
Location	Durban, South Africa	Durban, South Africa
Testing	Materials Analysis	Product Performance Evaluation

Control Product

	Product 3
Product Description	BCIC-7/12/7
Manufacturing Number	D551891
Material	BCIS

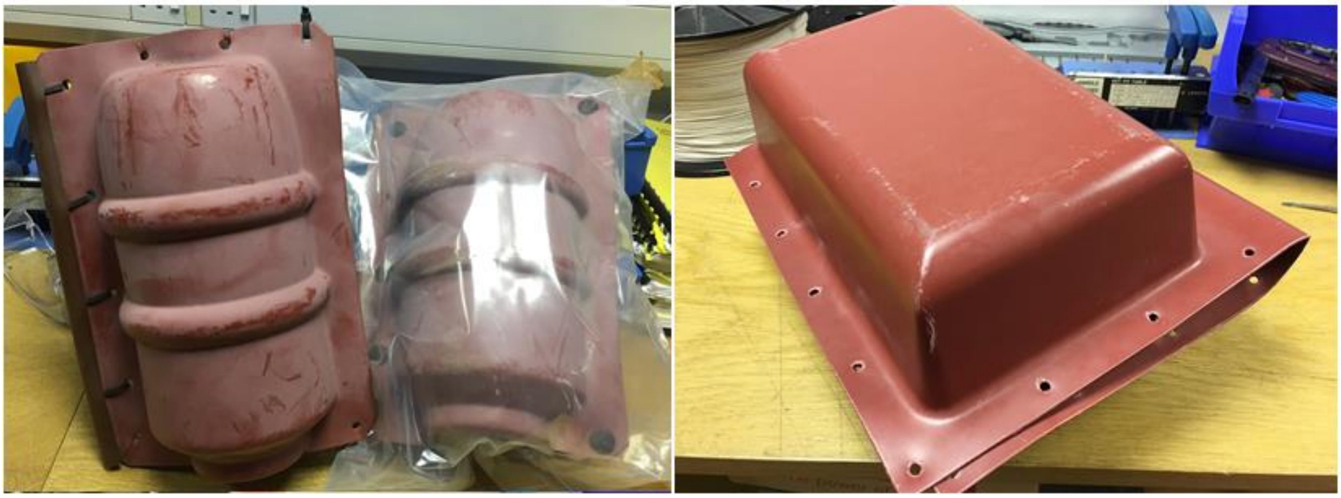

Figure 1 Product Samples: (Left) BCIC 5.5D/11-HO returned from 10 years field service; (right) BCIC-7/12/7 taken from stock with no in field service

3 Material and Product Analytical Evaluation

3.1 Bulk and Surface Elemental Analysis

Product composition analysis was performed on the field sample and compared to control material to identify if there has been any change in the material and to assess the types of contaminants present on the surface.

3.1.1 Material "Bulk" Analysis

An analysis of the material "bulk" was performed to identify if any contaminants have migrated / diffused into the material during service.

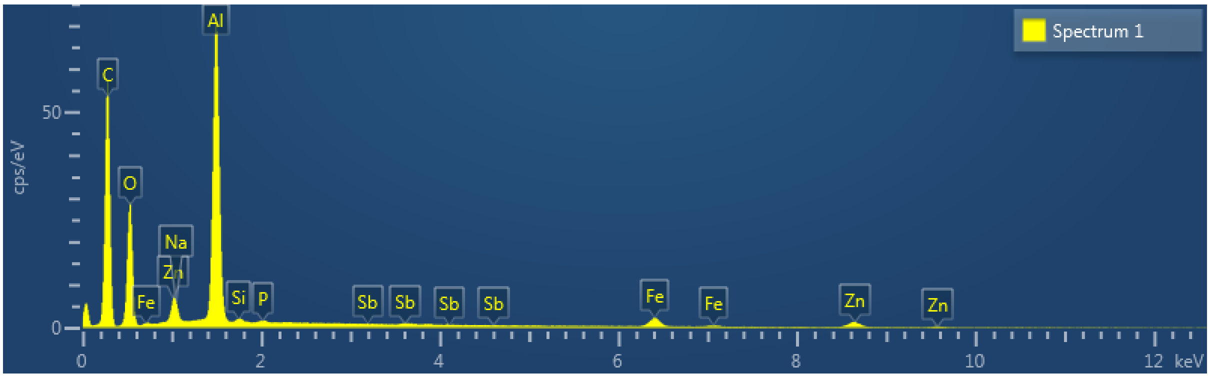

Figure 2 BCIC Control Sample Material Bulk SEM Trace

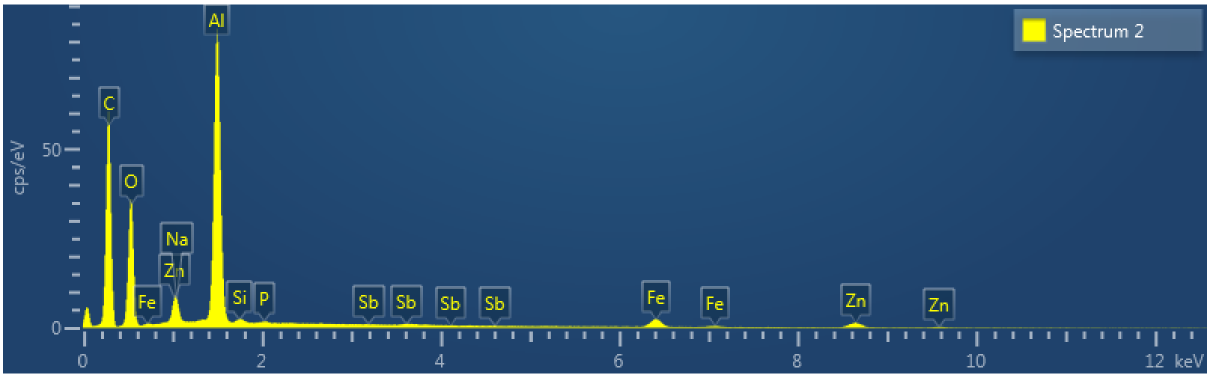

Figure 3 BCIC Field Sample Material Bulk SEM Trace

Comparison of the control with the in-field service sample shows no difference in the elemental trace which shows that the material has not had any foreign substances diffuse/migrate into the bulk of the material.

3.1.2 Product Surface Analysis

An analysis of the product surface was also performed to identify the pollution and air born substances which it has been exposed to during its service life.

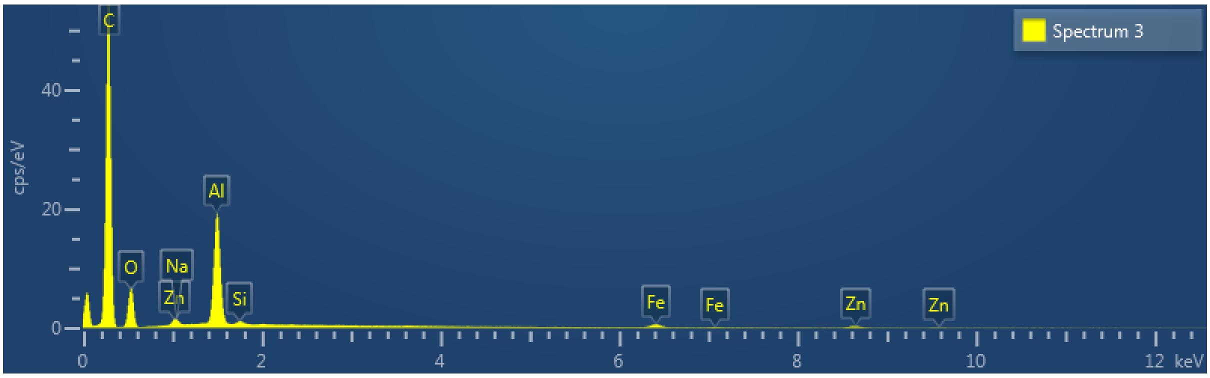

Figure 4 BCIC Control Sample Product surface SEM Trace

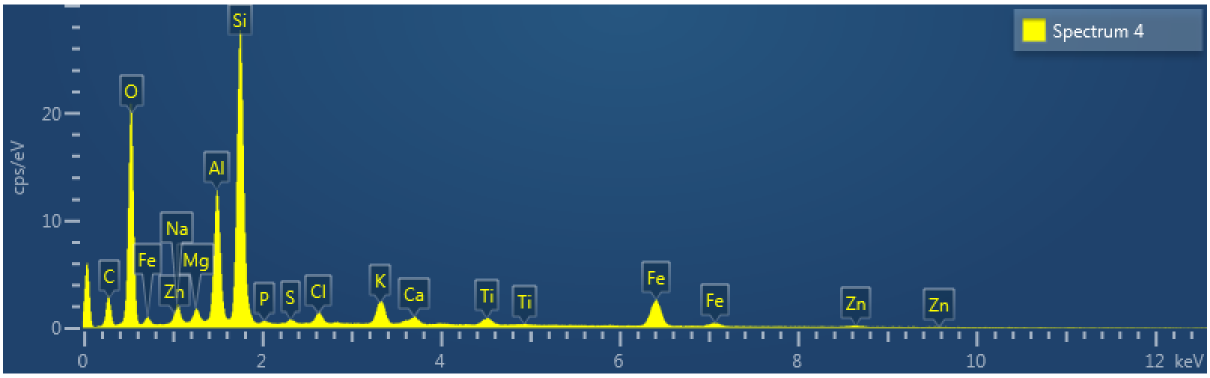

Figure 5 BCIC Field Sample Product surface SEM Trace

The field sample shows a range of elements which do not appear in the bulk or the surface of the material, from a strong silicon peak to trace amounts of potassium, titanium, chlorine and sulphur. These can be identified as common pollutants such as the sodium chloride (salt – being near the coast this is expected) along with potassium; sulphur (sulphates) from fossil fuel / biomass combustion fumes; silicon from silicon dioxide (sand), trace amounts of titanium could be from flake paint and other coatings applied on or near by the substation.

4 Testing and Evaluation

Testing was performed in line with the TE Connectivity product performance specification which assesses a material's physical, electrical, chemical, thermal and resistance to UV performance. With the in-service products, this case study the evaluation of the materials physical and electrical properties normally performed on new material, will instead be used as an assessment for long-term in-service performance which has experienced 12 years in a harsh environment.

For further information on the test methods, reference the test standards.

4.1 Tensile Strength and Ultimate Elongation – ASTM D412-98A

Evaluation of the materials physical performance was conducted through tensile testing, in accordance to the ASTM test standard both the virgin material and the aged sample were tested to failure identifying the materials tensile properties of tensile strength and tensile strain for elasticity.

Sample Description	Tensile Strength (MPa)	Ultimate Elongation (%)
Product 3 (control)	12.0	500
Product 1 (field sample)	7.0	300
Degradation %	-30%	-40%

Table 1 BCIC Control and Field Sample Mechanical Test Data

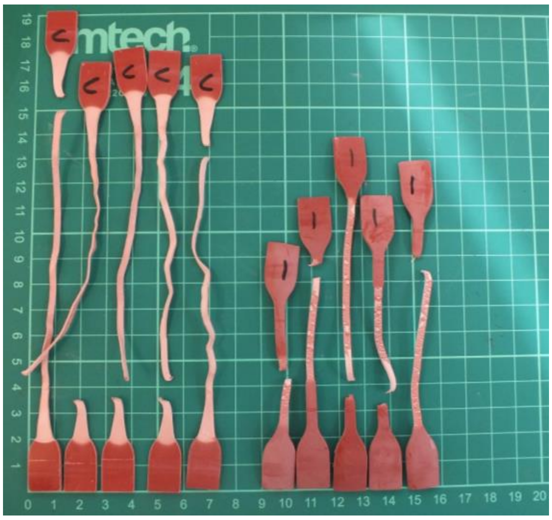

Figure 6 Tensile Tested Samples: (left) "C" is the control/ virgin BCIS material; (right) "1" refers to the in-service field BCIS sample

4.2 Accelerated Ageing: ASTM D2671-00

Accelerated ageing typically performed as a short-term thermal evaluation, assess a material's (and product in service) ability to withstand short term temperature spikes which can be induced by short circuit, a fault or connection degradation. This is part of the routine test programme which TE Connectivity uses to evaluate and qualify materials and is typically performed on new, unaged/exposed material, however it is also valuable to assess whether after a term in service (12 years) the material still exhibits the same robust properties then when it was firstly installed.

Sample Description	Control State		After 168 hours at 150°C	
	Tensile Strength (MPa)	Ultimate Elongation (%)	Tensile Strength (MPa)	Ultimate Elongation (%)
Product 3 (control)	12.0	500	11.0	500
Product 1 (field sample)	7.0	300	8.0	300

Table 2 BCIC Control and Field Sample Accelerated Ageing Mechanical Test Data

The control and the field sample exhibit predictable behaviour through accelerated ageing test, with the both materials showing no degradation to the ultimate tensile strain and only a minor change in the tensile strength. This shows that despite being in service for a prolonged period the material still exhibits excellent robust properties ideally suited for its application in substations and overhead line equipment.

4.3 Dielectric Strength – ASTM D149-97A

A critical product performance property is it great to see that even after 12 years in field service and with degradation in the physical properties (up to 40%) there is no change in the materials dielectric withstand performance, indicating that it still provides the same protection now than when it was installed 12 years ago. It should also be noted that the application voltage for the bushings and busbars was 36kV, whereas the materials breakdown performance exceeds 50kV.

Sample Description	Thickness (mm)	Breakdown Voltage (kV)	Dielectric Strength (kV/mm)	Dielectric Strength (kV/cm)
Product 3 (control)	2.05	51.0	25.3	252.0
Product 1 (field sample)	2.1	51.7	24.5	245.0

Table 3 BCIC Control and Field Sample Dielectric Strength Test Data

4.4 Volume Resistivity – ASTM D257-99 and Surface Resistivity – ASTM D257-99

Insulation enhancement is the purpose of the product and thus the material, it is then important that even during exposure and presence of pollutants the surface and bulk of the material does not exhibit any change other than insulating. As detailed below it can be seen that the volume resistivity is the same between both samples, indicating that no pollutant or contaminant has migrated through the material or degraded during its service causing an effect on the insulation performance of the material.

With the surface of the products it should be noted that the material was tested without the surface of the field sample being cleaned.

Sample Description	Thickness (mm)	Volume Resistivity (Ωcm)	Surface Resistivity (Ω)
Product 3 (control)	1.5	1.0E+15	2.0E+16
Product 1 (field sample)	2.0	2.0E+15	5.0E+14

Table 4 BCIC Control and Field Sample Volume and Surface Resistivity Test Data

4.5 Dielectric Constant – IEC 60250:1996

Dielectric Constant is used to determine the ability of an insulator to store electrical energy. The dielectric constant is the ratio of the capacitance induced by two metallic plates with an insulator between them to the capacitance of the same plates with air or a vacuum between them. A material characteristic used in collaboration with volume resistivity this ensures that the material has not changed from being an insulating material, no significant change in the materials dielectric constant supports the volume resistivity value determined in section 4.4.

Sample Description	Dielectric Constant
Product 3 (control)	3.5
Product 1 (field sample)	3.75

Table 5 BCIC Control and Field Sample Dielectric Constant Test Data

4.6 Tracking and Erosion Resistance Incline Plane

This test is performed to simulate a contaminated environment through applying a conductive fluid across an abraded and wetted surface, to imitate a weathered surface. When the test is running the voltage causes the formation of a dry band where electrical discharges occur at the bottom electrode. This localized and persistent discharge activity can rise the temperature to cause degradation, and it's this degradation that measures the performance of the material. The sample is fixed at the angle of 45° and the conductive solution flows through the lower surface of the test sample.

The method consists of two alternative test procedures: the constant value of the test voltage is used for 6 hours (IEC 60587) or the voltage is increased after one hour (ASTM D2303-97). The sample passes the test when the erosion channel or tracking path is shorter than 25 mm after 6 hours and the current was smaller than 60 mA.

4.6.1 Variable Step Voltage Test Method - ASTM D2303

The voltage and time at failure mode are recorded.

The test regime is according to the table below:

Time (minutes)	Voltage (kV)	Contaminant Flow Rate (ml/min)	Series Resistor
0 – 60	2.50	0.15	10kΩ
60 – 120	2.75	0.15	10kΩ
120 – 180	3.00	0.30	50kΩ
180 - 240	3.25	0.30	50kΩ
240 – 300	3.5	0.30	50kΩ

Table 6 ASTM D2303 Inclined Plane Tracking and Erosion Step Test Conditions and Parameters

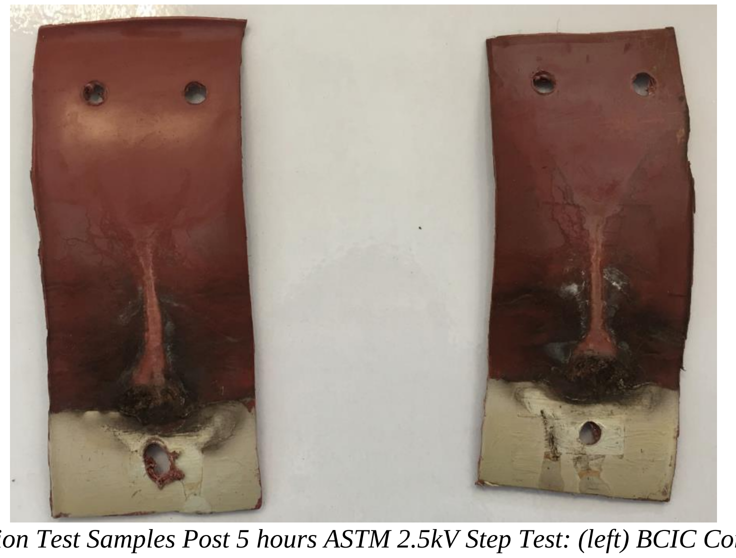

Figure 7 Tracking and Erosion Test Samples Post 5 hours ASTM 2.5kV Step Test: (left) BCIC Control Product; (right) BCIC In-Field Service Product

4.6.2 *Constant Voltage Test Method – IEC 60587*

Experimental test method and sample preparation are the same as that as for the ASTM D2303 except as can be seen there is no silver paint applied to the material where the bottom electrode is located.

The test regime is according to the table below:

Time (minutes)	Voltage (kV)	Contaminant Flow Rate (ml/min)	Series Resistor
0 – 360	4.50	0.6	50kΩ

Table 7 IEC Inclined Plane Tracking and Erosion Step Test Conditions and Parameters

Figure 8 Tracking and Erosion Test Samples Post 6 hours IEC 4.5kV Constant Test: (left) BCIC Control Product; (right) BCIC In-Field Service Product

4.7 Thermal Endurance – IEC 60216

Thermal Endurance test results taken from PPR-3326 in accordance to IEC 60216, defined as the continuous service temperature at which the material will last 20,000 hours was found to be 115°C. The results were based on three aging temperatures 150°C, 162°C, and 175°C and the elongation at break values at sequential take outs are shown below. The tensile test results from the field sample have been plotted on the same graph indicated with orange circles. This shows that the material is around 45-50% through its expected service life, resulting in a 24-26 year service.

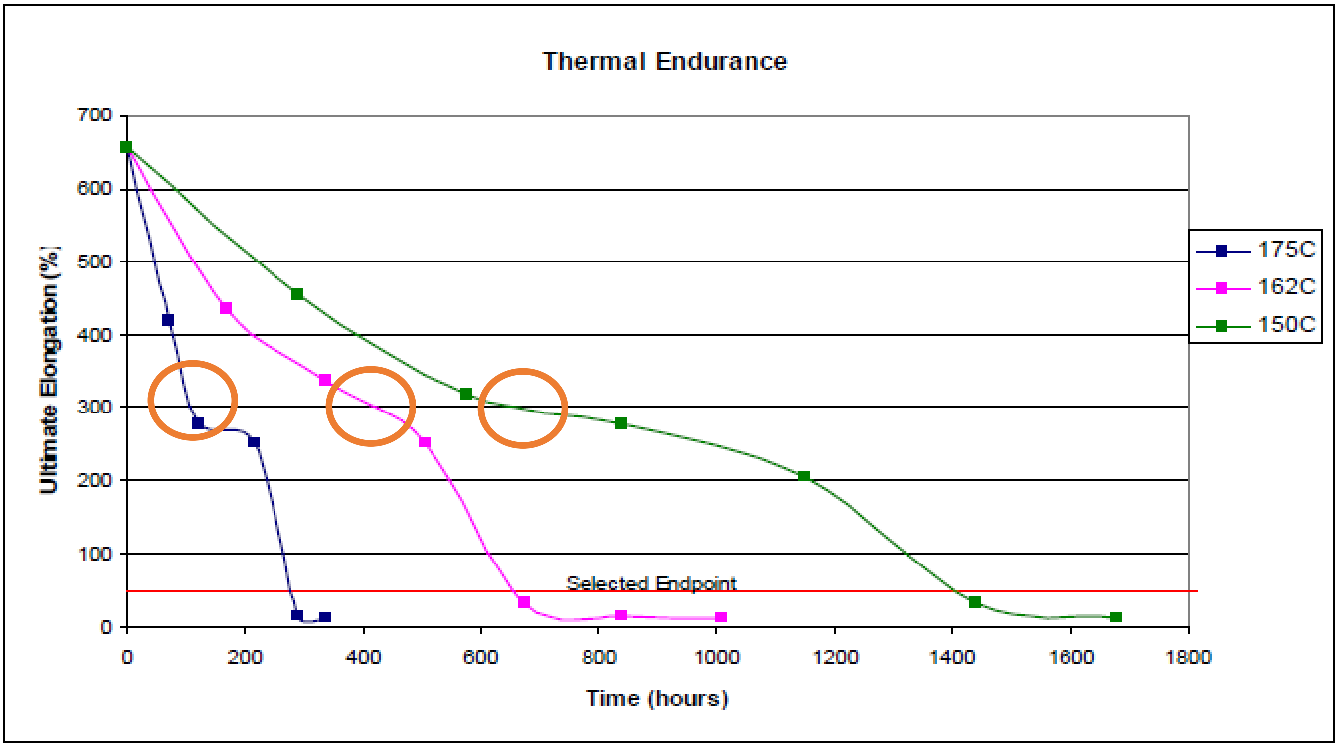

Figure 9 Thermal Endurance, 3 tested temperatures showing the elongation at break values vs time; tensile performance of the in-service field sample has been marked on the 3 traces

4.8 AC Withstand Test – IEEE std. 4a-2001

4.8.1 AC Withstand Test 1

Two samples were tested. One sample had been installed in the field for 12 years. This sample had a level of contamination present from the period it was installed. The second sample was a brand-new cover from inventory. The samples were installed between the first two skirts of a bushing with a MVCC insulated conductor exiting out the top of the cover.

Figure 10 AC Withstand Test Set up showing the product with 12 years in-field service (left), which is heavily contaminated with residue on the inside and outside and new unexposed cover (right), the steel mesh represents a ground plane

The withstand test was performed in accordance with IEEE std. 4a-2001. A wire mesh was wrapped around the outside of the cover. The voltage was then brought up to 20kV (34kV ph-ph) and held for 1 minute. The voltage was then raised 2kV per minute until a flashover occurred.

Both covers passed 20kV (34kV ph-ph) for 1 minute. The new cover flashed at 31kV (53kV ph-ph) through the bottom of the cover and the field cover flashed at 30kV (52kV ph-ph) through the bottom.

4.8.2 AC Withstand Test 2

The withstand test was then performed a second time using a probe on the side of the cover simulating point contact and the shortest distance between insulated bushing/insulators at different phases.

Figure 11 AC Withstand Test Set up showing the product with 12 years in-field service (left), which is heavily contaminated with residue on the inside and outside and new unexposed cover (right), the probe represents a ground point contact

The in-field service cover passed 20.2kV (34kV ph-ph) for 1 minute and with increasing the voltage flashed at 46kV (79kV ph-ph) through the flange. The new cover passed 20.2kV (34kV ph-ph) for 1 minute and then flashed at 47kV (80kV ph-ph) through the flange.

4.8.3 AC Wet Withstand Test 3

AC Withstand Test 3 was performed using the same setup as Test 2 with the probe on the side of the cover, except the covers were placed in a climatic chamber where a wet contaminated solution of 100 µs was sprayed on the samples for 5 minutes. After 5 minutes of wetting, voltage is applied and held for 1 minute while the solution continuously sprays, if passed the voltage is then increased until failure is witnessed.

The in-field service cover at 20.2kV (34kV ph-ph) flashed over after 35 seconds. The new cover passed 20.2kV (34kV ph-ph) for 1 minute and then flashed at 27kV (46kV ph-ph) through the flange.

4.8.4 AC Wet Withstand Test 4

AC Withstand Test 4 was performed using the same setup as Test 1 with the mesh, except the covers were placed in a chamber where a wet contaminated solution of 100 µs was sprayed on the samples for 5 minutes. After 5 minutes of wetting, voltage is applied and held for 1 minute while the solution continuously sprays. The voltage is then increased till failure.

The in-field service cover passed 20.2kV (34kV ph-ph) for 1 minute and with increasing the voltage flashed at 35kV (60kV ph-ph) , there was a lot of surface electrical activity. The new cover passed 20.2kV (34kV ph-ph) for 1 minute and then flashed at 43kV (74kV ph-ph) through the flange.

4.9 AC Withstand Testing Evaluation

The field sample and the new cover from inventory had very similar dry withstand test results. The wet withstand results were also similar with the wire mesh around the middle which a worse case test. When using the probe, the new cover performed slightly better. The time spent in the field and the level of contamination did not affect the cover's performance to withstand incidental animal contact.

5 Summary of Results

Test		Standard	Units	Requirement	New BCIC (Product 3)	Field BCIC (Product 1)
Ultimate Elongation (23°C ± 2)		ASTM D412	%	500 min.	500	300
Ultimate Tensile Strength (23°C ± 2)		ASTM D412	MPa	8.0 min.	12.0	7.0
Accelerated Ageing Ultimate Elongation (168hrs @ 150°C)		ASTM D2671	%	400 min.	11.0	8.0
Accelerated Ageing Tensile Strength (168hrs @ 150°C)		ASTM D2671	MPa	8.0 min	500	300
Volume Resistivity		ASTM D257	Ωcm	1.0 E+14 min.	1.0E+15	2.0E+15
Surface Resistivity			Ω	n/a	2.0E+16	5.0E+14
Dielectric Constant				5 max	3.5	3.75
Dielectric Strength	Thickness (±0.1)	IEC 60243	mm	2.5	252	245
	Breakdown Voltage		kV / cm	180 min.		
Tracking Erosion Resistance Test		ASTM D2303	n/a	1hr @2.5kV 1hr @2.75kV 1hr @3kV	1hr @ 2.5kV 1hr @ 2.75kV 1hr @ 3kV 1hr @ 3.25kV 1hrs @ 3.5kV	1hr @ 2.5kV 1hr @ 2.75kV 1hr @ 3kV 1hr @ 3.25kV 1hrs @ 3.5kV
Tracking Erosion Resistance Test		IEC 60587	n/a	n/a	6hrs @ 4.5kV	6hrs @ 4.5kV
Dry AC Withstand		IEEE std. 4-2001	Pass/Fail	34kV ph-ph	Passed	Passed
Dry AC Withstand (to failure)		IEEE std. 4-2001	ph-ph kV	-	53	52
Wet AC Withstand		IEEE std. 4-2001	Pass/Fail	34kV ph-ph	Passed	Passed (35 seconds)
Wet AC Withstand (to failure)		IEEE std. 4-2001	ph-ph kV	-	46	34

Table 8 BCIC 5.5D/11-HO Product and Material Performance Summary comparing the heavily contaminated and exposed in-field service samples to new products

6 Conclusion

Evaluation of the field product from Durban, South Africa after 12 years of operational service has shown that the expectation of TE Connectivity (formally Raychem) materials are in alignment with the material properties of the BCIC product. Product performance from the physical degradation suggests that the material should meet or exceed its predicted service life of 25 years, it should be noted that this is especially important due to the location which is extremely hostile for a material with exposure to salt, pollution and high temperatures, humidity and UV radiation.