Material Analysis of Composite Hollow Core Insulators after one Decade of Observation in Martigues Test Station

A. Baumer[1], J. Seifert[1], C. Baer[2], J. Lambrecht[2], K. Hindelang[2]

[1] Reinhausen Power Composites GmbH

[2] Wacker Chemie AG

Agenda

1. **Introduction & Motivation**
2. **Installation and Observation at EDF Martigues Research Center**
   - Martigues Test Station
   - Inspection Program
3. **Investigation of Hollow Core Insulators after Removal from the Test Station**
   - Investigations at Complete Insulator
   - Material Analysis
4. **Conclusion & Outlook**

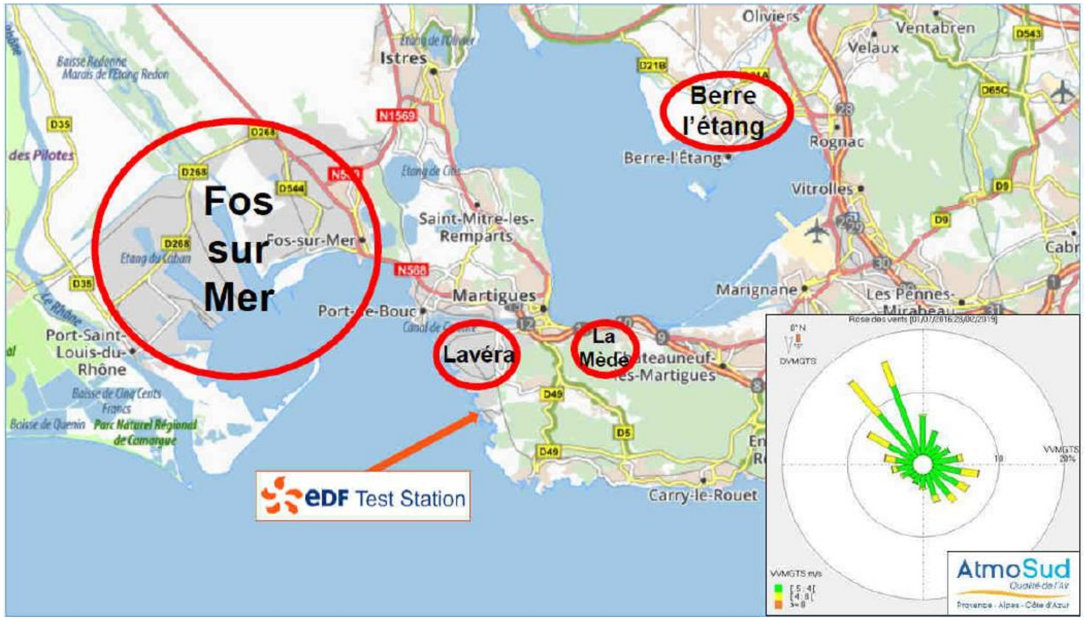
1. Introduction & Motivation

- Main functions of composite hollow core insulators:
  - Providing electrical insulation of the high voltage to the ground potential,
  - Withstanding occurring mechanical loads, especially seismic loads,
  - Maintaining the tightness of the inner volume to the outer environment

  under given outdoor environment with exposure to UV radiation, precipitation, dew, wind loads, temperatures cycles and pollution.

- International standards for appropriate insulator designs [1, 2, 3]
  - IEC TR 62039 | selection of polymeric insulating materials
  - IEC 62217 | design of composite insulators
  - IEC 61462 | requirements for composite hollow insulators

- Long-term testing for specific service conditions
  ⇨ EDF LME test station in Martigues, France [4]
  - > 2.800 h of solar radiation per annum
  - High marine pollution from S-SE direction
  - High industrial pollution from N-NW direction



EDF R&D test station in Martigues, industrial sites and local wind rose [4]

2. Installation and Observation at EDF Martigues Research Center

Martigues Test Station

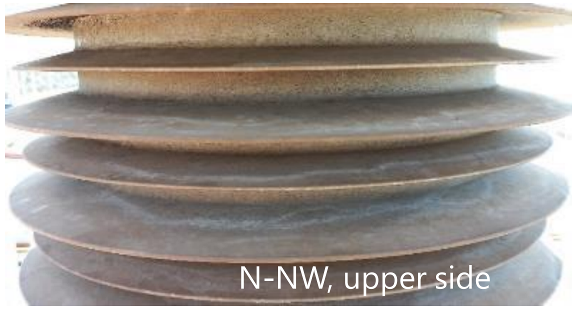
+ Installation of two RPC composite hollow core insulators (400 kV) at Martigues test station
  - One with HCR housing (since 2008)
  - One with LSR housing (since 2015)
+ Inspection twice a year (May, November)
+ Inspection programm at Martigues test station
  - Visual examination
  - Pollution analysis (ESDD)
  - DDDG measurement
  - Hydrophobicity test
  - Leakage current
+ Termination of long-term test by end of 2023
  ⇨ Final examinations on insulators and material analysis of silicone housings

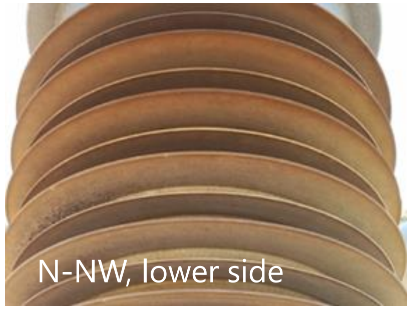
Composite hollow core insulator with LSR housing	
Voltage class	420 kV
Housing material	POWERSIL® XLR® 630
Average diameter	475,5 mm
Diameter corr. factor	1,09
Total creepage distance	14.490 mm
Creepage factor	4
Specific creepage distance, corrected	37,6 mm/kV
Ratio shed overhang to shed spacing	1,07
Profile	Alternating
Rated voltage	245 kV AC

2. Installation and Observation at EDF Martigues Research Center

Inspection Program

+ Visual inspection
  - Examination from bottom to top (silicone housing, flanges, corona ring, power bracket screws, fastening screws)
  - Point of view: N-NW (industrial pollution), S-SE (marine pollution)
  - Focus on corrosion, erosion, (partial)-discharge induced damages, etc.
    ⇨ No signs of intense deterioration and wear found
  - Leakage control of N_2 pressurization (3 bar)



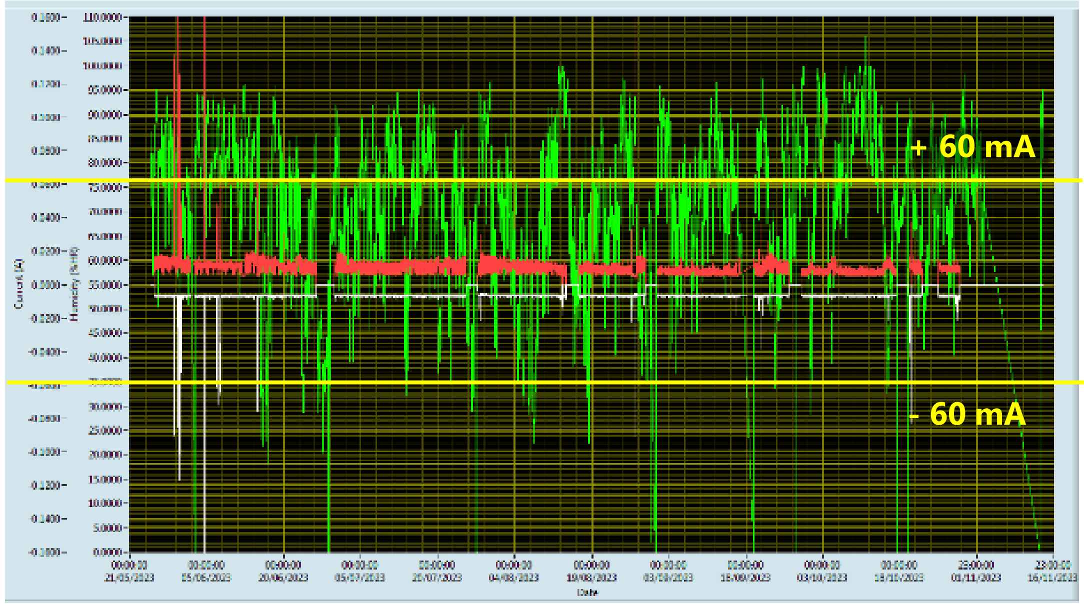


2. Installation and Observation at EDF Martigues Research Center

Inspection Program

+ Leakage current
  - Continuous measurement
  - Leakage current never exceeded 60 mA
    (only during a few periods with extreme weather conditions)

Leakage current measuring collar

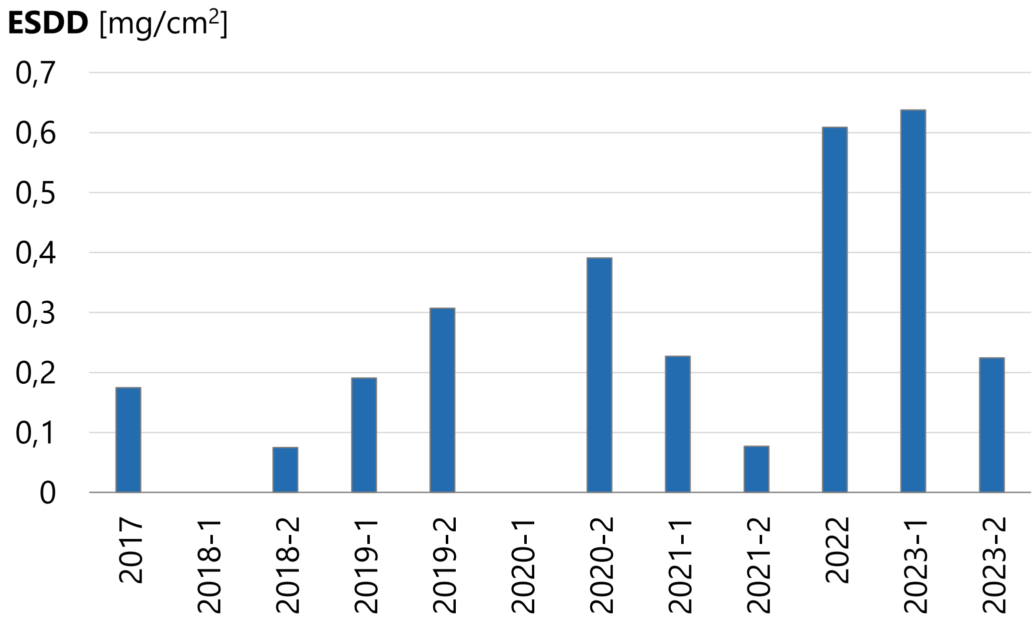


Leakage current measurement (red) for the period from 25.05.2023 to 14.11.2023; humidity scale 0 – 110 % (green).

2. Installation and Observation at EDF Martigues Research Center

Inspection Program

+ Pollution Analysis
  Equivalent salt deposit density (ESDD) according to IEC 60815-1:2008 [5]



+ DDDG Measurement
  Directional dust deposit gauge, according to IEC 60815-1:2008, Annex E [5]

Period		SPS class
2015	Q1	C
2016	Q1	C
	Q2	D
	Q3	
	Q4	
2017	Q1	D
	Q2	C
	Q3	
	Q4	
2018	Q1	C
	Q2	
	Q3	
	Q4	
2019	Q1	D
	Q2	
	Q3	
	Q4	

Period		SPS class
2020	Q1	C
	Q2	
	Q3	
	Q4	D
2021	Q1	D
	Q2	
	Q3	
	Q4	C
2022	Q1	C
	Q2	
	Q3	
	Q4	
2023	Q1	C
	Q2	
	Q3	E
	Q4	

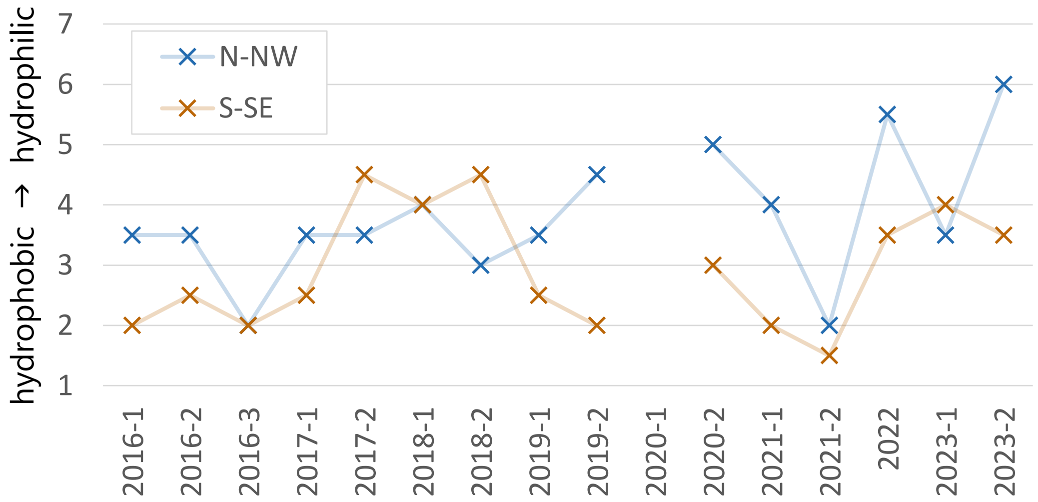
2. Installation and Observation at EDF Martigues Research Center

Inspection Program

+ Hydrophobicity Test
  - „Spray method“ according to IEC 62073 [6]
  - Evaluation alongside most polluted zones of the insulator: N-NW (towards industrial site), S-SE (towards sea)
  - Determination of wettability class of
    - Upper shed side
    - Lower shed side
    - Shed sheath

    on three different insulator positions (bottom, middle, top)
  - Diagram shows wettability class of upper shed sides at the top of the insulator.

Inspection 11 / 2023
Upper shed side
Top of insulator
Wettability class: 6



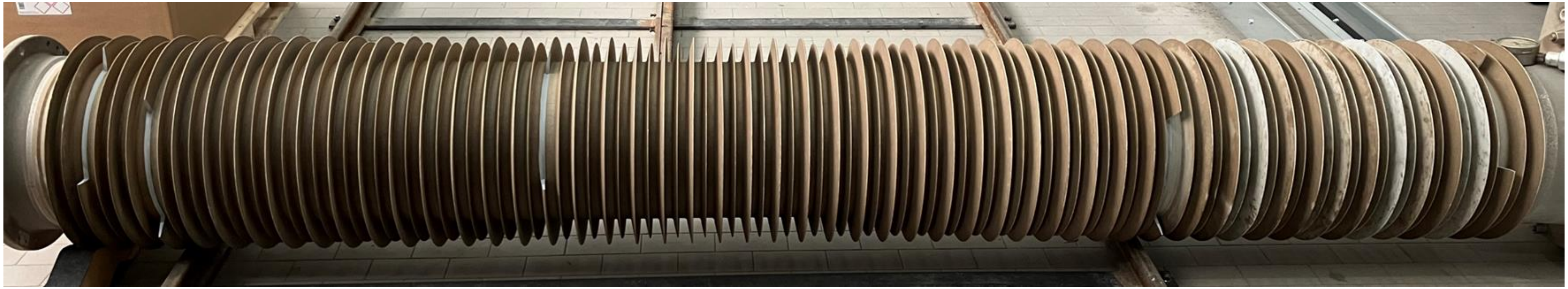
3. Investigation of Hollow Core Insulators after Removal from the Test Station

Investigations at the complete insulator

+ Detailed visual examination of the insulator after dismantling
+ Adhesion / peel-off test of the silicone housing
+ Bending type test (according to IEC 61462, 8.5)

Material analysis

+ Pollution layer
  - (SEM, EDX)
  - Partial layer conductivity
  - Hydrophobicity measurements
+ Fingerprinting



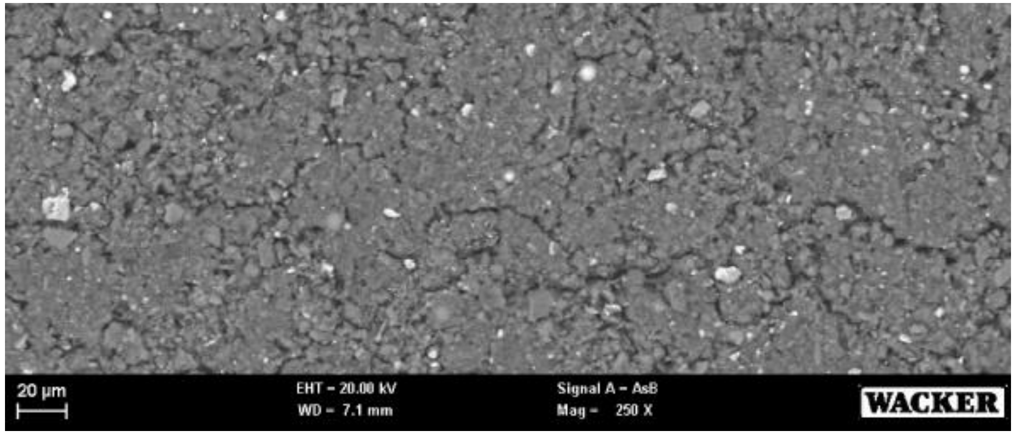
3. Investigation of Hollow Core Insulators after Removal from the Test Station

Material analysis | pollution layer

+ Scanning Electron Microscopy (SEM)
  - A rather loose pollution layer that can be removed by cleaning.

+ Energy-Dispersive X-ray Spectroscopy (EDX)
  - The housing surface was fully intact, no formation of cracks could be found.

Microscopic image of a sample cut from the top side of the insulator with N-NW orientation.

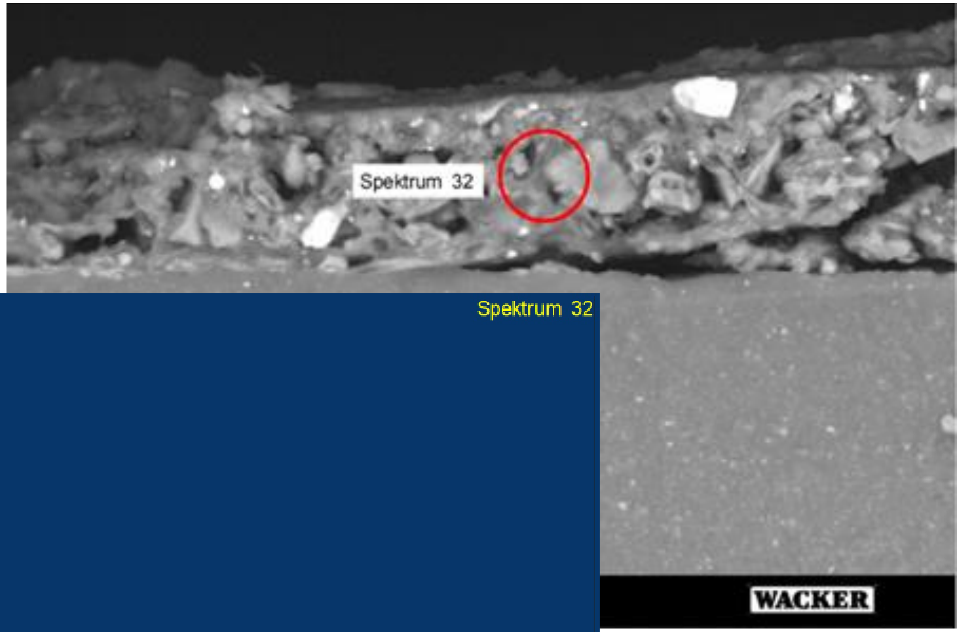


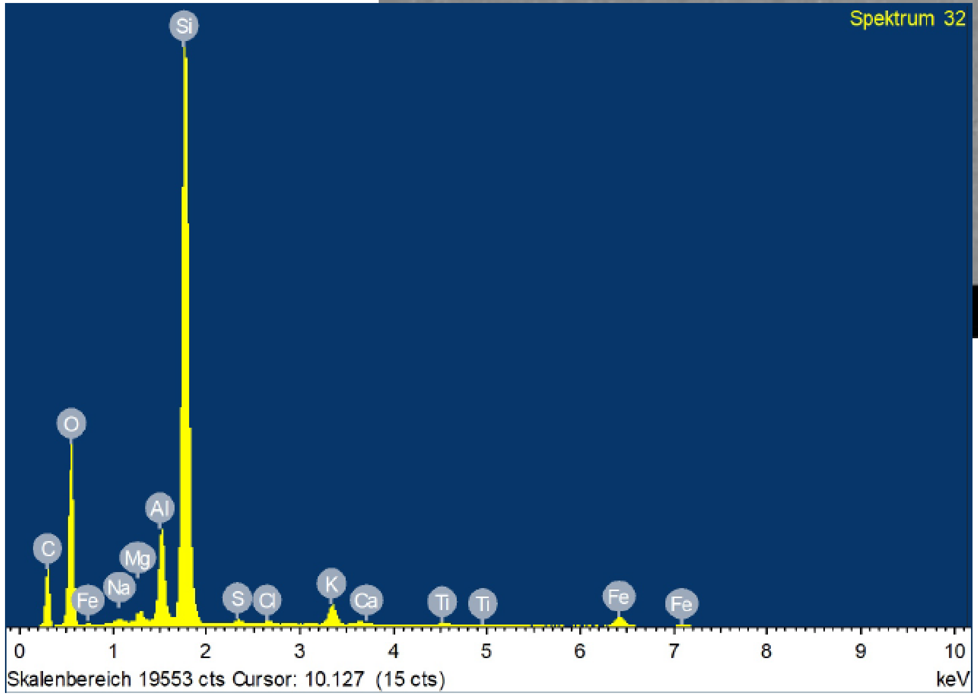
SEM image of a sample cut from the top side of the insulator with N-NW orientation.

3. Investigation of Hollow Core Insulators after Removal from the Test Station

Material analysis | pollution layer cross-section

+ Energy-Dispersive X-ray Spectroscopy (EDX)
  - SEM image of a cross-section of a sample cut from the top side of the insulator with N-NW orientation,
  - No formation of hardened silicone layers have been found,
  - Detected chemical elements in the pollution layer are silicon, oxygen, carbon (either from organic pollution of from silicone polymer) as well as aluminium, iron, calcium, potassium, sodium, magnesium originating from the surrounding environment and industry area.





3. Investigation of Hollow Core Insulators after Removal from the Test Station

Material analysis | pollution layer

+ Measurement of partial layer conductivity [7]
  - Big deviations alongside the insulator surface meaning strongly non-homogeneous formation of the pollution layer
  - Higher pollution level of conductive components has been found at the lower shed faces => missing washing effects of rain

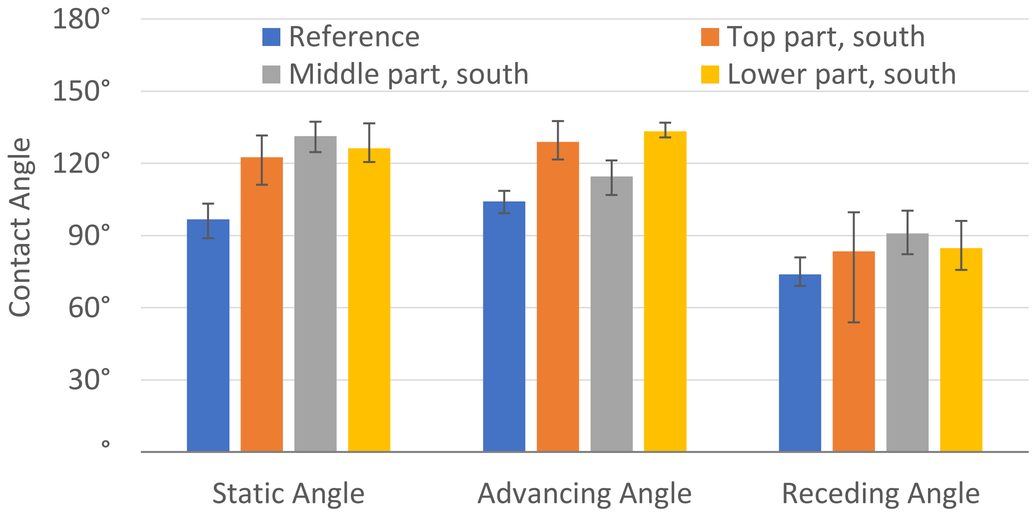
Partial layer conductivity measurements for shed surfaces on the top, middle and lower part of the insulator.

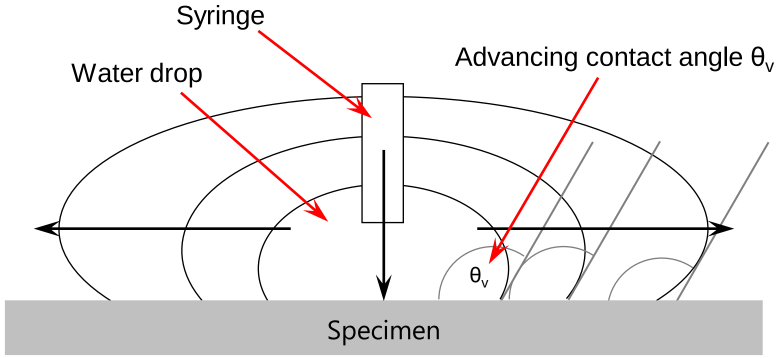
Shed surface, partial layer conductivity [µS]	Upper shed face, outer part	Upper shed face, inner part	Lower shed face, Outer part	Lower shed face, inner part
1-Top shed, south	11,80	11,30	35,50	14,40
2-Top shed, south	68,75	94,00	370,00	44,70
1-Top shed, north	21,70	19,90	359,60	71,70
2-Top shed, north	38,70	19,50	498,70	168,10
1-Middle shed, south	28,44	88,97	66,90	74,64
2-Middle shed, south	174,5	16,20	60,50	38,50
1-Middle shed, north	23,68	32,53	176,86	15,18
2-Middle shed, north	17,80	12,90	149,00	25,20
Lower shed, south	69,36	26,21	42,01	65,87
Lower shed, north	26,40	13,50	210,80	44,50

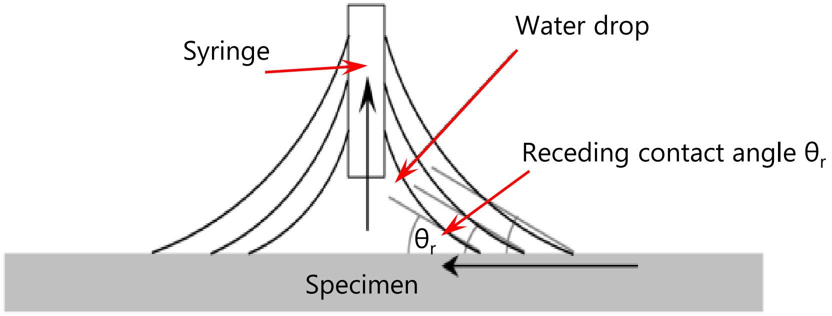
3. Investigation of Hollow Core Insulators after Removal from the Test Station

Material analysis | pollution layer

+ Hydrophobicity measurement
  - Determination of static and dynamic (advancing and receding contact angles) [8]
  - Usage of an automated goniometer
  - Measured values can be correlated to hydrophobicity class 1 – 2 (according to IEC TR 62073) [6]







⇨ Difference to hydrophobicity measurement on site at Martigues might be caused by a hydrophobicity transfer over the storage time of the samples after dismantling.

3. Investigation of Hollow Core Insulators after Removal from the Test Station

Material analysis | Fingerprinting

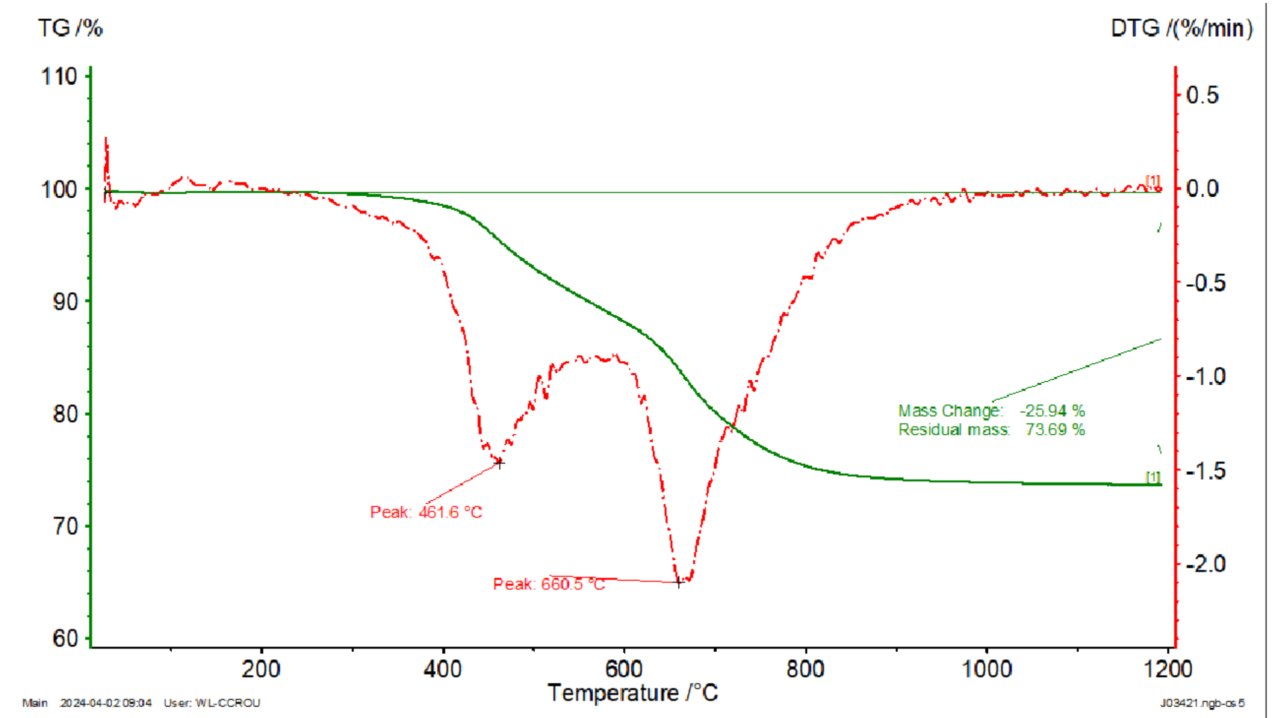
+ According to CIGRE TB 595 [9], fingerprinting includes
  - Density
  - Thermogravimetric Analysis (TGA)
  - Differential Scanning Calorimetry (DSC)
  - Fourier Transforming Infrared Spectroscopy (FITR)

Shed surface	Density (g/cm³)	TGA mass loss @ 1200 °C	DSC cristallization point
Top shed, north	1,166	25,94 %	-37,8 °C
Middle shed, south	1,172	30,60 %	-36,1 °C
Lower shed, south	1,168	31,16 %	-38,3 °C
Reference	1,157	23,57 %	-40,9 °C

3. Investigation of Hollow Core Insulators after Removal from the Test Station

Material analysis | Fingerprinting

+ Thermogravimetric Analysis (TGA)
  - Diagram shows mass loss during TGA from 20 °C to 1.200 °C (reference & top shed, N-NW orientation)
  - Thermal material decomposition from about 250 °C up to 800 °C, mass loss approx. 25 %



Instrument: NETZSCH STA 449F5 File: C:\NETZSCH\Proteus80\data\J03421.ngb-ss5 Method: 25_1200_R20_N2

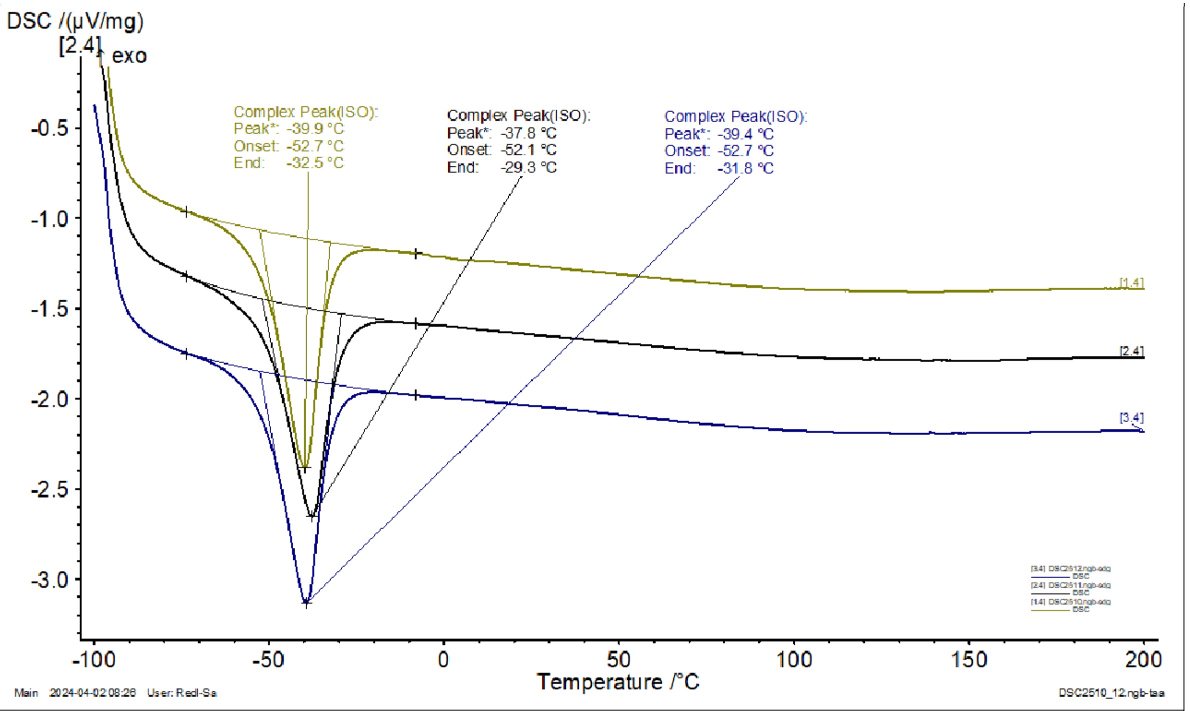
Project:		Sample:	LSR-1-K-N/1, 25.00 mg	Range:	25°C/20.0(K/min)/1200°C	Atmosphere:	– / N2 / N2
Identity:	4144238	Reference:	-----,0 mg	Sample car./TC:	DSC/TG Octo S / S	TG corr./m. range:	0:9:0/35000 mg
Date/time:	28.03.2024 23:09:03	Material:		Mode/type of meas.:	DSC-TG / Sample	DSC corr./m. range:	0:9:0/5000 µV
Laboratory:	Dr. Ehmann	Correction file:	--	Segments:	1/1	Pre Mment Cycles:	0xVac
Operator:	Re	Temp.Cal./Sens. Files:	TCALZERO.TCX / SENSZERO.EXX	Crucible:	Al2O3 85 µl, open		

Created with NETZSCH Proteus software

3. Investigation of Hollow Core Insulators after Removal from the Test Station

Material analysis | Fingerprinting

- Differential Scanning Calorimetry (DSC)
  - Diagram shows DSC for three samples from -100 °C to 200 °C (reference & top shed, N-NW orientation)



[#] Instrument	File	Date	Identity	Sample	Mass/mg	Segment	Range	Atmosphere	Corr.
[1.4] DSC 214	DSC2510.ngb-sdg	2024-03-28	4144250	LSR-1-K-N/1	17.48	4/4	-100°C/20.0(K/min)/200°C	N2, 40.0ml/min / N2, 60.0ml/min	---
[2.4] DSC 214	DSC2511.ngb-sdg	2024-03-28	4144251	LSR-1-K-N/2	20.07	4/4	-100°C/20.0(K/min)/200°C	N2, 40.0ml/min / N2, 60.0ml/min	---
[3.4] DSC 214	DSC2512.ngb-sdg	2024-03-28	4144252	LSR-1-K-N/3	19.76	4/4	-100°C/20.0(K/min)/200°C	N2, 40.0ml/min / N2, 60.0ml/min	---

Created with NETZSCH Proteus software

4. Conclusion & Outlook

+ This contribution presents first investigations at a dismantled composite hollow core insulator with LSR housing after almost a decade long-term test under severe pollution conditions at EDF test station in Martigues, France.
+ Leakage current and contact angle measurement show good hydrophobicity performance of the Wacker silicone.
+ Partial layer conductivity appears to be strongly inhomogeneous; lasting hydrophobicity suppresses higher leakage currents and helps to prevent pollution flashovers.
+ Fingerprinting reveals no major changes of characteristic material parameters; POWERSIL XLR 630 after long-term test still in very good condition.

⇨ Further material analysis, examinations on the complete insulators and a comparison between the LSR and HCR housing will be published in a CIGRE paper.

5. References

[1] IEC TR 62039-2: 2021, Selection guidelines for polymeric materials for outdoor use under HV stress.

[2] IEC 62217-2:2012, Polymeric HV insulators for indoor and outdoor use - General definitions, test methods and acceptance criteria.

[3] IEC 61462-2:2023, Composite hollow insulators - Pressurized and unpressurized insulators for use in electrical equipment with AC rated voltage greater than 1 000 V AC and D.C. voltage greater than 1500V - Definitions, test methods, acceptance criteria and design recommendations.

[4] G. Rocchectti, J. Seifert, N. Nguyen, et al., Experience of composite insulators on HV substation: Some French examples, Paper No. A3-PS1, ID – 843, CIGRE session, Paris, 2022.

[5] IEC 60815-1:2008, Selection and Dimensioning of High-Voltage Insulators Intended for use in Polluted Conditions – Part 1: Definitions, information and general principles.

[6] IEC TR 62073-2:2016, Guidance on the measurement of hydrophobicity of insulator surfaces.

[7] K. Papailiou, F. Schmuck: Silikon-Verbundisolatoren, Werkstoffe, Dimensionierung, Anwendungen, Kapitel 6 (contribution by J. Pilling and R. Bärsch), 2nd Edition, Springer, 2022.

[8] C. Baer, F. Schmuck, S. Kornhuber, R. Baersch, V. Brade: Influence of the Material Composition on the Dynamic Hydrophobicity of Silicone Elastomers for high-voltage Outdoor Application, CIGRE Session 2018, paper D1-310.

[9] Cigre TB 595: Fingerprinting of Polymeric Insulating Materials for outdoor use, October 2014.

Thank you for your interest.

Please contact us:

Andreas Baumer, M.Sc.
Development Engineer
Reinhausen Power Composites GmbH
+49 941 4090-2468
a.baumer@reinhausen.com

Dr.-Ing. Christiane Bär
Application Engineer
Wacker Chemie AG
+49 8677 83 89884
christiane.baer@wacker.com