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Silicone rubber high voltage outdoor insulation – a key component in a reliable and robust power transmission system

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Pushing innovation since




1891

6000



People worldwide

Complete provider of power cables and accessories from



1 kV to 640 kV



SCIENCE BASED TARGETS

We have reduced our total scope **1&2 emissions (68%)** since 2019

2024 revenue



EUR

3.3 bn



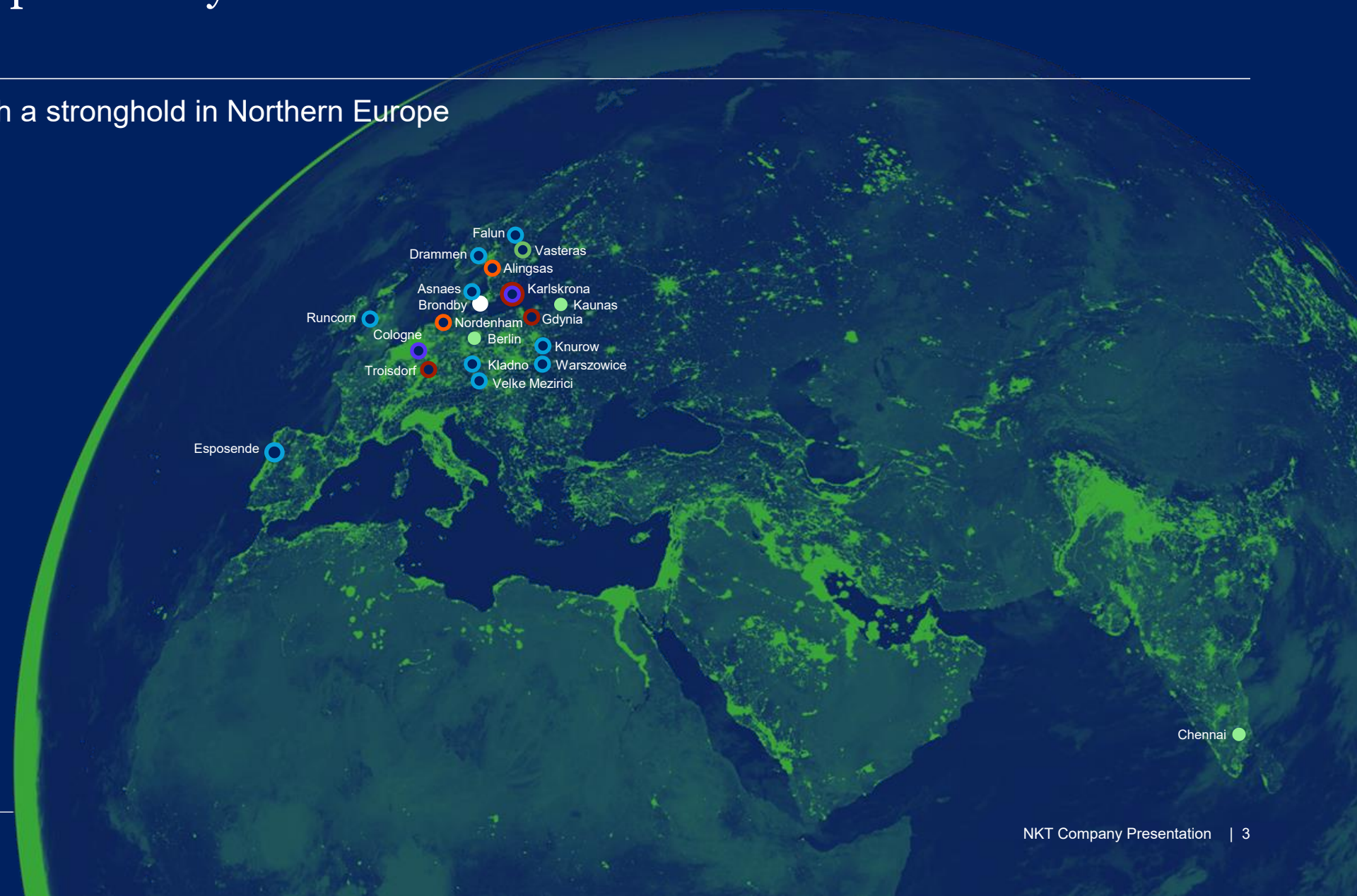
Global organization

Geographical footprint – key locations

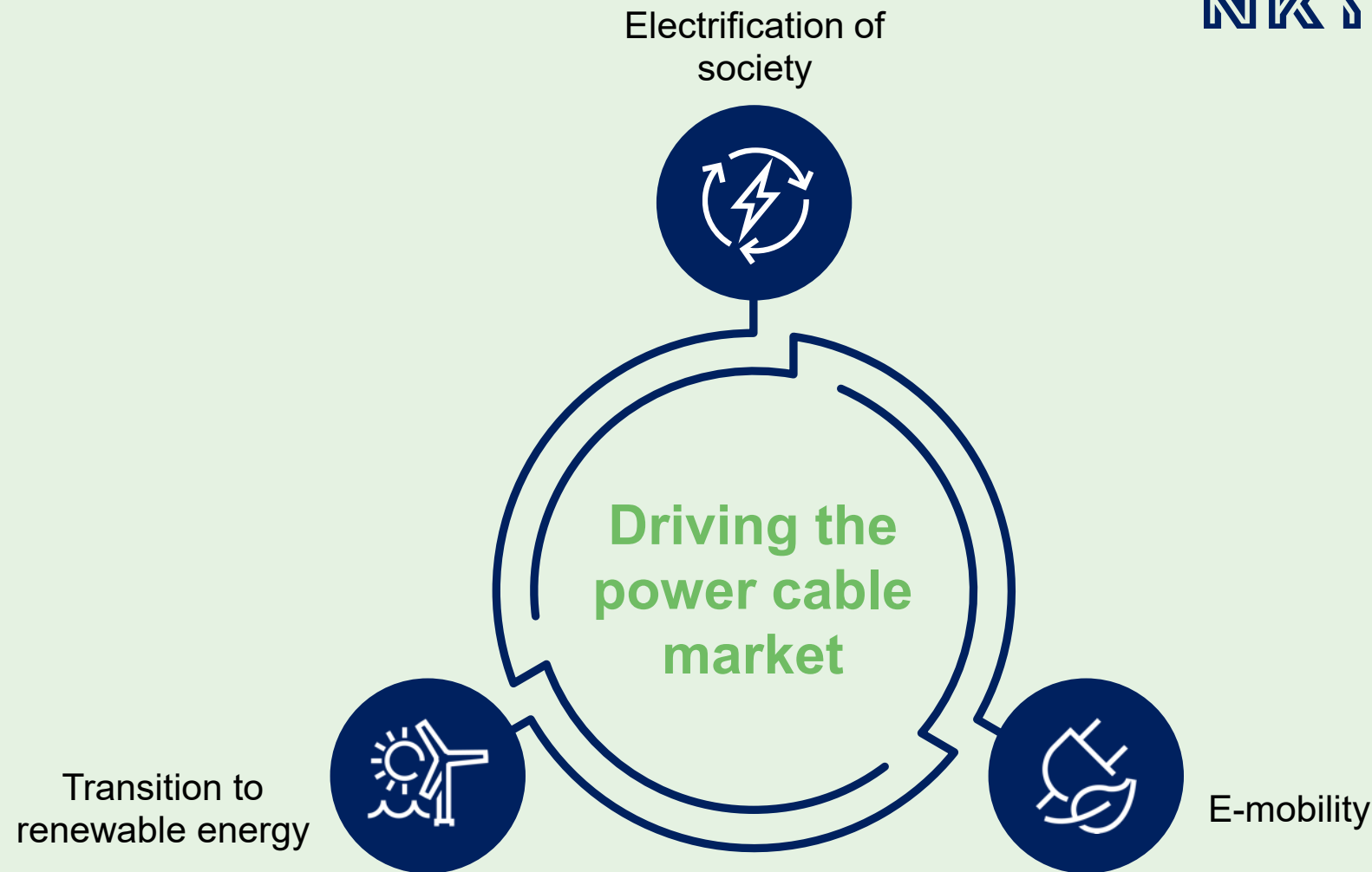


NKT operates globally with a stronghold in Northern Europe

- Shared Service Centre
- Solutions production sites
- Applications production sites
- Accessories production sites
- Service hubs
- Technology consulting
- Headquarters



Megatrends shaping the industry



800 kV High voltage DC power lines (China, India)

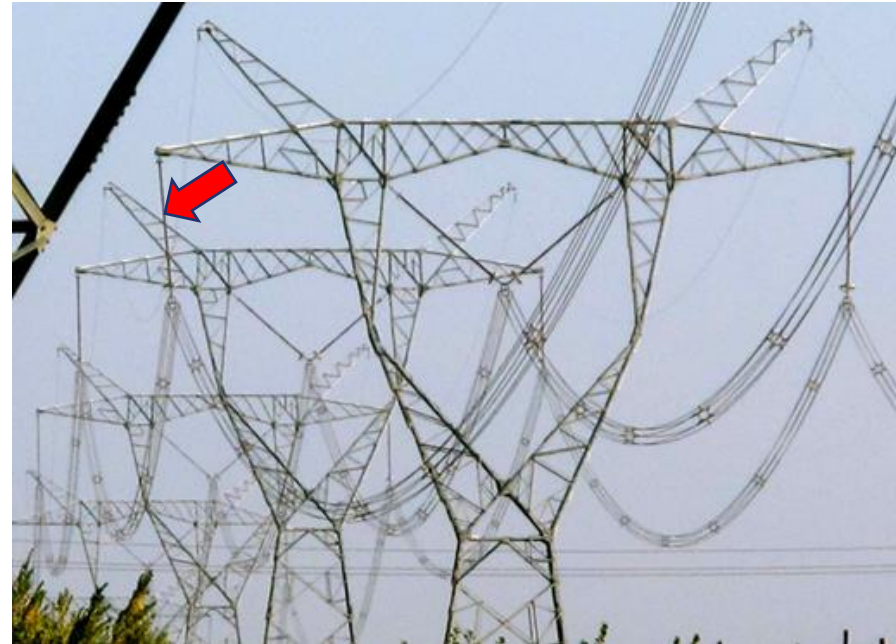


Impact of using ceramic or silicone rubber outdoor insulation



800 kV HVDC line – ceramic insulators

The weight of the ceramic insulators is reflected in the design of the transmission towers



800 kV HVDC line – composite insulators

Load bearing composite rods protected by silicone rubber outdoor insulation. Lower weight allowing for a more compact design

Silicone rubber – ideal material for high voltage outdoor insulation

- Low surface and bulk conductivity
- Water repelling (hydrophobic)
- Good long-term properties- resistant towards discharges, UV, pollutants- hydrophobicity recovery
- Good fire properties
- Good mechanical properties over a wide temperature range (-40°C to +150°C)
- Processable with many different manufacturing technologies

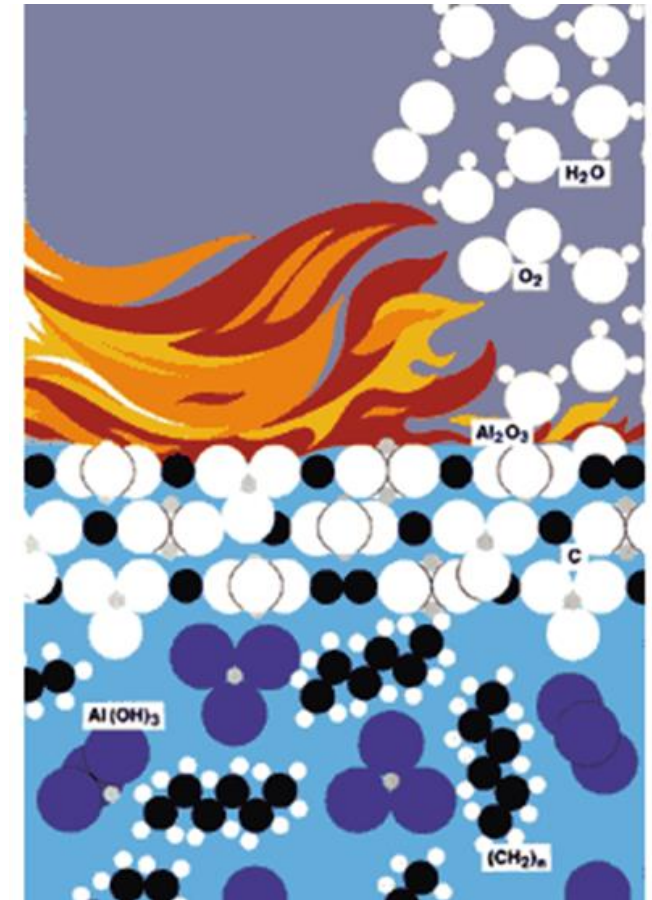


Example of silicone formulation for high voltage outdoor insulation

- Polydimethylsiloxane (PDMS) 25 - 60% (by wt.)
- Reinforcing silica (fumed SiO₂) 3 - 20%
- Alumina trihydrate (ATH) 30 - 70%
- Curing system: Peroxide 1 - 3%
Pt. cat. 20 - 200 ppm
- Functional additives: e.g. color, inhibitors, accelerators...


▪ Typical dielectric properties

Dielectric constant (ϵ_r):	3 - 4
Loss factor $\tan \delta$:	0.004 - 0.04
Volume resistivity:	$10^{13} \Omega \text{ m}$
Dielectric strength:	20 – 25 kV/mm



ATH flame retardant

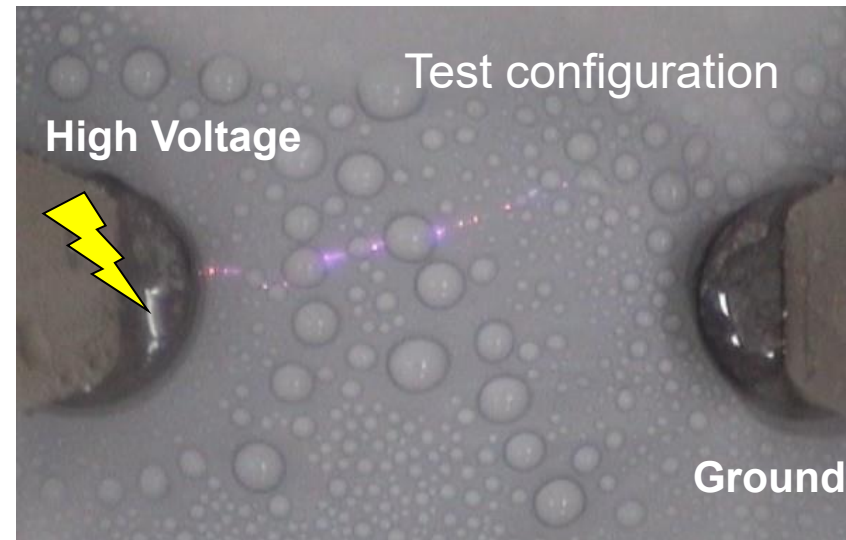
How to utilize the water repellency of silicone rubber

 High voltage power lines



High voltage outdoor insulation:

Hydrophobicity prevents electrical flash-over along insulator surfaces → More reliable design



High Voltage Outdoor Products



Switchgear Modules



“Switch & disconnect”



Circuit Breakers



Surge Arresters



“Fuses”



Instrument Transformers

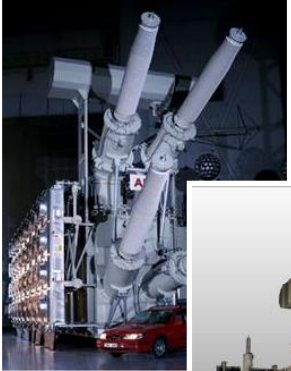


“Measure voltage/current”



Bushings

“Power through walls”



HVAC/DC Transformers



“Increase/decrease Voltage”



Injection moulding of HTV silicone rubber

- **Injection moulding** of silicone rubber housings for HV surge arresters (“electrical fuses”)
- Silicone rubber formulations heavily filled with alumina trihydrate flame retardant – high viscosity
- Peroxide or addition curing formulations, depending on need
- Challenge: excellent adhesion to numerous types of substrates



Cross-section of Pexlim HV surge arrester with silicone rubber insulation

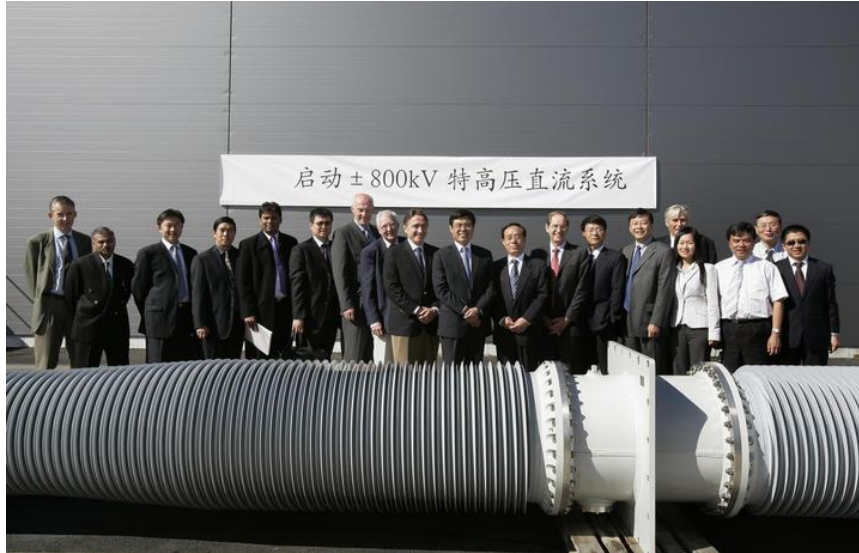
Helical extrusion process for manufacturing of composite hollow core insulators



- A HTV silicone profile is continuously extruded onto a composite hollow core insulator. Subsequent curing of silicone in hot-air oven or autoclave
- Flexibility in insulator shape, length and diameter
- Viscosity of HTV compound must be exactly “right”; hand work at start and end of the “spiral”

800 kV HVDC: The largest power transmission system in the world (at that time ~2006)

Silicone rubber outdoor insulation needed for compact design

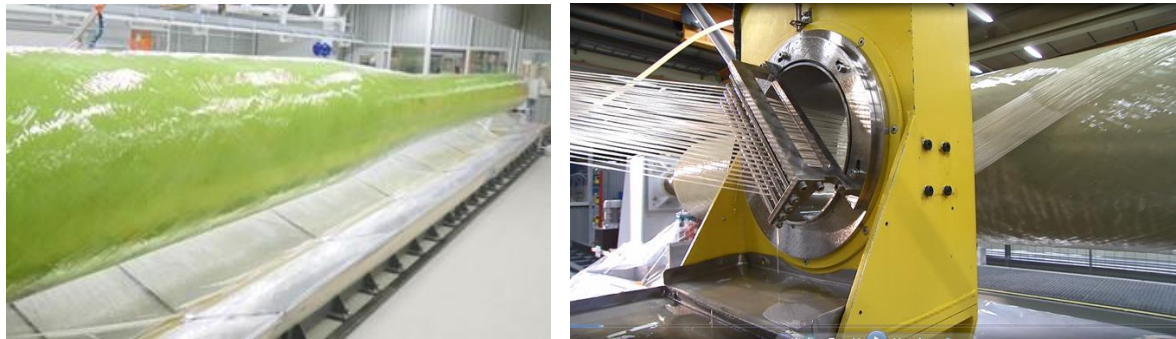


Provided 31 million people in Shanghai with electrical power (6 GW)



Manufacturing of high voltage composite insulators

Filament winding – one piece tube design



Adhesive bonding



HTV silicone extrusion – joint free housing



Routine bend & pressure/ tightness test.



Helical extrusion of HTV silicone rubber

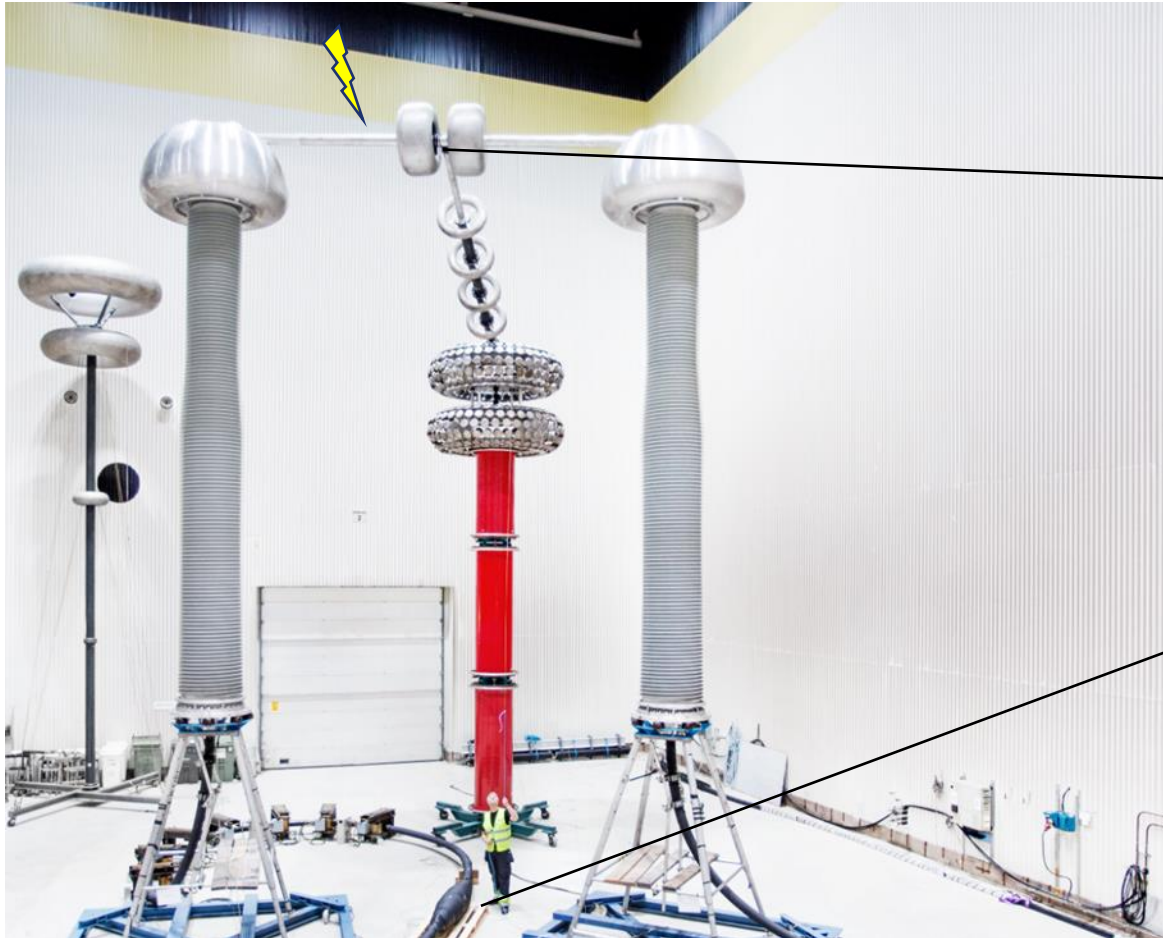
- Few limitations in size and shape



From ABB to Hitachi Energy and NKT



- 525 KV HVDC cable system released by **ABB** 2014



Hitachi Energy– supplier of power stations



NKT – Manufacturer of HV cable systems

Inspection of composite insulators (11 m height) 800 kV HVDC station - India

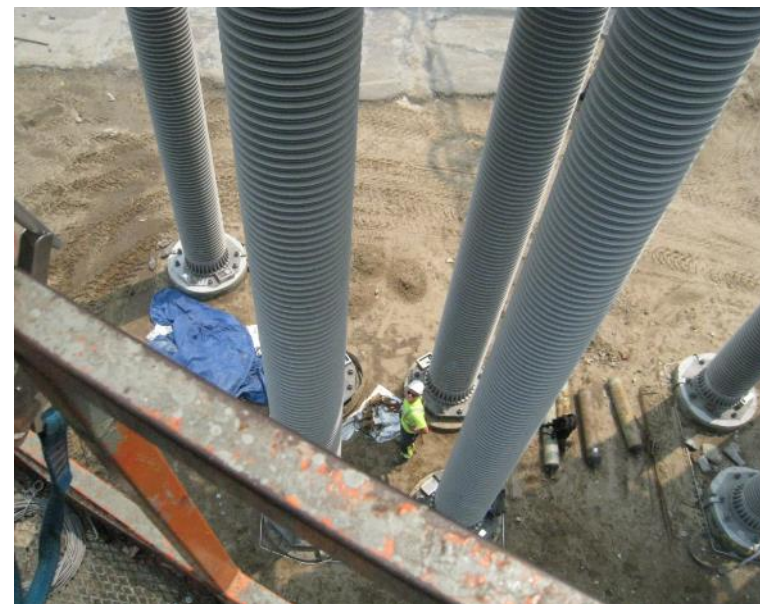
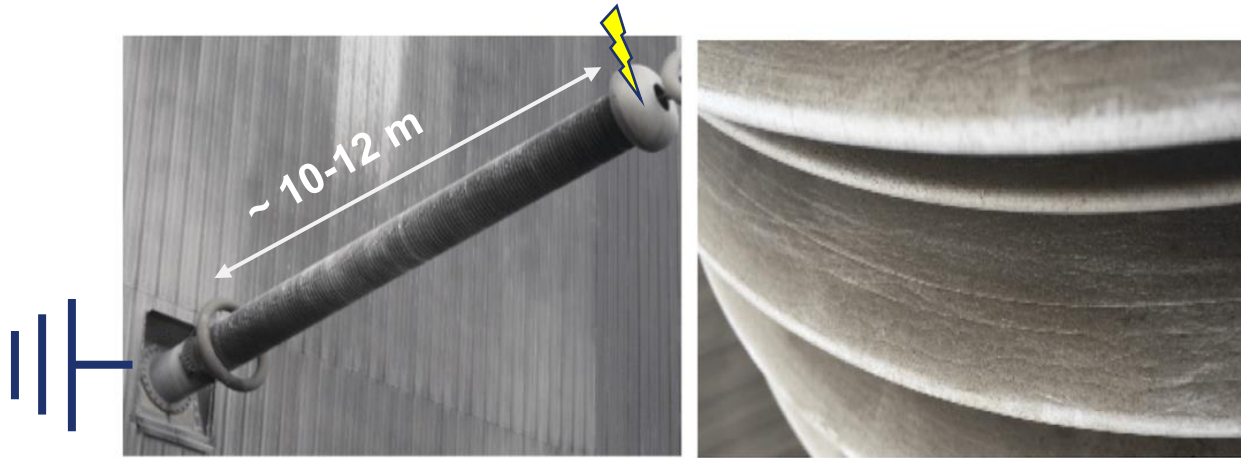


Illustration of surface hydrophobicity of silicone rubber



In general, excellent service experience – however material ageing has been reported



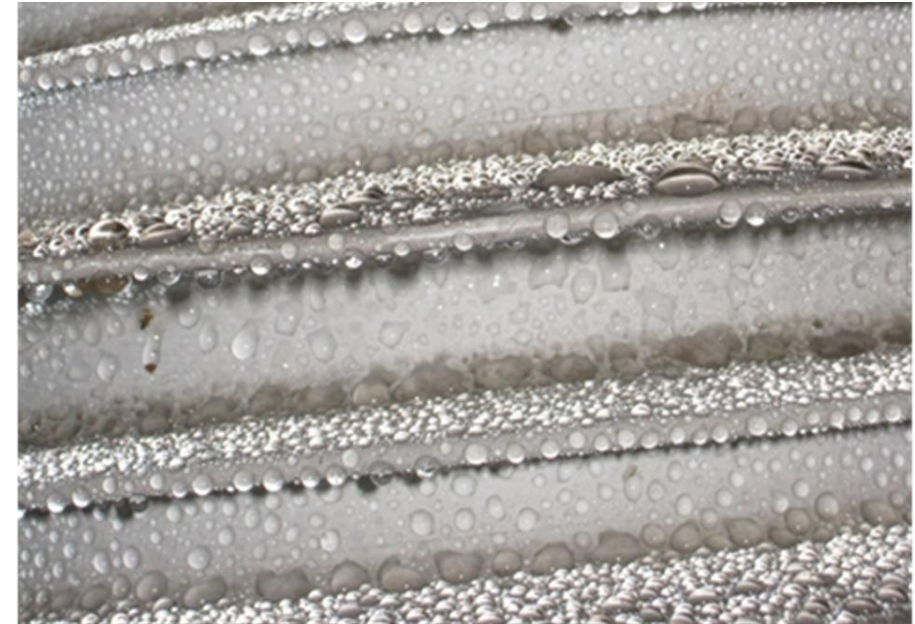
(a) HVDC wall bushing

(b) Crack



(c) Chalking

(d) Loss of hydrophobicity



Silicone rubber outdoor insulation after 10 years of service in a HV substation located close to the sea, Sweden

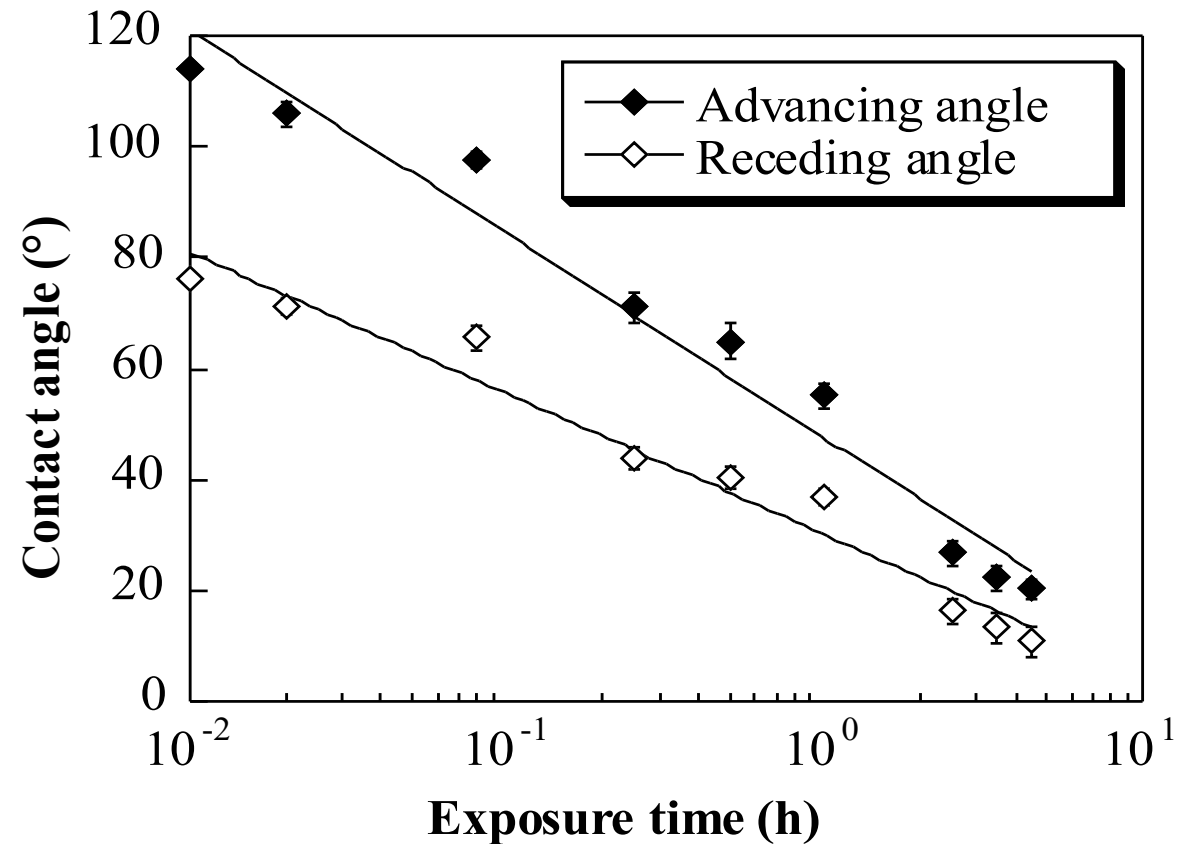
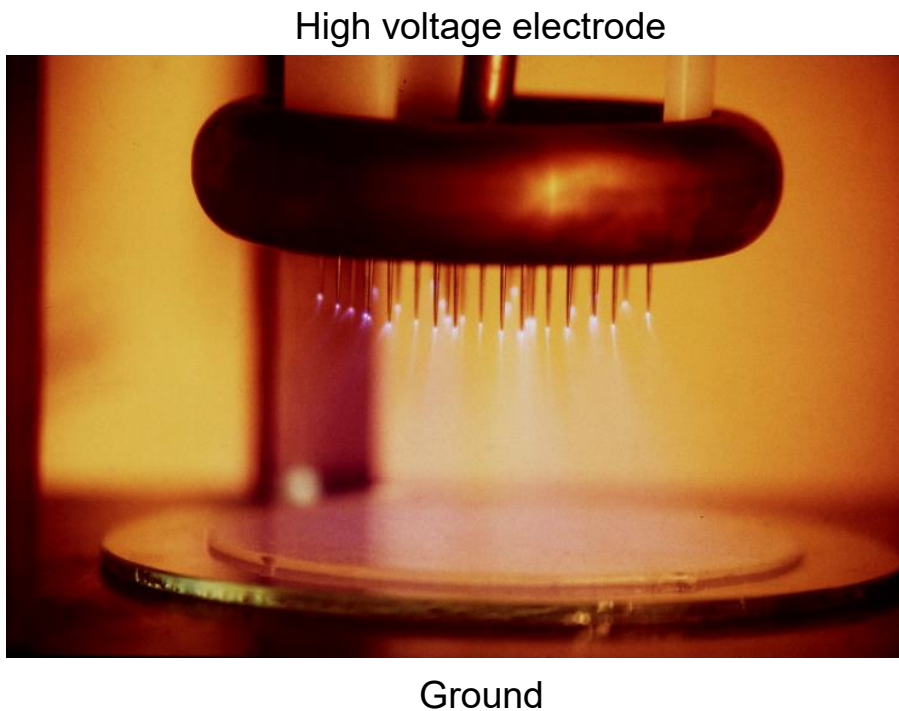
~ 2017: Ageing of HVDC wall bushing in China (in service for 15 years)

Liang Xidong et al.

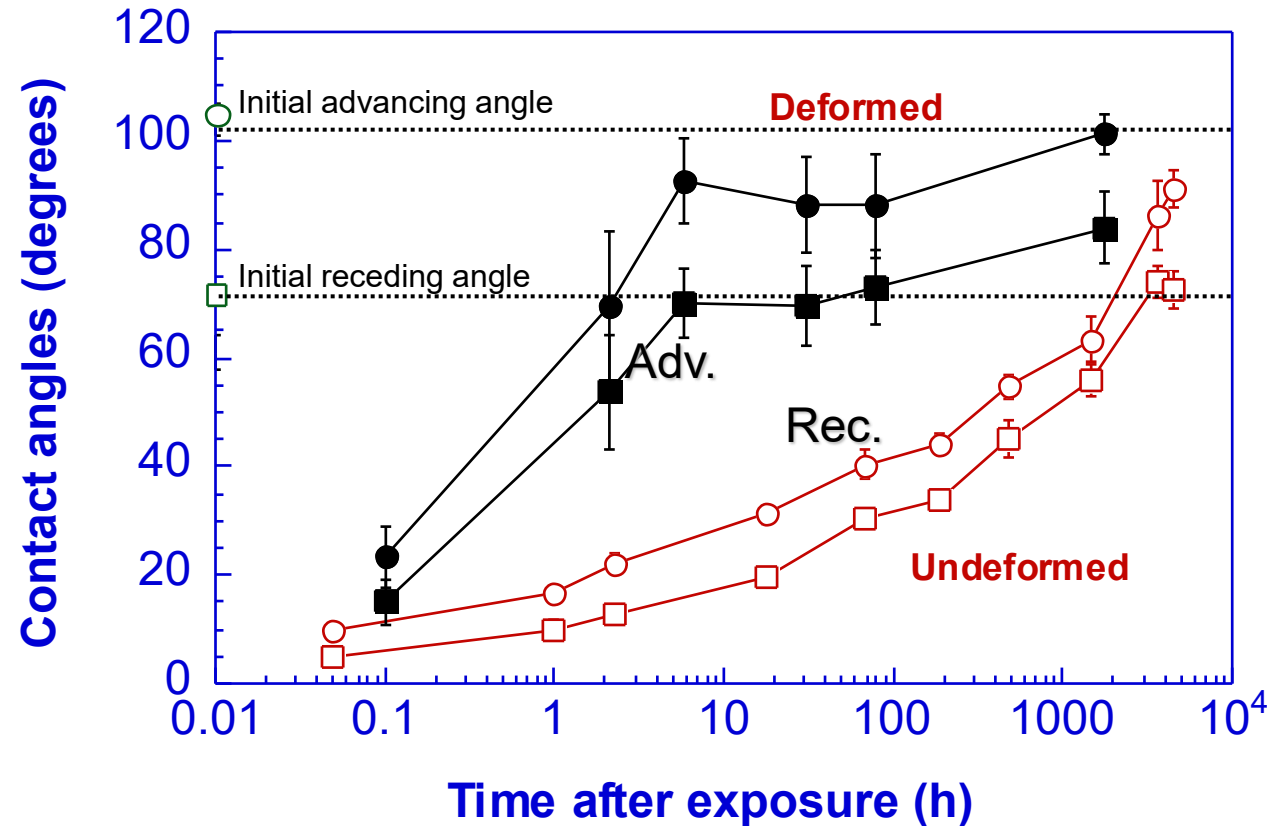
<https://www.inmr.com/key-issues-for-future-development-of-composite-insulator-technology/>

Silicone rubber: Effects of corona discharges

~1990 – 2000: During introduction of silicone rubber as HV outdoor insulation -
Testing in lab: Hydrophobicity loss of silicone rubber as function of corona exposure time

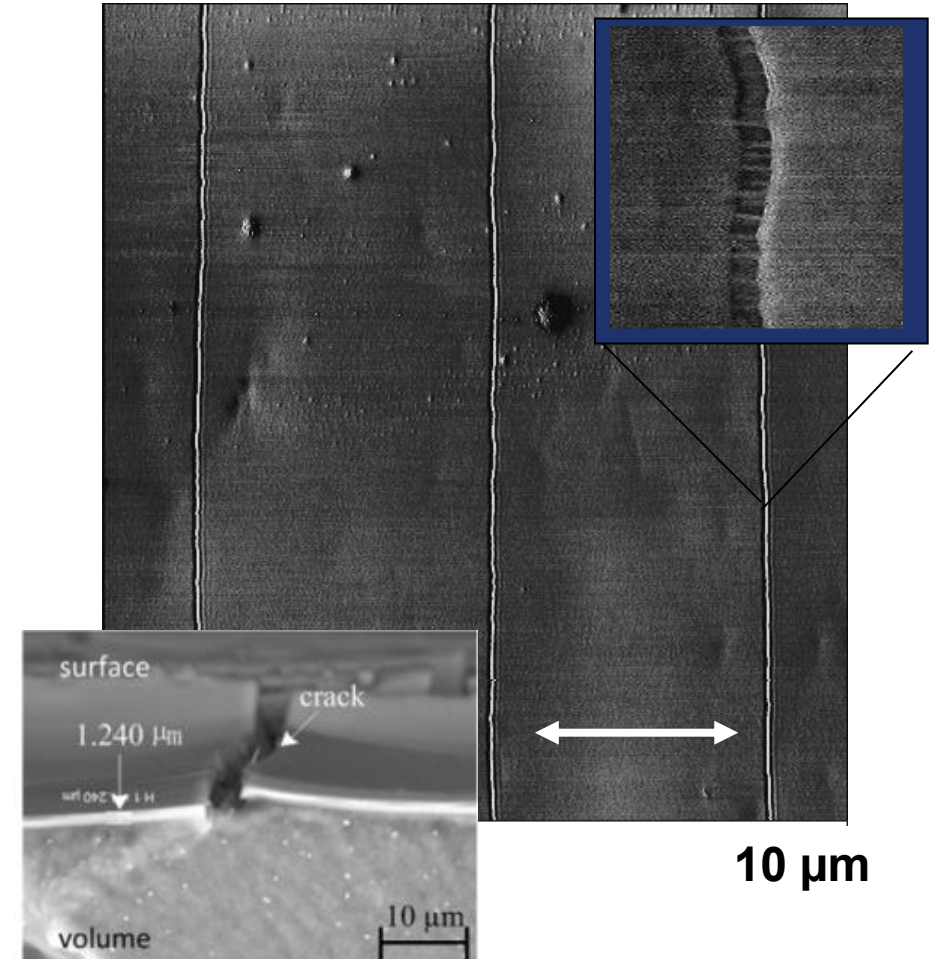


Recovery of hydrophobicity of oxidized silicone rubber



H. Hillborg et al, *Polymer*, 42, 7349 (2001)

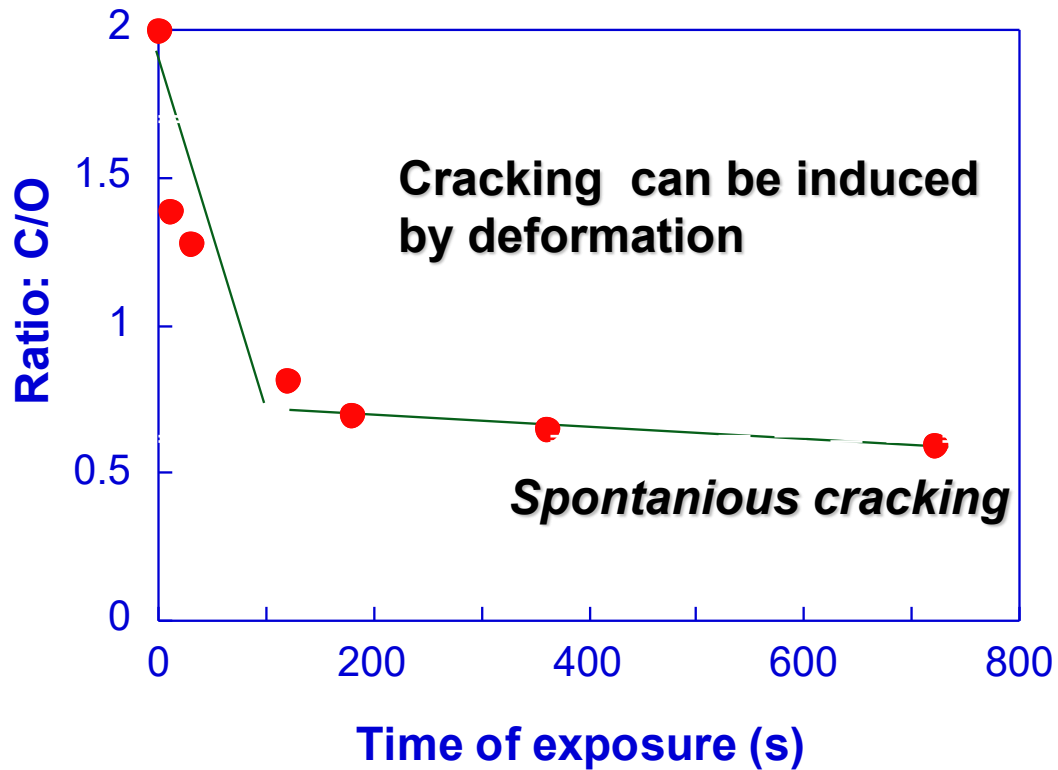
Surface cracking induced by stretching (AFM)



Bi et al. , *Electra*, 267, 4 (2013)

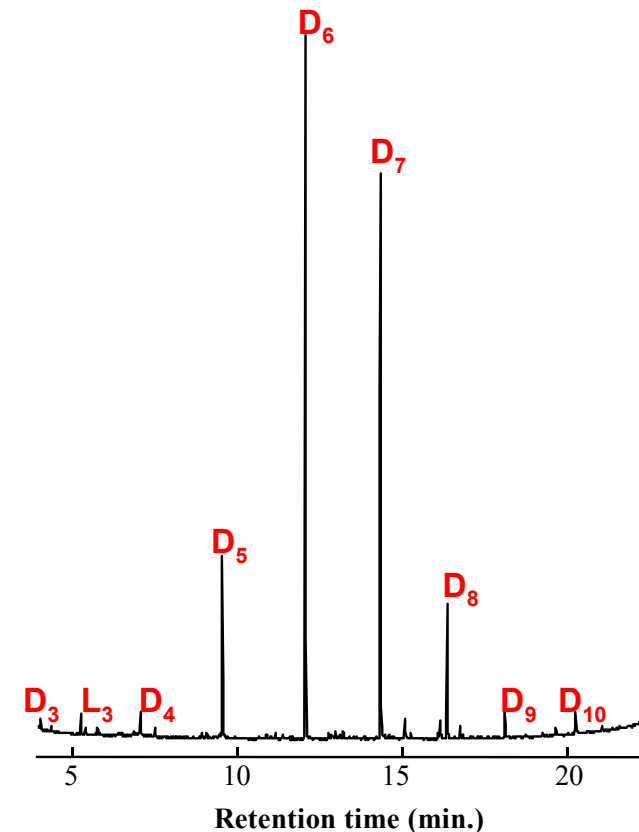
Effect on plasma exposure time on silicone surface composition

- X-ray Photoelectron Spectroscopy (XPS) assess the atomic surface composition in the outermost surface layer (probed depth ca 20 nm)
- Ratio between Carbon (C) and oxygen (O):



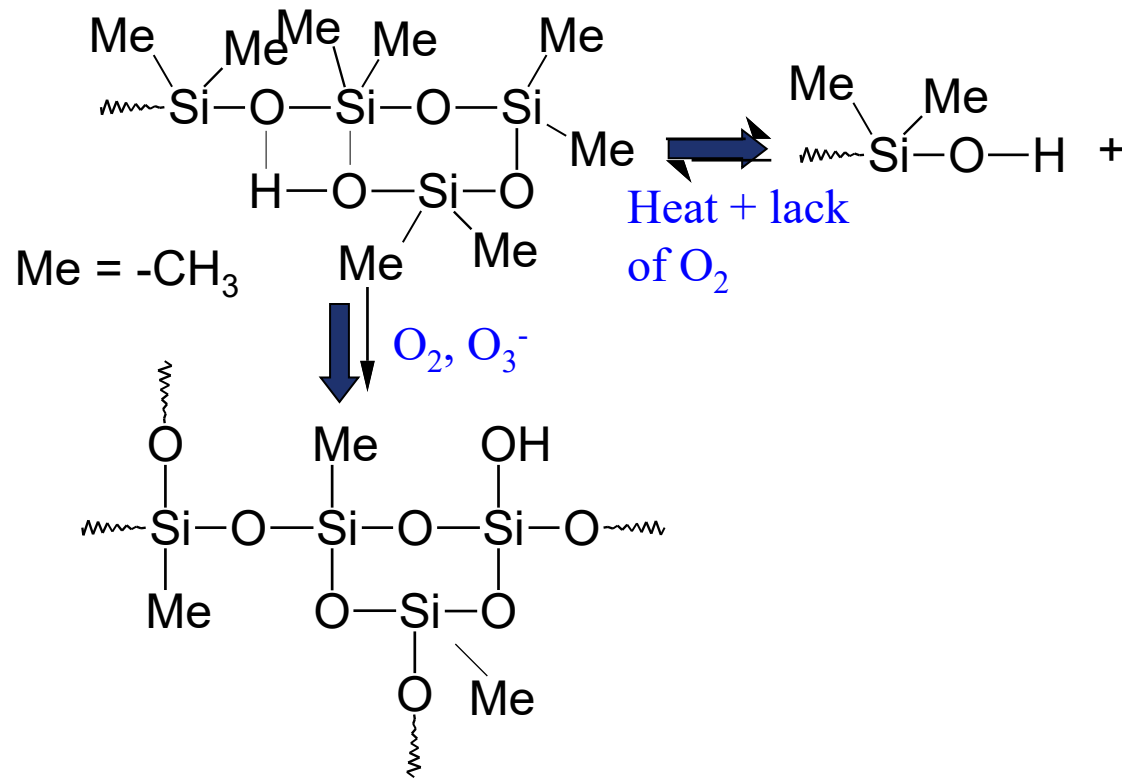
H. Hillborg et al, *Polymer*, 42, 7349 (2001)

- Chromatography: Series of mainly cyclic (D_n , $n=4-8$) dimethylsiloxane oligomers, both on unexposed and exposed silicone rubber

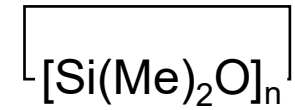


H. Hillborg et al *Polymer*, 42, 8883 (2001)

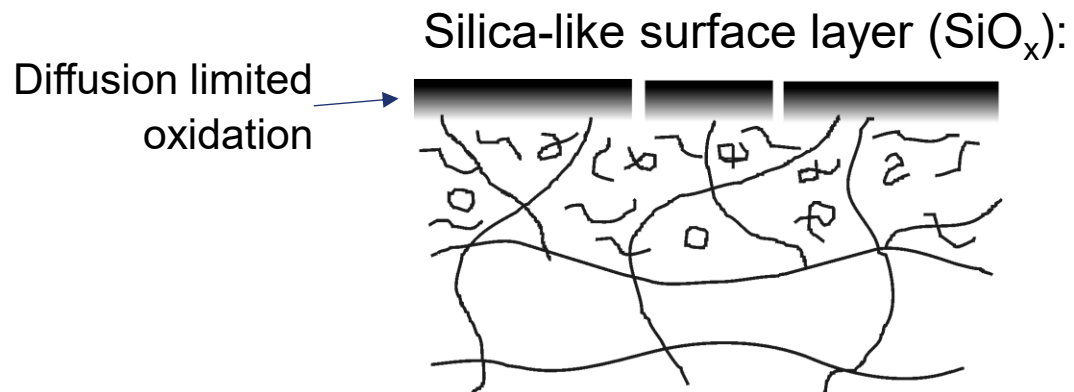
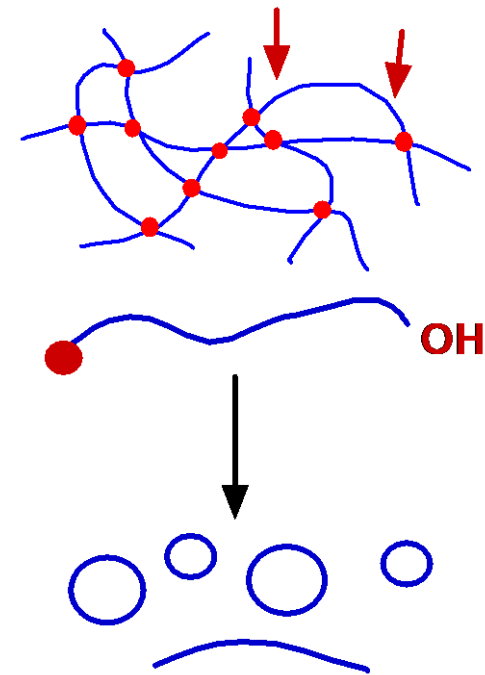
Degradation mechanisms of silicone rubber (PDMS)



Mobile cyclic silicones



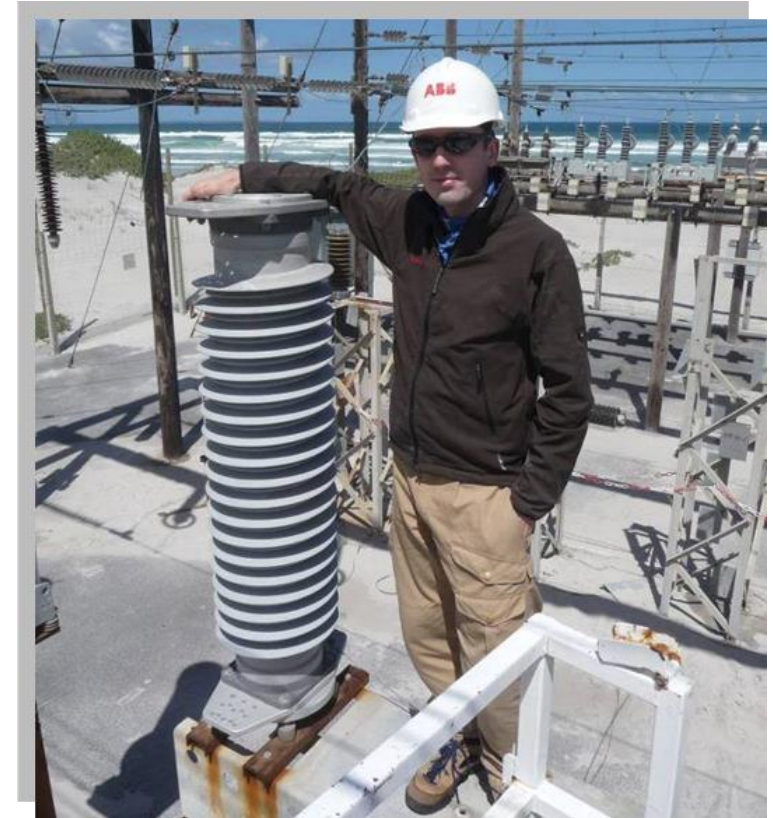
Depolymerization:



Summary

Silicone rubber high voltage outdoor insulation

- **Silicone rubber** has been **successfully used as outdoor insulation for > 25 years**. An enabler for HVDC power transmission systems!
- The production method is typically selected depending on application:
 - Customized products in smaller series – helical extrusion.
 - Standardized products in large series – injection moulding.
- **Hydrophobicity/ hydrophobic recovery** are important parameters for **excellent reliability** of the silicone outdoor insulation.
- Thin (typically < 1 - 100 μm) silica-like surface layers may be formed on silicone rubber, due to oxidation.
- Hydrophobicity recovery mechanism is still active though; due to migration of mobile silicones from the bulk, through the silica-like layer and/or pollution layers.



Koberg Insulator Test Station, South Africa