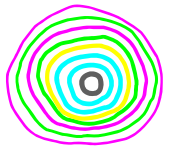
High-Voltage Insulation Aging under Service and Laboratory conditions

IRIS Rotating Machine Conference - Orlando, USA, 2017-06-20-21



Welcome
to the Next
150 Years

Motivation

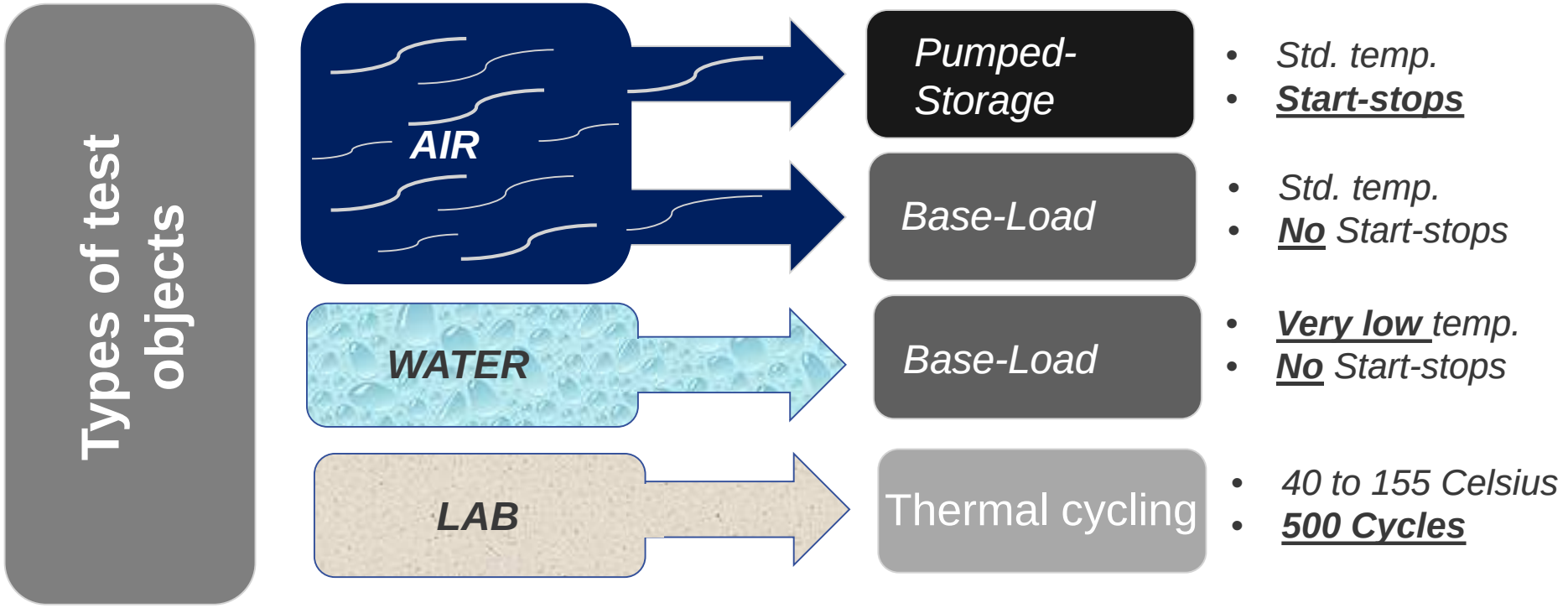
- Normally most of OEMs attention is focused on new components (design, manufacture, control, testing, etc);

- This work studied Roebel stator bars aged under long-term operation service to evaluate the eventual effects of insulation stressors on aging;

- In addition, bars aged under test conditions of IEEE 1310 are used for comparison.

Test Objects

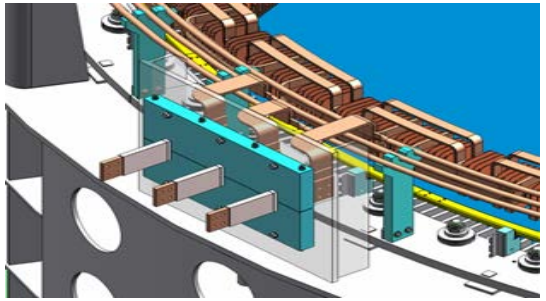
- Roebel bars from three large hydro units aged under service (Base-load and Pumped-storage);
- Roebel bars aged under IEEE 1310 test conditions.



Test Objects

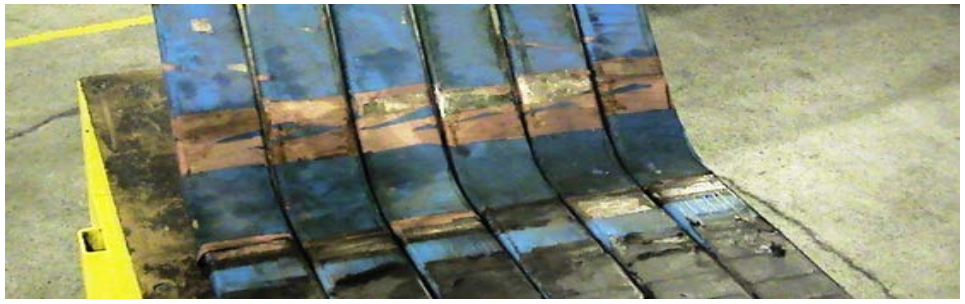
TYPE A – Air-cooled Pumped-Storage

DESIGN	Power (MVA)	Rated Voltage (kV)	Core Length (mm)
	447	***20***	2870



OPERATION	Mode	Cooling	RTD (oC)	Start-Stops	Service (years)
	Pumped-Storage	Air	~100	***+ 10,000***	10

INSULATION	Type	Issues	# bars
	Epoxy-Mica	No	8



Test Objects

TYPE B – Air-cooled Base-Load

DESIGN	Power (MVA)	Rated Voltage (kV)	Core Length (mm)
	374	***19***	2565

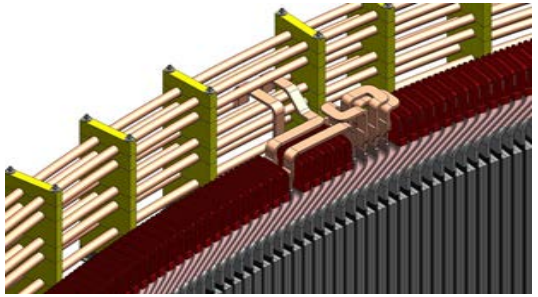
OPERATION	Mode	Cooling	RTD (oC)	Start-Stops	Service (years)
	Base-Load	Air	**~120**	*- 200*	**30**

INSULATION	Type	Issues	# bars
	Epoxy-Mica	**Yes**	6

Test Objects

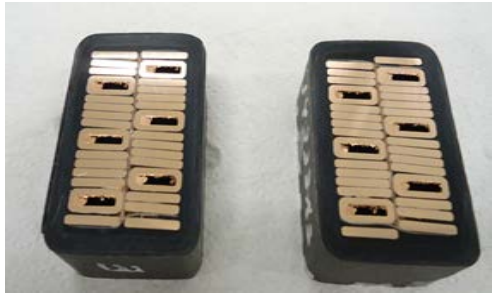
TYPE C – Water-Cooled Base-Load

DESIGN	Power (MVA)	Rated Voltage (kV)	Core Length (mm)
	766	*18*	3260



OPERATION	Mode	Cooling	RTD (oC)	Start-Stops	Service (years)
	Base-Load	Water	~55	*- 1000*	20

INSULATION	Type	Issues	# bars
	Epoxy-Mica	No	12(*)



(*) Segments

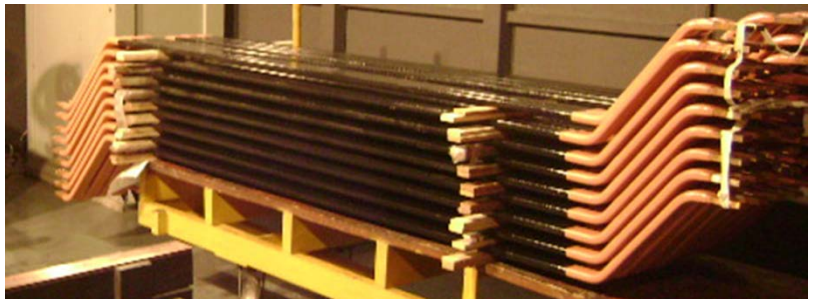
Test Objects

TYPE D – Laboratory Aged Bars

DESIGN	Power (MVA)	Rated Voltage (kV)	Core Length (mm)
	235	***14.4***	1930

OPERATION	Mode	Cooling	RTD (oC)	Start-Stops	Service (years)
	NOT APPLICABLE				

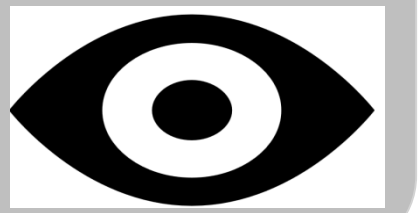
INSULATION	Type	Issues	# bars
	Epoxy-Mica	N. A.	11



Experimental Methods

VISUAL INSPECTIONS

- Initial condition;
- Existing defects;
- Aging traces.



#1

ELECTRICAL TESTS

- Meeger;
- Tangent Delta;
- Voltage Endurance.

#2

DISSECTION & MICROSCOPY

- Insulation Morphology;
- Delaminations;
- Voids.

#3

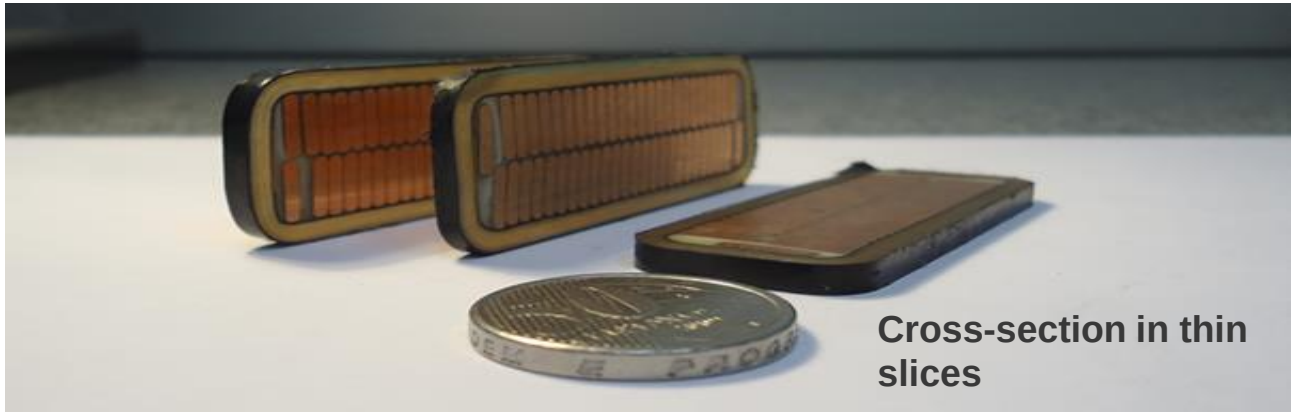
INSULATION-COPPER COHERENCE

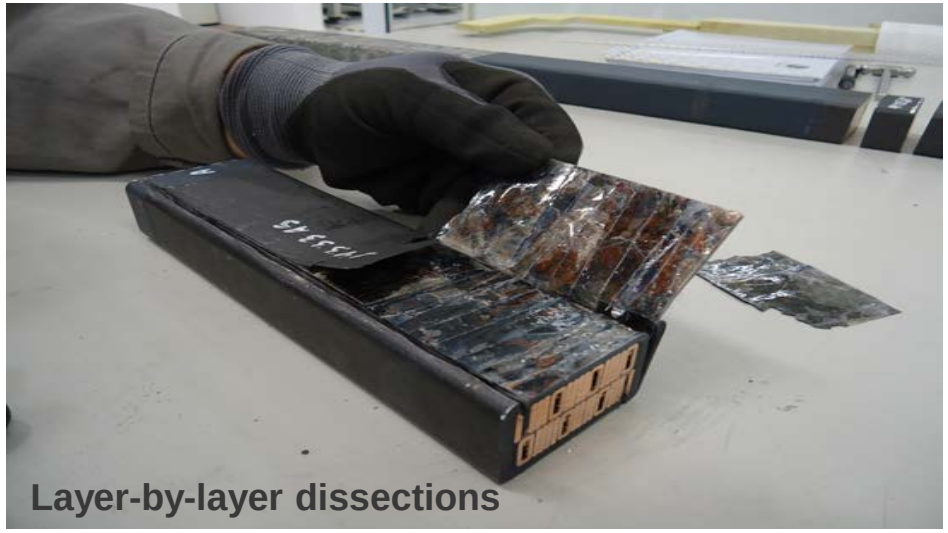
HOW TO CHECK IT??

#4

Experimental Methods – Insulation-Copper Coherence

First, what we DID <u>NOT</u> rely on…



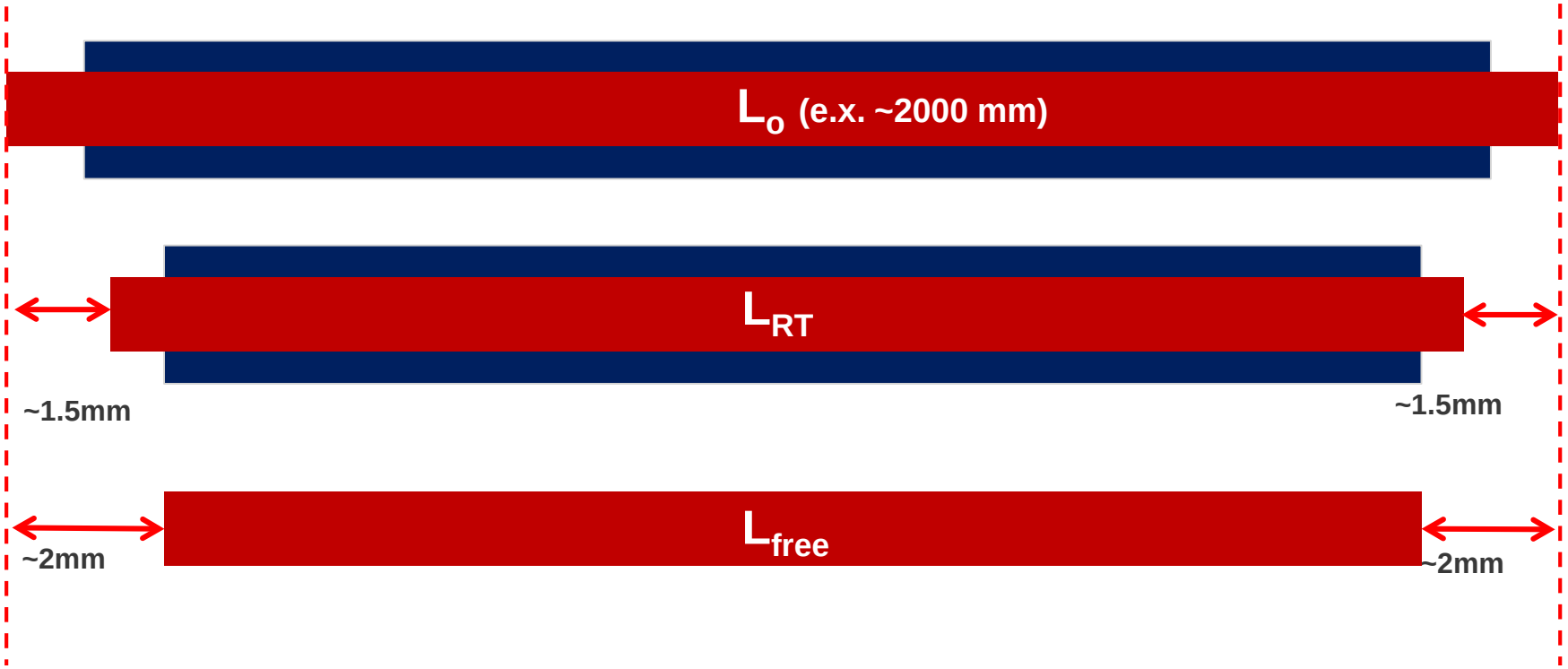


… then what ?

Experimental Methods – Insulation-Copper Coherence

VOITH

The Method



Consolidated at high temp

Cu+Insulation at RT

“Free” Cu at RT

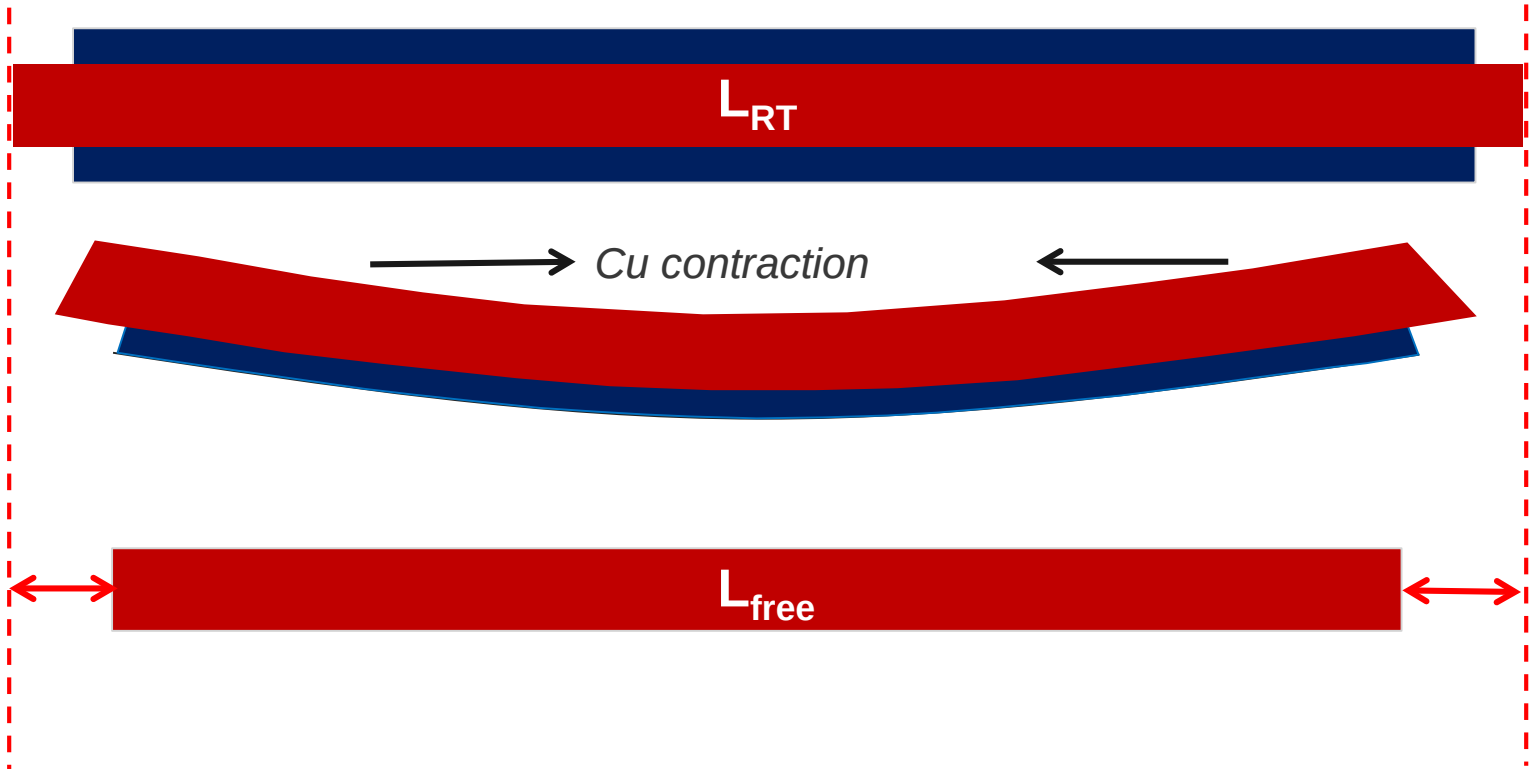
ΔT (K)	$\alpha_{cu}(K^{-1})$
120	$17x10^{-6}$

The differences in copper length with and without insulation is an approximated measure of how good is the Cu-Insulation consolidation.

Experimental Methods – Insulation-Copper Coherence

VOITH

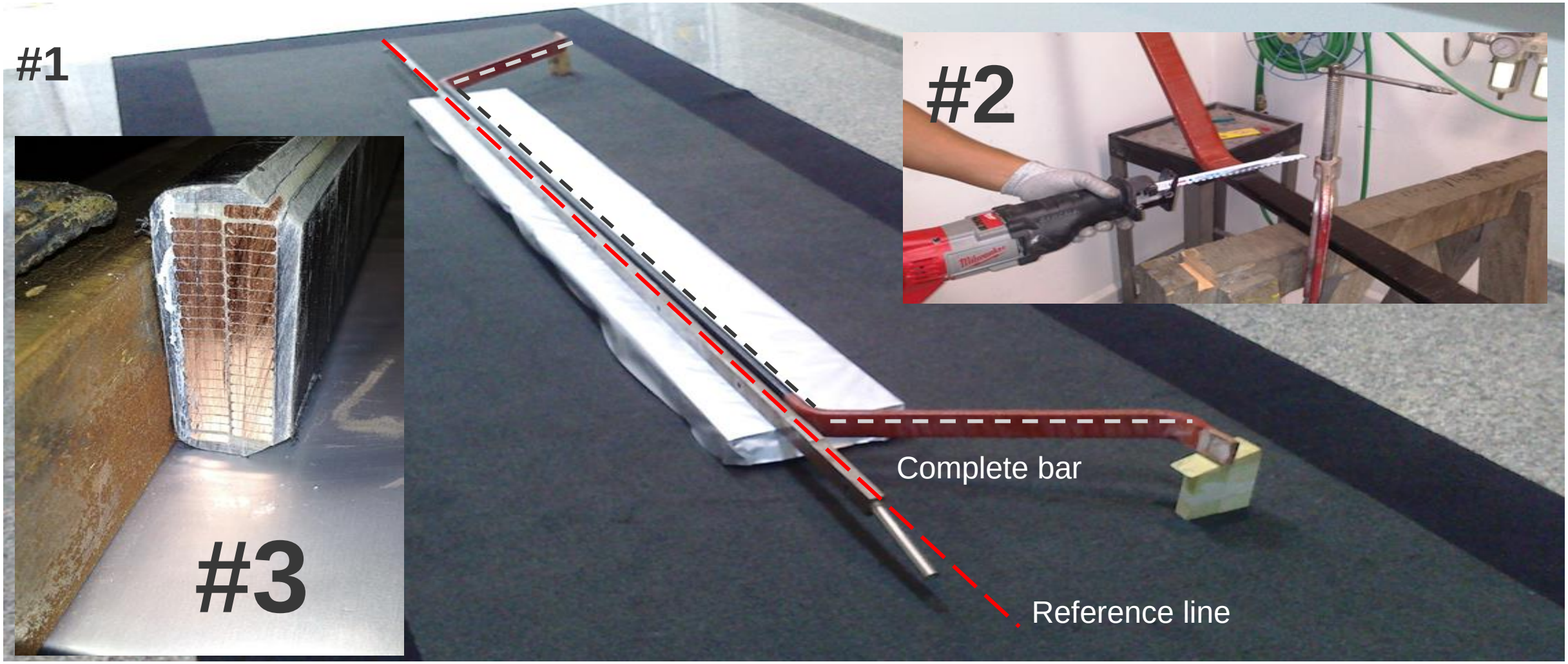
The Method



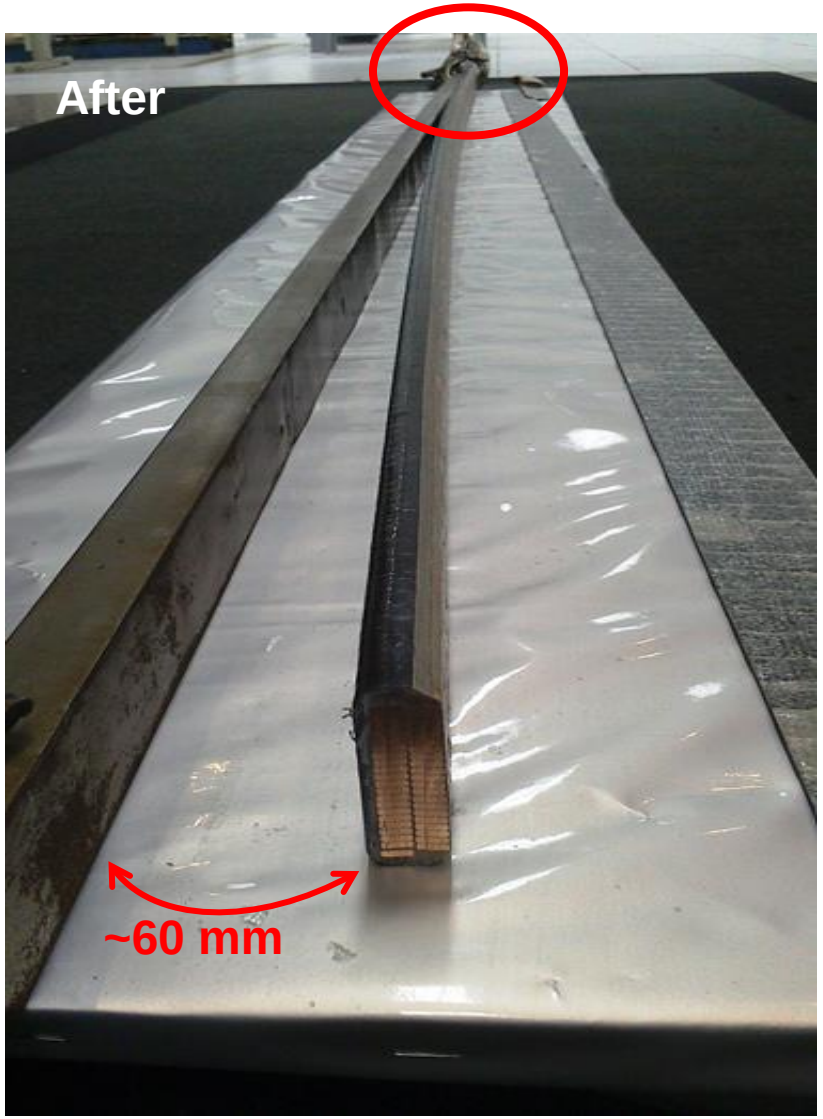
ΔT (K)	$\alpha_{cu}(K^{-1})$
120	$17x10^{-6}$

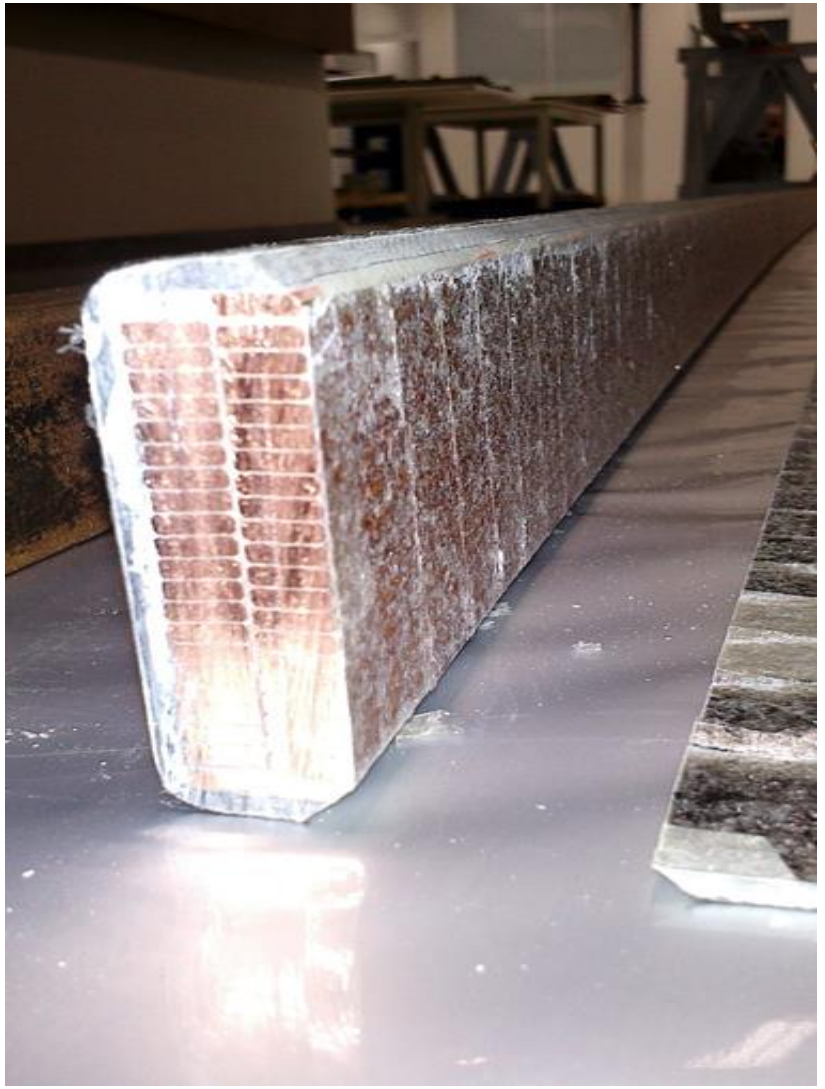
An intermediate case where insulation is removed from one side will cause the cooper to bend if insulation is well attached to it.

Experimental Methods – Insulation-Copper Coherence



Experimental Methods – Insulation-Copper Coherence





Results

Type A – Air-cooled Pumped-Storage

Results

TYPE A – Air-cooled Pumped-Storage

Visual inspections

As-received

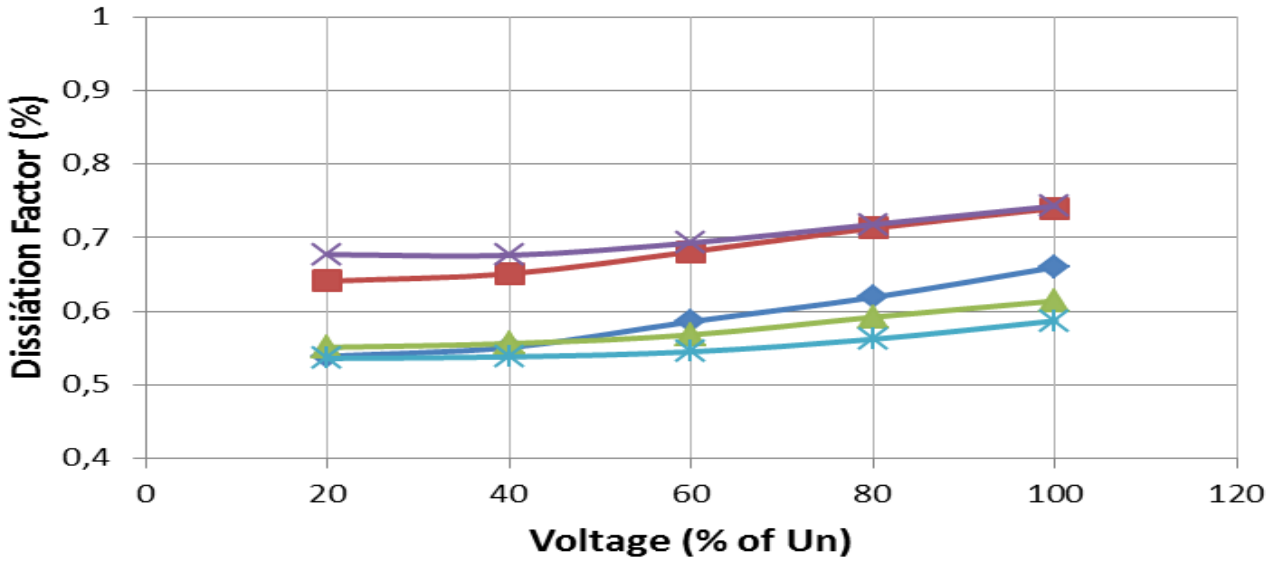
1. *No severe damage visually detectable;*
2. *No critical damages caused by the removal of the bars from slots;*
3. *Recover of corona protection systems (slot and grading) needed.*

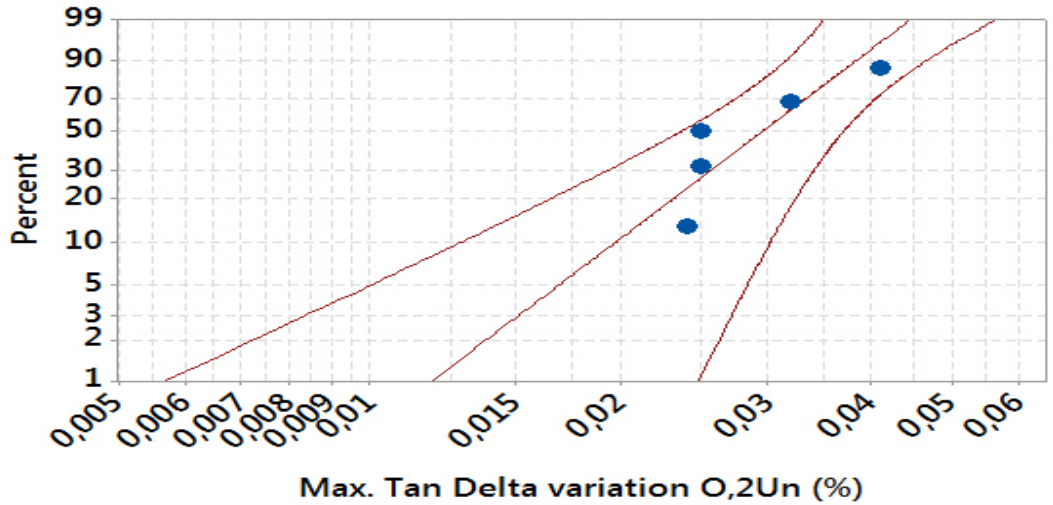
Results

TYPE A – Air-cooled Pumped-Storage

Electrical Tests

Dissipation factor and tip-ups show that the overall insulation condition is ok.



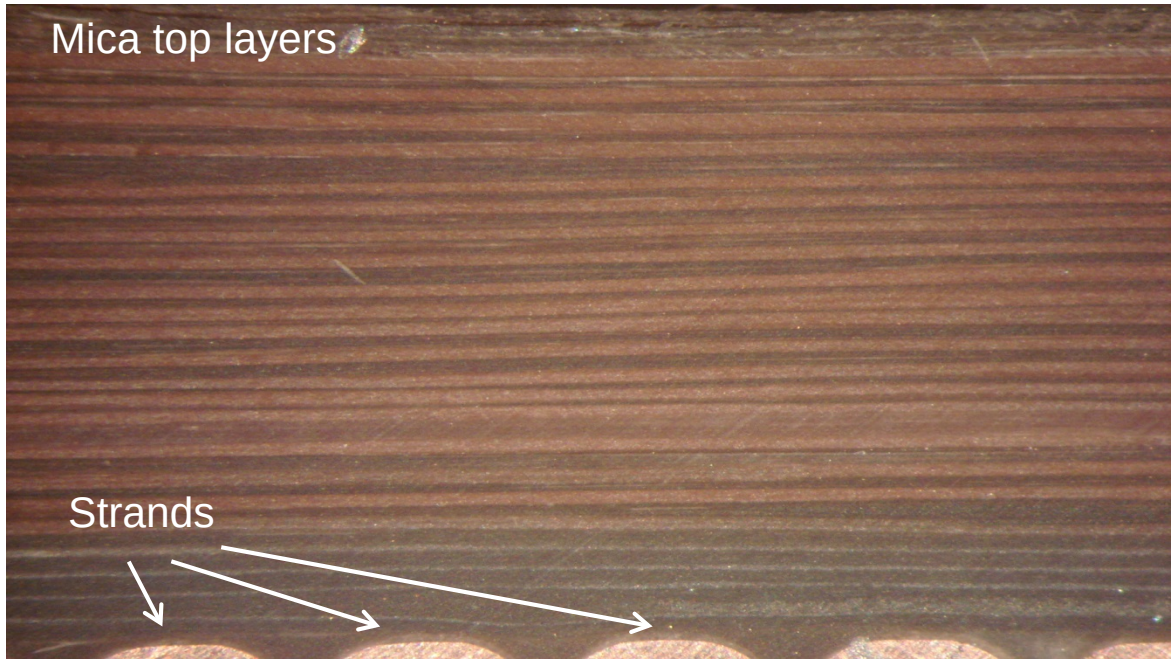


Results

TYPE A – Air-cooled Pumped-Storage

Dissection & Microscopy

Overall morphology is fine, but with several local delaminations at the mica layers.

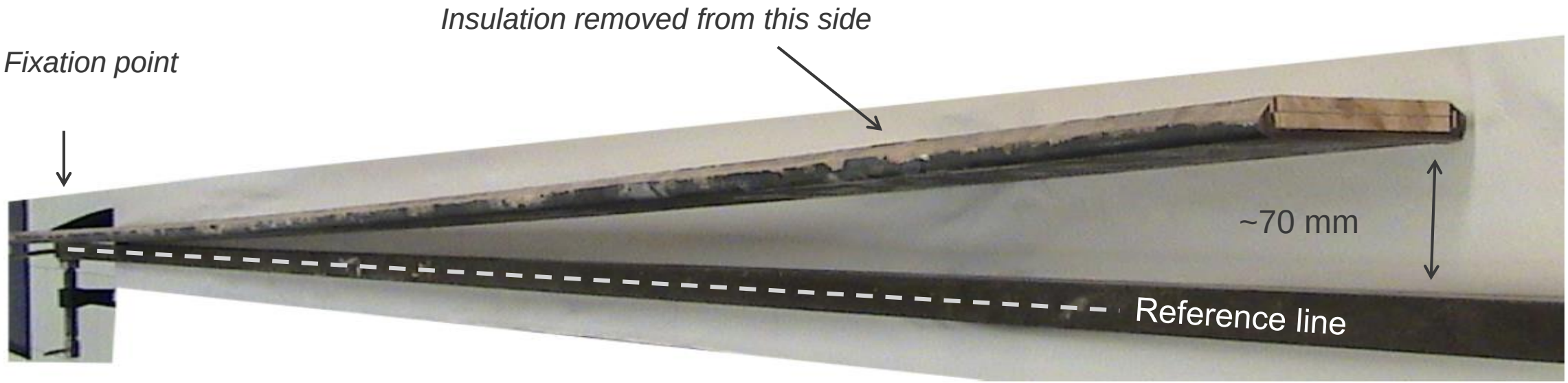


Results

TYPE A – Air-cooled Pumped-Storage

Copper-Insulation Coherence

Copper-Insulation interface is coherent.



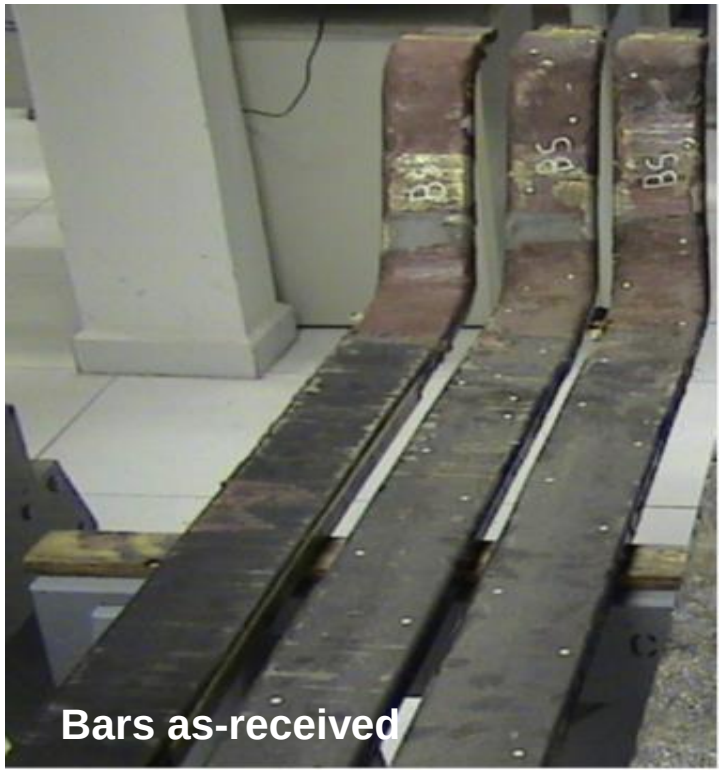
Results

Type B – Air-cooled Base-Load

Results

TYPE B – Air-cooled Base-load

Visual inspections



Bars as-received

1. *From “outside”, nothing special could be detected;*
2. *Touching or tapping the bars revealed a type of “hollow” sound all the way along the whole length.*

Bars as-received

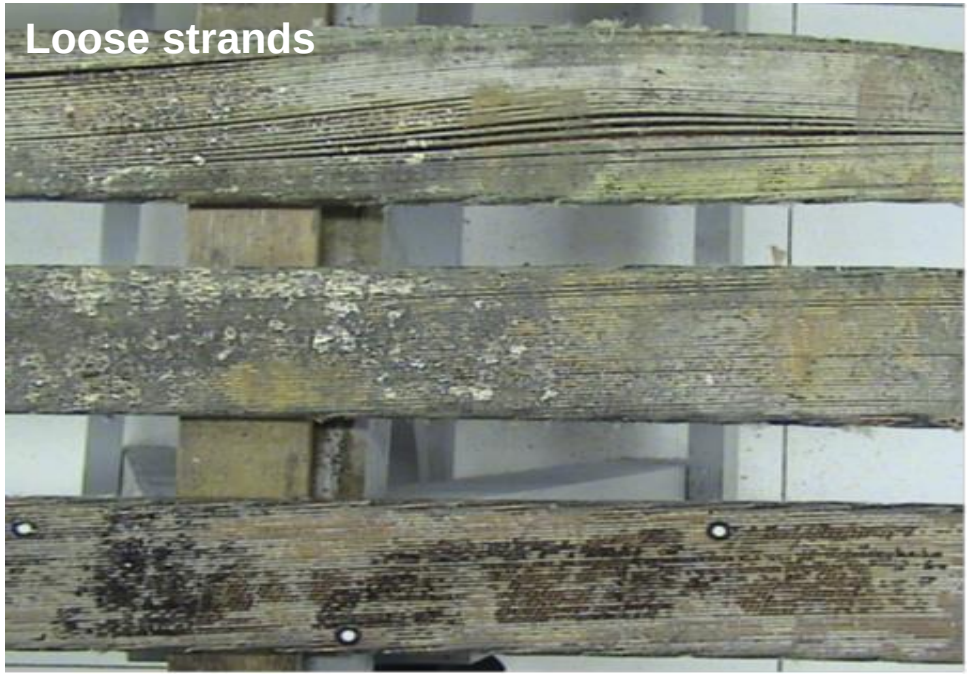
Results

TYPE B – Air-cooled Base-load

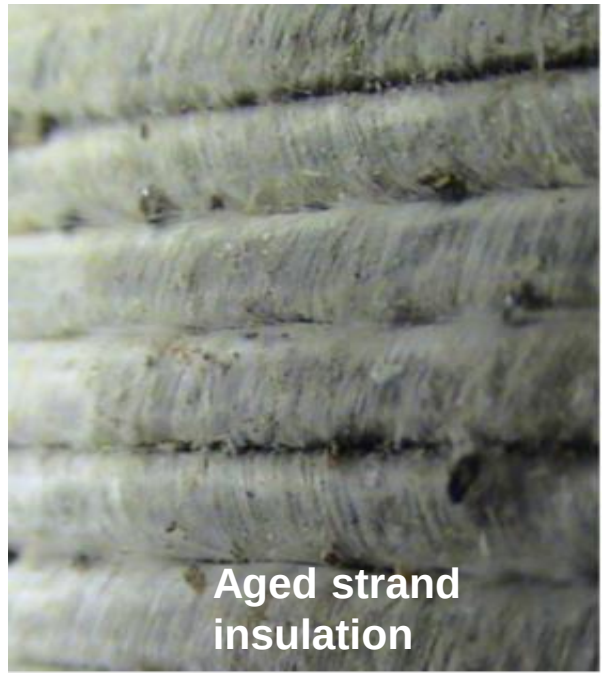
Dissection & Microscopy

1. *Copper bars “loose”;*
2. *Strand insulation is “gone”;*
3. *Groundwall insulation is fine.*

Copper bars after insulation removal



Loose strands



Aged strand insulation

Results

TYPE B – Air-cooled Base-load

Copper-Insulation Coherence

Copper-Insulation interface completely decoupled for TYPE B bars.

Results

Type C – Water-cooled Base-Load

Results

TYPE C – Water-cooled Base-load

Visual inspections


Bars as-received


Severe damages
during removal from slots

1. *Severe damages caused by the removal from slots;*
2. *1.5m-long segments prepared for testing;*

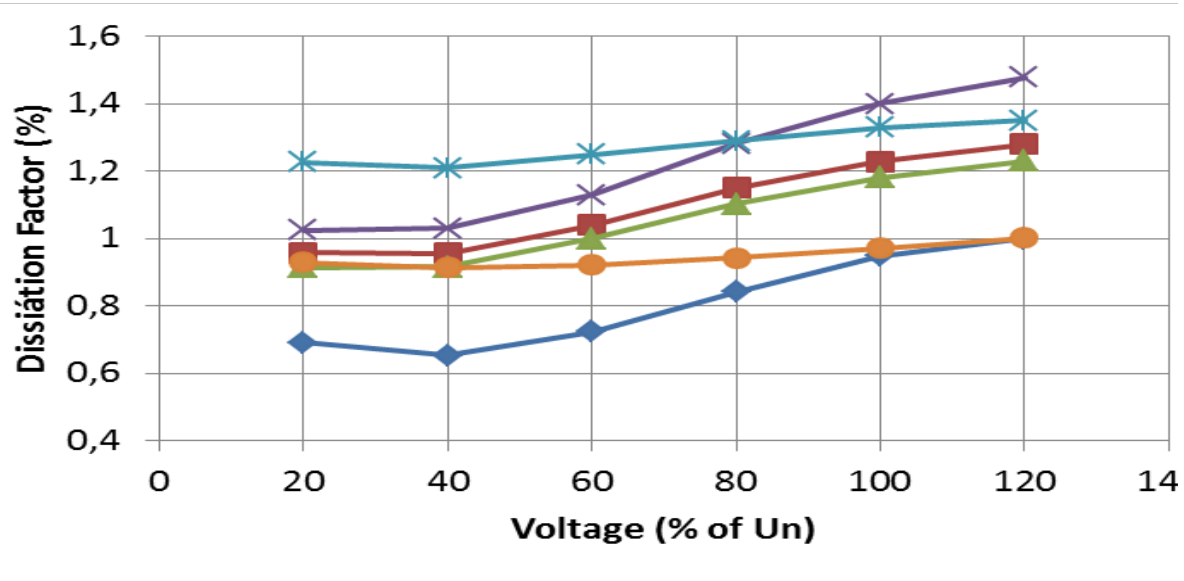

Bars segments
for testing

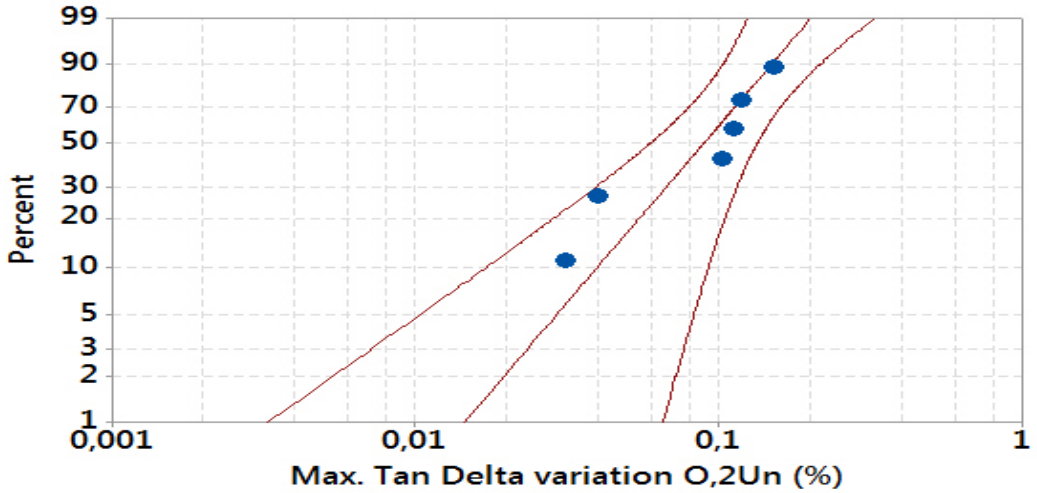
Results

TYPE C – Water-cooled Base-load

Electrical Tests

Dissipation factor and tip-ups suggest good conditions for the groundwall insulation.

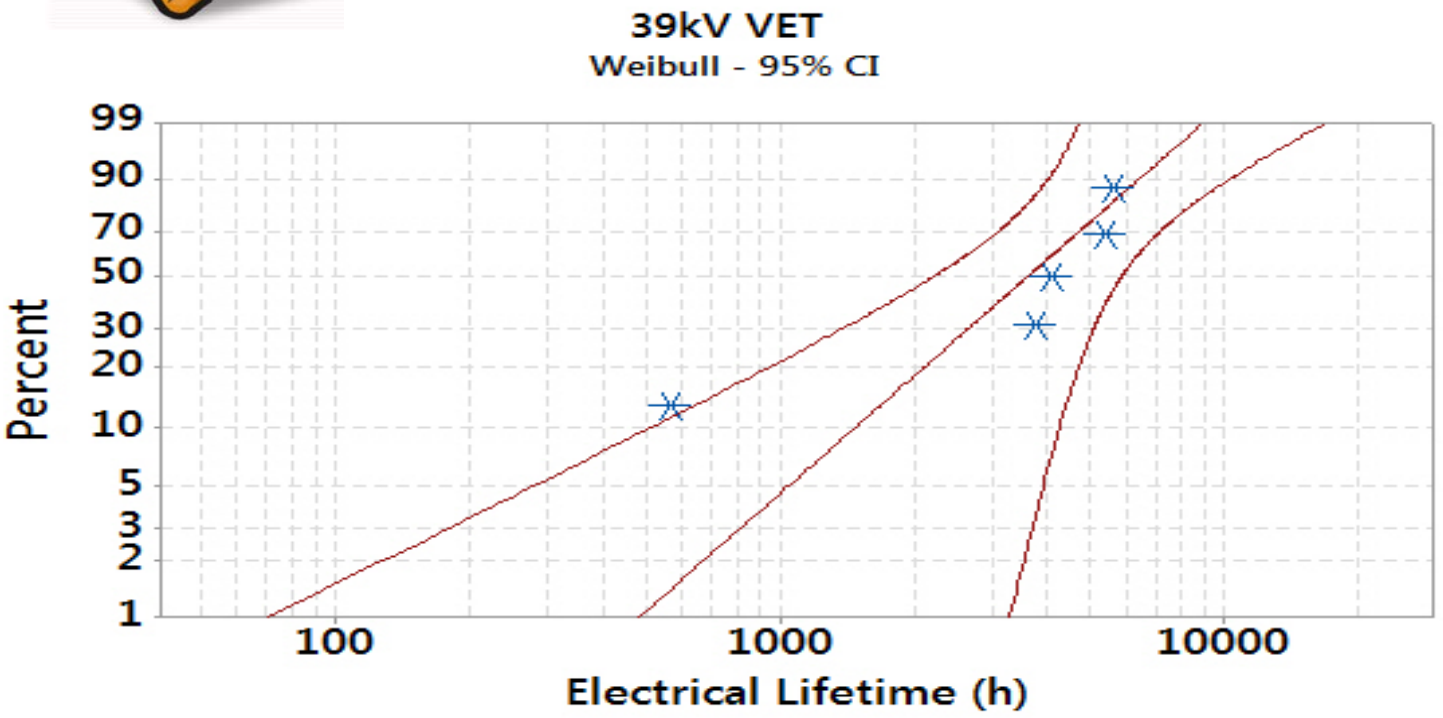




Results

TYPE C – Water-cooled Base-load

Electrical Tests

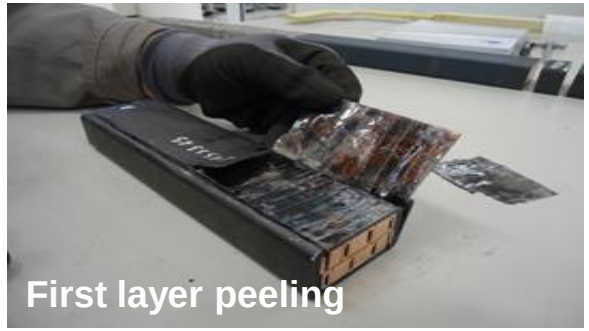


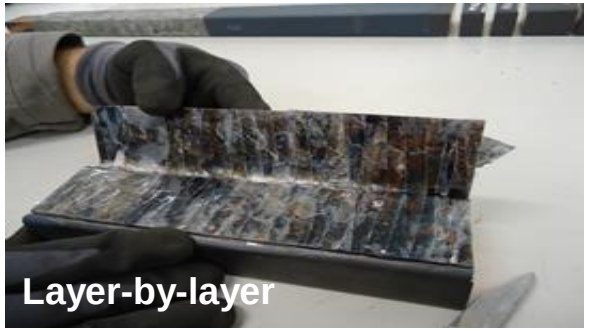
Voltage endurance tests at the level of IEEE 1553 Schedule A shows average of about 3000h.

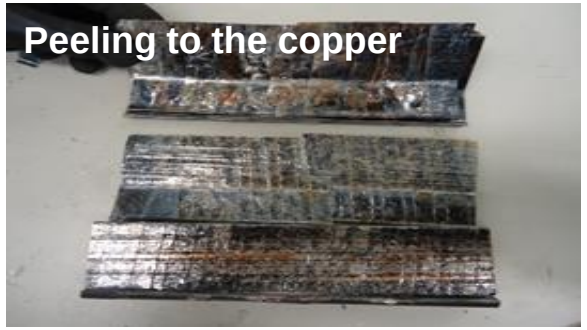
Results

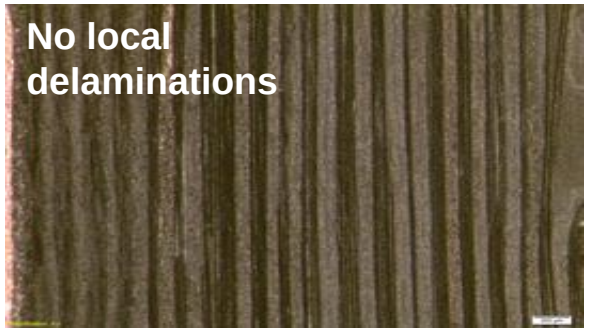
TYPE C – Water-cooled Base-load

Dissection & Microscopy









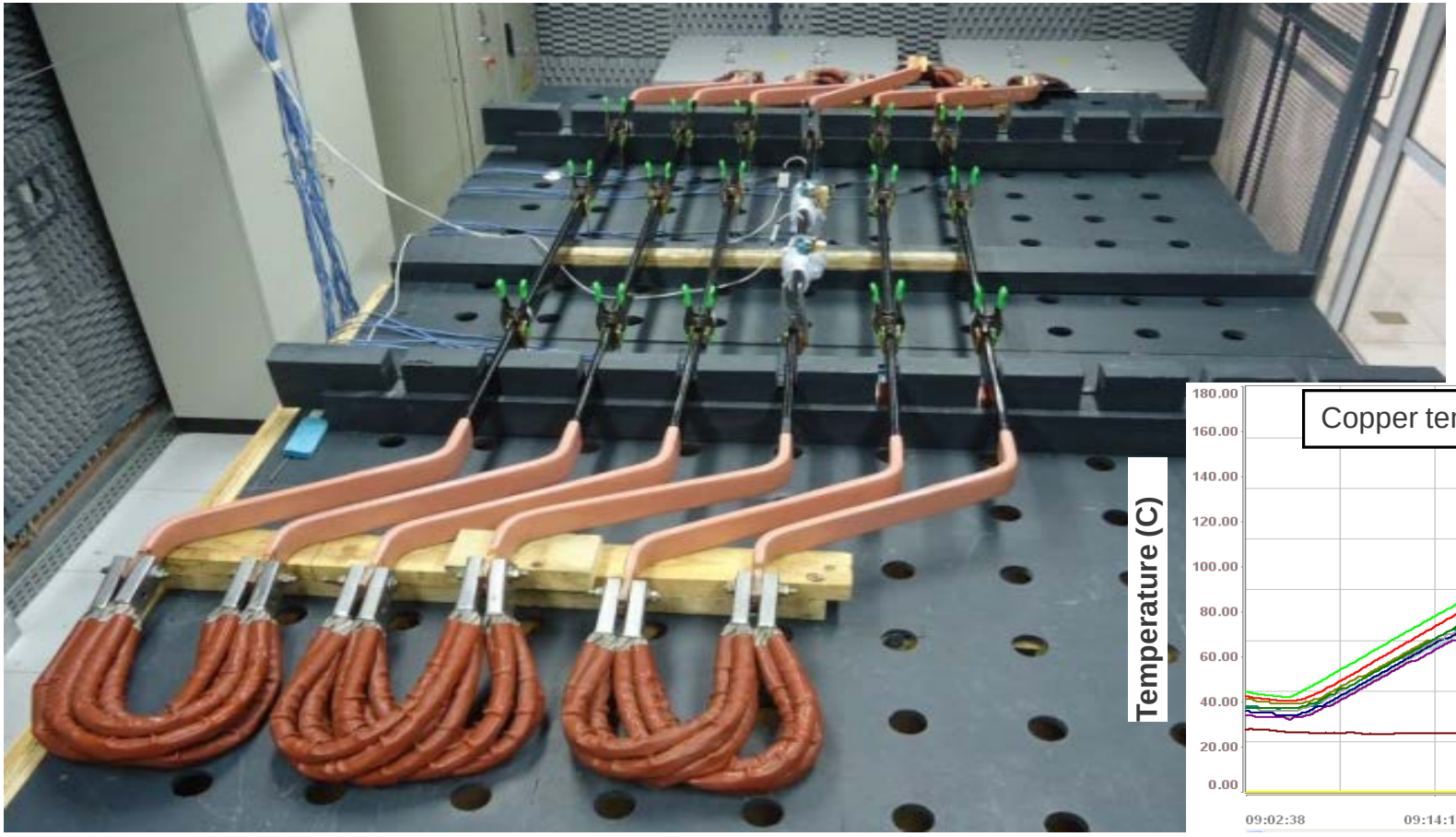
1. *Overall morphology on groundwall insulation is fine;*
2. *Layer-by-layer dissection showed good consolidation;*
3. *No local delaminations found in cross sections.*

Results

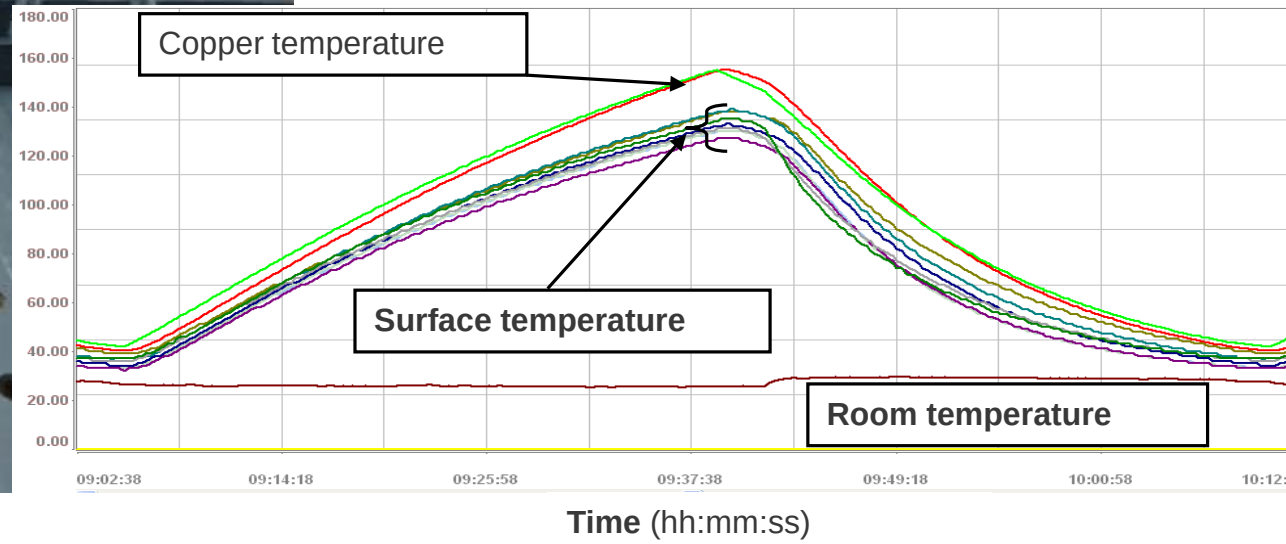
Type D – Laboratory Aged Bars

Results – IEEE 1310 test

TYPE D – Laboratory Aged Bars



- ✓ *500 Cycles*
- ✓ *40 to 155 C*

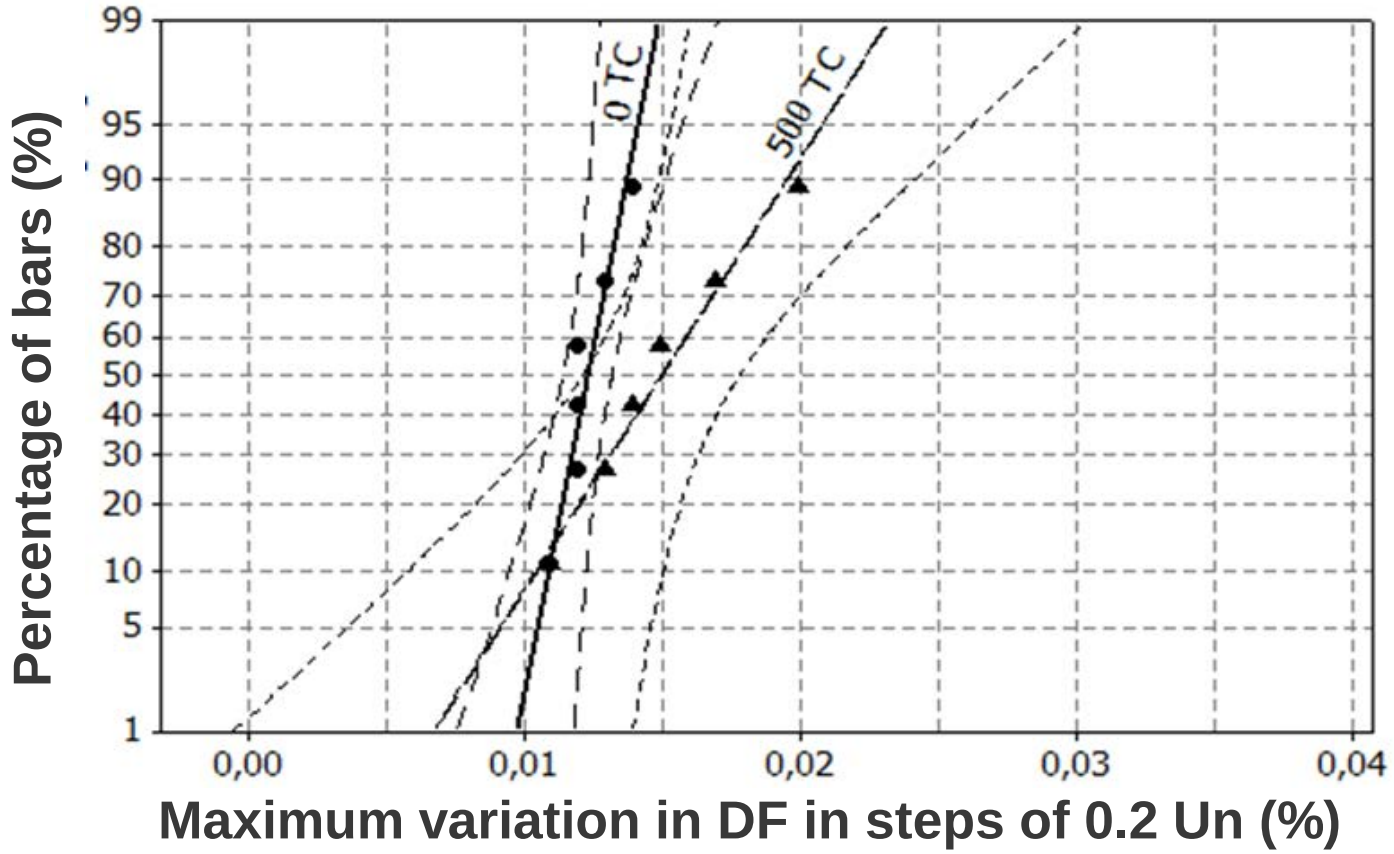


Results

TYPE D – Laboratory Aged Bars

Electrical Tests

No significant changes were found before and after 500 cycles at Dissipation factor and tip-ups values.

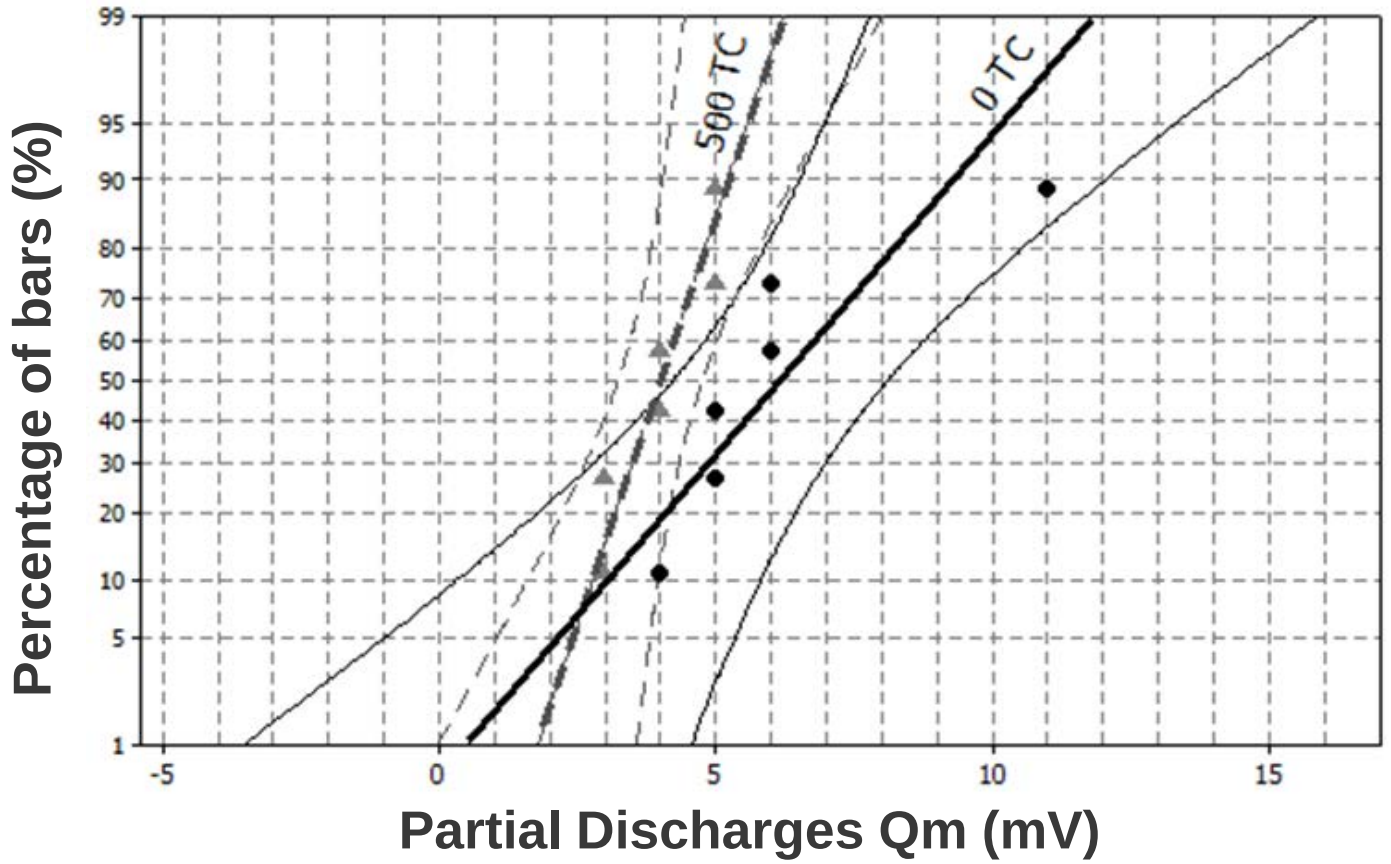


Results

No significant variation were seen before and after 500 cycles at Partial Discharges values.

TYPE D – Laboratory Aged Bars

Electrical Tests

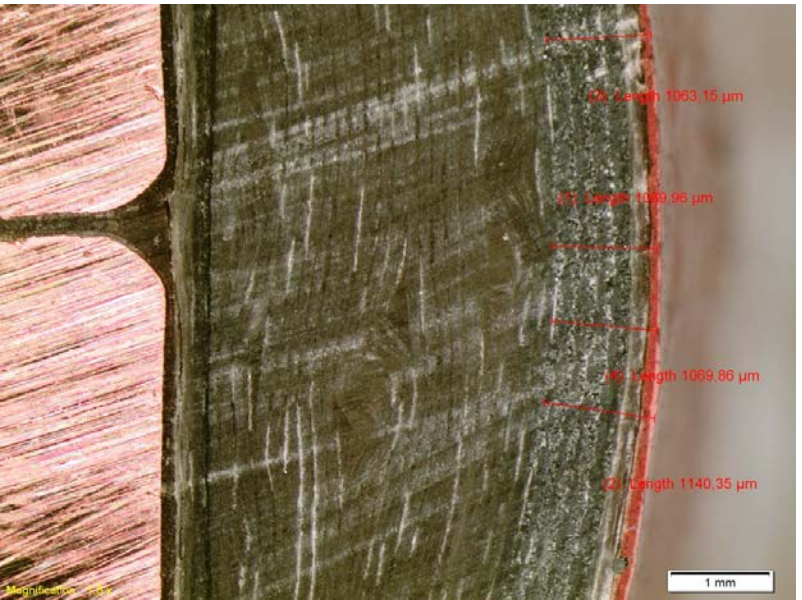


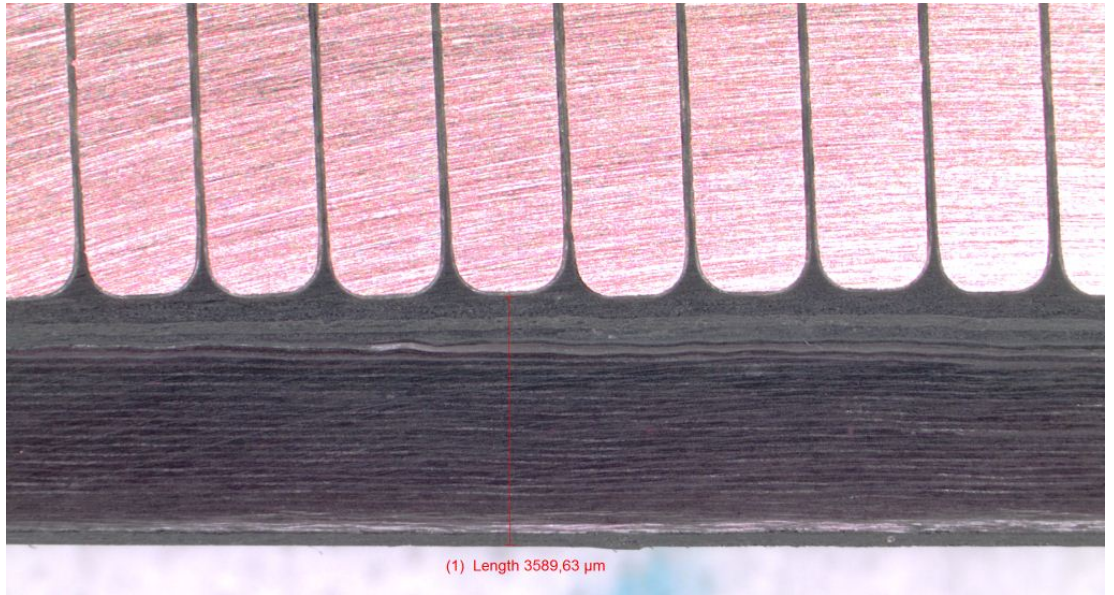
Results

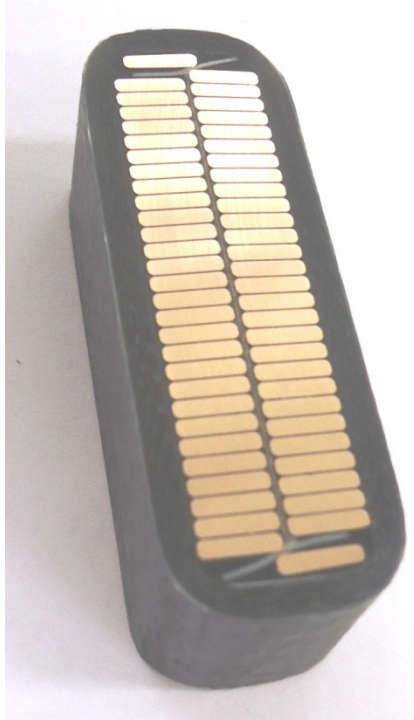
TYPE D – Laboratory Aged Bars

Dissection & Microscopy

1. *Overall morphology on groundwall insulation is fine;*
2. *No local delaminations found in cross sections.*







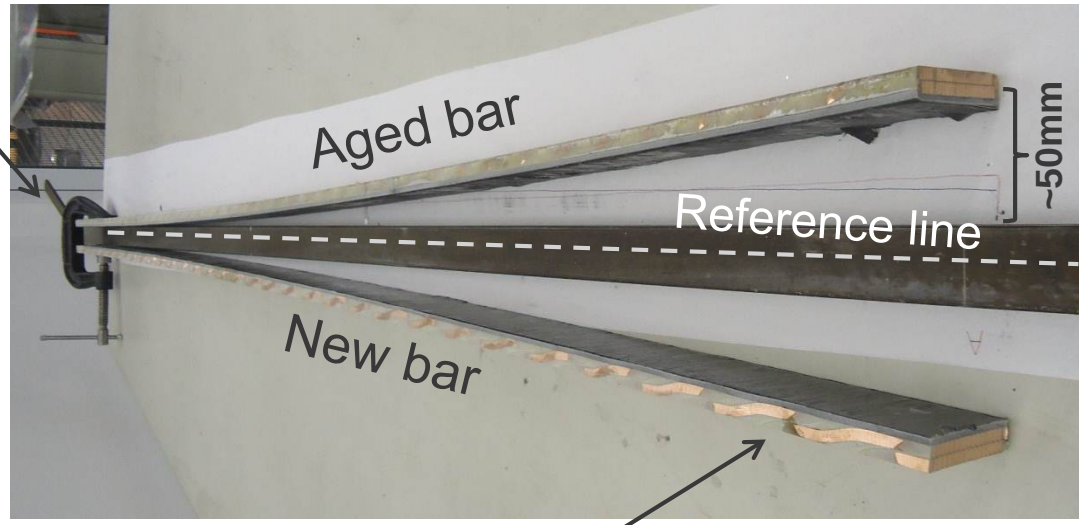
Results

TYPE D – Laboratory Aged Bars

Copper-Insulation Coherence

Copper-Insulation interface is coherent.

Fixation point



Insulation removed from this side

Conclusions

- Well-designed and manufactured epoxy-mica insulation can withstand the typical pumped-storage operation regime without the development of relevant aging mechanisms;
- Situations where the operation is assumed to be less critical – such as the base-load regime - can, however, give raise to relevant failure modes;
- No significant electrical or thermal-mechanical effects were found in lab aged bars comparing the conditions before and after aging;
- The differences in the coefficient of thermal expansion of copper and insulation and the deformations that can come from such difference can be used as a good method to evaluate the interface coherence.

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