



Behavior of Rubber Materials under Exposure to High Electric Fields

Candela Garolera, Anna; Holbøll, Joachim; Henriksen, M,

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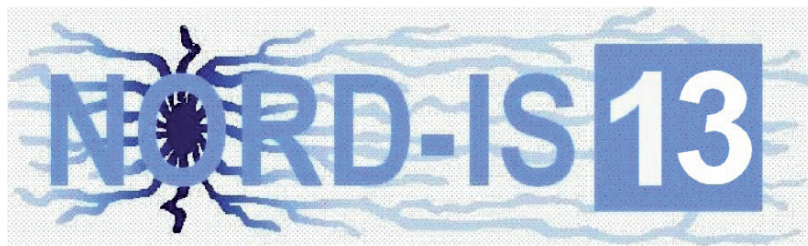
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Proceedings of the

**23rd NORDIC INSULATION
SYMPOSIUM**



June 9–12, 2013
Trondheim, Norway

Department of Electric Power Engineering
NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

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Preface

This publication contains all the papers presented at the 23rd Nordic Insulation Symposium (Nord-IS 13) held in Trondheim, Norway, June 9 - 12, 2013. Before acceptance, the abstracts and then the 44 received papers were reviewed by members of the Organizing Committee and the Advisory Council with respect to relevance and quality. *Challenges arising from use of HVDC* is selected as the preferential subject for Nord-IS 13. All subjects dealt with at previous Nord-IS are, however, included. This means for example ageing and breakdown phenomena, condition assessment and measurement techniques.

The Symposium is an interdisciplinary forum for open discussion of ideas, research results and practical experiences related to application of insulating materials and systems in electrical power apparatus. It is addressed to PhD students, researchers and engineers working within academia, research institutes, power industry and power utility companies. Nord-IS is held every second year in one of the Nordic countries; Norway, Denmark, Sweden and Finland. Young researchers are particularly encouraged to contribute. English is the working language of Nord-IS and participants from outside the Nordic area are welcome.

I would like to express my gratitude to all those who have worked hard and contributed in many different ways to make Nord-IS 13 possible. Thanks are due to the members of the Organizing Committee and the Advisory Council for their cooperation in planning of the program and acting as session chairmen during the Symposium. I am particularly indebted to PhD fellow Pål Keim Olsen for his invaluable efforts as secretary, executing all the work associated with Nord-IS 13. – Last but not least I would like to thank all authors and participants for making Nord-IS 13 a success.

Trondheim, May 2013

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Department of Electric Power Engineering, NTNU

NO-7491 Trondheim

Mail: palkeim@ntnu.no

Phone: +47 73594722

Fax: +47 73594279

History

- 1: 1968 - Nord-PD in Västerås, Sweden
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- 3: 1972 - Trondheim, Norway
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- 19: 2005 - Trondheim, Norway
- 20: 2007 - Lyngby, Denmark
- 21: 2009 - Gothenburg, Sweden
- 22: 2011 - Tampere, Finland
- 23: 2013 - Trondheim, Norway

PROGRAM NORD-IS 2013

Sunday, June 9, 2013

17:00-19:00 Registration at NTNU. Mounting of Posters

Monday, June 10, 2013

08:00 - 09:00 Registration and mounting of posters

**09:00 - 09:10 Opening of symposium: Welcome to NTNU by head of department
prof. Olav Fosso**

09:10 - 09:40 Opening lecture: "Challenges arising from use of HVDC".....p. XVII

Erling Ildstad, NTNU, Norway

09:40 - 10:00 Coffee break and mounting of posters

10:00 - 12:00 Session 1 - HVDC Challenges

Chair: Bjørn Sanden, StatNett (Norway)

**Conduction behavior of polyaniline/elastomer composites and the
influence of carbon black addition.....p. 3**

Bjørn Sonerud¹, Knut Magne Furuheim¹, Staffan Josefsson¹, Jani Pelto², Marjo
Ketonen², Outi Härkki²

¹ Nexans Norway AS

² VTT Technical Research Institute of Finland

**Short and long term behavior of functionally filled polymeric insulating
materials for HVDC insulators in compact gas-insulated systems.....p. 7**

Michael Tenzer, Maximilian Secklehner, Volker Hinrichsen

TU Darmstadt, High Voltage Laboratories

**Comparison of simulated and measured field dependent charge injection
in mineral oil under dc bias.....p. 11**

Olof Hjortstam, Christian Sonehag, Joachim Schiessling

ABB Corporate Research

**Space Charge Accumulation in XLPE versus Temperature and Water
Content.....p. 15**

Torbjørn Andersen Ve, Frank Mauseth, Erling Ildstad

NTNU

Surface Potential Decay on Silicon Rubber Samples at Reduced Gas Pressure.....p. 18
Shahid Alam, Yuriy Serdyuk, Stanislaw Gubanski
Chalmers University of Technology

Challenges when measuring the DC electric field very close to an insulator surface.....p. 23
Birgitta Källstrand¹, Daniel Borg¹, Lars Walfridsson¹, Charles Doiron²,
Kenneth Johansson¹
¹ *ABB AB, Corporate Research*
² *ABB Schweiz AG, Corporate Research*

12:00 - 13:00 Lunch

13:00 - 14:15 Poster Session 1 and coffee break

14:15 - 15:35 Session 2 - Breakdown and Ageing of Solid Insulation Systems

Chair: Hans Edin, KTH (Sweden)

The Effect of DC Electro-thermal Ageing on Electrical Treeing in Polyethylene.....p. 29
Adrian Mantsch, Xiangrong Chen, Jörgen Blennow, Stanislaw Gubanski
Department of Materials and Manufacturing Technology, Chalmers University of Technology

Effect of Film Thickness and Electrode Area on the Dielectric Breakdown Characteristics of Metallized Capacitor Films.....p. 33
Ilkka Rytöluoto, Kari Lahti
Tampere University of Technology

Development of insulation system for variable speed driven motors; performance of a corona resistant magnet wire.....p. 39
Tomi Nuorala¹, Janne Lehtonen², Markus Takala¹
¹ *ABB Oy, BU Motors and Generators*
² *ABB Oy, BU Transformers*

Enhancement of Water Tree Initiation due to Residual and Applied Mechanical Strain on XLPE Cables.....p. 43
Erling Ildstad¹, Simon Årdal Aarseth¹, Hallvard Faremo²
¹ *NTNU*
² *Sintef Energy Research*

15:30 - 16:00 Coffee break

16:00 - 17:00 Session 3 - Breakdown and Ageing of Solid Insulation Systems

Chair: Jørgen Blennow, Chalmers (Sweden)

Thermal Ageing of XLPE Cable Insulation under Operational Temperatures – Does It Exist?.....p. 49

Rasmus Olsen¹, Joachim Holboell², Mogens Henriksen², Jens Hansen³

¹ *Energinet.dk*

² *Technical University of Denmark*

³ *Danish Energy Association*

Influence of DC Stress Superimposed with High Frequency AC on Water Tree Growth in XLPE Insulation.....p. 53

Frank Mauseth¹, Sverre Hvidsten², Hans-Helmer Sæternes², Jørund Aakervik²

¹ *NTNU*

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Influence of antioxidants in epoxy-anhydride resin used for HV applications.....p. 57

Chau Hon Ho, Emmanuel Logakis, Andrej Krivda

ABB Switzerland Ltd. - Corporate Research

19:00 - 21:30 Symposium opening banquet at Banksalen, Trondheim city centre

Tuesday, June 11, 2013

08:00 – 09:00 Mounting of Poster Session 2

09:00 - 10:50 Session 4 - Condition Assessment and Test Procedures

Chair: Petri Hyvönen, Aalto University (Finland)

On-line condition monitoring importance and evolution.....p. 63

Nicolaie Fantana
ABB DECRC

Study of the dielectric response of ester impregnated cellulose for moisture content evaluation.....p. 67

Andrzej Graczkowski, Jarosław Gielniak, Piotr Przybyłek, Krzysztof Walczak, Hubert Morańda
Poznan University of Technology

Correction of Geometric Influence in Permittivity Determination.....p. 71

Xiangdong Xu¹, Tord Bengtsson², Jörgen Blennow¹, Stanislaw Gubanski¹
¹ *Chalmers University of Technology*
² *Chalmers University of Technology and ABB Corporate Research*

System for detection and analysis of partial discharges under transient voltage application.....p. 75

Søren Valdemar Kjær¹, Joachim Holbøll²
¹ *DONG Energy*
² *Technical University of Denmark*

VLF testing for High Voltage Cables, state of the art.....p. 79

Peter Mohaupt, Kurt Misteli, Harald Geyer
Mohaupt High Voltage

10:50 - 11:00 Coffee break

11:00 - 12:00 Poster Session 2

12:00 - 13:00 Lunch

13:00 – 16:00 Technical visits – NTNU/SINTEF laboratories and Leirfossen Hydro Power Station

18:30 - 19:30 Greetings from the Mayor’s Office and Concert in Nidarosdomen

19:30 - 20:30 Tour Nidarosdomen

Wednesday, June 12, 2013

09:00 - 10:30 Session 5 Breakdown and Ageing of Liquid Insulation Systems

Chair: Henrik Hillborg, ABB Corporate Research (Sweden)

Oil Aging due to Partial Discharge Activity.....p. 85

Mohamad Ghaffarian Niasar, Respicius Cemence Kizza, Hans Edin

KTH Royal Institute of Technology, Stockholm

Streamer Propagation in a Long Gap in Model Liquids.....p. 89

Van Dung Nguyen¹, Hans Kristian Høidalen¹, Dag Linhjell², Lars E

Lundgaard², Mikael Unge³

¹ *Norwegian University of Science and Technology*

² *SINTEF Energy Research*

³ *ABB Corporate Research*

Investigation of the Static Breakdown Voltage of the Lubricating Film in a Mechanical Ball Bearing.....p. 94

Abhishek Joshi, Jörgen Blennow

Chalmers University of Technology, Gothenburg

Measurement techniques for identifying polarity dependence of ion injection in transformer oil.....p. 98

Joachim Schiessling¹, Deepthi Kubevoor-Ramesh¹, Yuriy Serdyuk², Olof

Hjortstam¹

¹ *ABB Corporate Research*

² *Chalmers University Gothenborg*

10:30 - 10:45 Coffee break

10:45 - 12:05 Session 6 Gaseous and Impregnated Insulation Systems

Chair: Rolf Hegerberg, Sintef Energy (Norway)

Mechanical Simulations Regarding the Influence of Paper Insulation Degradation on the Radial Mechanical Strength of Continuously Transposed Conductors for Power Transformers.....p. 103

Daniel Geißler, Thomas Leibfried

Institute of Electric Energy Systems and High Voltage Technology at Karlsruhe Institute of Technology (KIT)

Effect of High Voltage Impulses on Surface Discharge at the Oil-Paper Interface.....p. 108

Respicius Clemence Kiiza, Mohamad Ghaffarian Niasar, Roya Nikjoo, Xiaolei

Wang, Hans Edin

KTH

Radial Flow Paths for Oil in Mass Impregnated HVDC Subsea Cablesp.112
Bendik Støa¹, Erling Ildstad¹, Magne Runde²
¹ *Norwegian University of Science and Technology*
² *SINTEF Energy Research/Norwegian University of Science and Technology*

Corona at Large Coated Electrodes.....p. 116
Mats Larsson¹, Olof Hjortstam¹, Håkan Faleke¹, Ming Li¹, Liliana Arevalo², Dong Wu²
¹ *ABB Corporate Research*
² *ABB HVDC*

12:05 - 13:05 Lunch

13:05 - 14:45 Session 7 – Design and Modeling of Electric Components

Chair: Anders Jensen, NKT Cables (Denmark)

Strategies for Inclusion of Structural Mass Estimates in the Direct-Drive Generator Optimization Process.....p. 123
Matthew Henriksen, Bogi Jensen
Technical University of Denmark

Estimating Transmission Line Parameters of Three-core Power Cables with Common Earth Screen.....p. 127
Yan LI¹, Peter A. A. F. Wouters¹, Paul Wagenaars², Peter C. J. M. van der Wielen², E. Fred Steennis²
¹ *Eindhoven University of Technology*
² *DNV KEMA Energy & Sustainability*

Effects of Ambient Conditions on the Dielectric Properties of Thermally Sprayed Ceramic Coating.....p. 131
Minna Niittymäki¹, Tomi Suhonen², Jarkko Metsäjoki², Kari Lahti³
¹ *Department of Electrical Engineering, Tampere University of Technology*
² *Advanced Materials, VTT Technical Research Centre of Finland*
³ *Department of Electrical Engineering, Tampere University of Technology*

Water Diffusion Barrier – A Novel Design for High Voltage Subsea Cables.....p. 136
Knut Magne Furuheim¹, Susanne Nilsson¹, Svein Magne Hellesø², Sverre Hvidsten²
¹ *Nexans Norway AS*
² *Sintef Energy Research*

Robustness Analysis of Classical High Voltage Joint Design Under High Voltage DC Stress.....p. 140
Fredrik Fälth¹, Santhosh Kumar BVMP², Hossein Ghorbani¹
¹ *ABB High Voltage Cables*
² *ABB GISL*

14:45 - 15:00 Closing of the symposium

Poster Session 1

- Charge Decay Measurements on Polymeric Insulation Material under Controlled Humidity Conditions**.....p. 149
Yvonne Späck, Sarath Kumara, Stanislaw M. Gubanski
Chalmers University of Technology
- Dielectric Breakdown Strength of Polymer Nanocomposites-The Effect of Nanofiller Content**.....p. 153
Markus Takala
ABB Oy, BU Motors and Generators
- Sensitivity Improvement of Acoustic Partial Discharge Detection Measurements through Wavelet Analysis**.....p. 157
Demetres Evagorou, Patrick Janus, Mohamad Ghaffarian Niasar, Hans Edin
KTH Royal Institute of Technology
- Comparison of Test Setups for High Field Conductivity of HVDC Insulation Materials**.....p. 161
Johan Andersson¹, Villgot Englund¹, Per-Ola Hagstrand¹, Carl-Olof Olsson²,
Andreas Friberg²
¹ *Borealis AB*
² *ABB AB, Corporate Research*
- Influence of Applied Voltage and Temperature on the Current through the Alumina-filled poly(ethylene-co-butyl acrylate) Nanocomposites Under Constant Stress**.....p. 165
Nadja Jaeverberg, Bandapalle Venkatesulu, Lars Jonsson, Hans Edin
KTH
- Mechanical Stress Distribution inside Dry Capacitor Elements**.....p. 169
Linnea Petersson, Kun Wei, Göran Paulsson, David Stromsten, Johan Ekh
ABB AB, Corporate Research

Poster Session 2

- Behavior of Rubber Materials under Exposure to High Electric Fields**.....p. 175
Anna Candela Garolera, Joachim Holböll, Mogens Henriksen
Technical University of Denmark
- Thickness Dependency in Dielectric Breakdown Strength of Biaxially Oriented Polypropylene-Silica Nanocomposite Films**.....p. 179
Hannes Ranta, Ilkka Rytöluoto, Kari Lahti
Tampere University of Technology, Department of Electrical Engineering
- Lumped-circuit Modeling of Surface Charge Decay in a Needle-plane geometry**.....p. 183
Xiaolei Wang, Nathaniel Taylor, Mohamad Ghaffarian Niasar, Respicius Clemence Kiiza, Hans Edin
KTH
- Capacitor performance limitations in high power converter applications**.....p. 187
Walid Ziad El-Khatib, Joachim Holböll, Tonny W. Rasmussen
Denmark Technical University
- Positive Breakdown Streamers and Acceleration in a Small Point-Plane Liquid Gap and Their Variation with Liquid Properties**.....p. 191
Dag Linhjell¹, Stian Ingebrigtsen¹, Lars Lundgaard¹, Mikael Unge²
¹ *SINTEF Energy Research*
² *ABB Corporate Research*
- Axial Water Ingress MV XLPE Cable Designs with Watertight Barrier**.....p. 197
Knut Brede Liland¹, Svein Magne Hellesø¹, Sverre Hvidsten¹, Karl Magnus Bengtsson², Arve Ryen²
¹ *SINTEF Energy*
² *NEXANS Norway*
- Modelling of Partial Discharges in Polymeric Insulation Exposed to Combined DC and AC Voltage**.....p. 202
Pål Keim Olsen, Frank Mauseth, Erling Ildstad
Norwegian university of science and technology



POSTER SESSION 2

Behavior of Rubber Materials under Exposure to High Electric Fields

A. Candela, J. Holboell, M. Henriksen

Technical University of Denmark, Department of Electrical Engineering

Kgs. Lyngby, Denmark

Abstract

The effect of high electrical stress on rubber materials is investigated by performing breakdown tests and tracking resistance tests on selected samples. The study is focused on the relationship between the dielectric strength and the thickness of the samples, as well as the influence of the interfaces between different layers of material. Tracking resistance tests are also performed on the rubber material. The purpose is to provide a complete study of the applicability of the rubber material in thunderstorm environments.

1. Introduction

In the recent years, new technologies have been developed to increase the efficiency of wind turbine blades, some of which involve the use of rubber materials in the blade structure. Amongst these technologies, the deformable flaps aim at reducing the load on the blade, thus alleviating the fatigue strain on the whole wind turbine [1]. This is achieved by installing a rubber flap in the trailing edge of the blade (Fig. 1), and controlling its deflection using a compressed-air system. Once installed in the blade, the rubber flap will be subjected to severe ambient conditions. This paper is focused on the effect of high electric fields on the electrical performance of rubber materials.

During their lifetime wind turbines are repeatedly exposed to high electric fields from thunderstorms, which degrade progressively the insulating properties of the blade materials [2]. The interaction between the thunderstorm electric field and the fiberglass material usually used in wind turbines has been widely studied, [3]. However, the behavior of the rubber material in a thunderstorm environment is not fully known and therefore needs to be assessed.

The IEC standard on lightning protection of wind turbines [2] defines the tests to be performed in wind turbines to reproduce the effects of direct lightning strike. However, there is a need for tests aimed at assessing the effects of repeated high electric field and discharge exposure on the insulating materials of the blade. In this study, the rubber behavior under high electric fields is investigated by performing breakdown and tracking resistance tests. These methods have been used previously to evaluate the performance of blade insulating materials against lightning [3], [4]. The criterion used to evaluate the tests results on fiberglass was to affect the material as it was seen in blades in service.

Samples of four different rubber materials have been subjected to breakdown and tracking tests. The samples and setups used in the tests are described in section 2. Section 3 summarizes the test results, comparing the different rubber materials. The relationship between the breakdown strength and the thickness of the samples and the influence of the interfaces between the layers of material are also investigated and described in this section. Finally, the outcome of the tests is discussed in section 5, where the suitability of rubber materials in wind turbine blades is discussed.

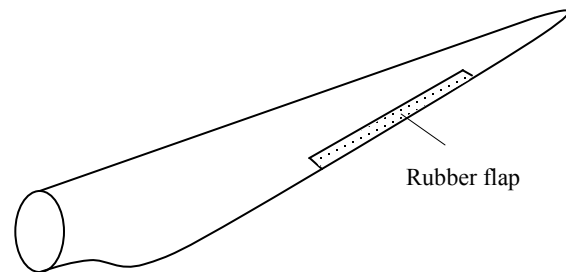


Fig.1 – Wind turbine blade equipped with a rubber flap system, installed on the blade trailing edge.

2. Materials and tests description

Four different rubber materials are used for both the breakdown and the tracking resistance tests. These materials are a representative selection of different types of rubber:

- Santoprene 121-73W175 (Polyolefin elastomer)
- Silicone rubber 5060-5
- PUR 8070-3 (Polyurethane)
- EPDM 2165-1 (Ethylene Propylene Diene monomer (M-class))

2.1. Breakdown strength tests

The specimens used for this test are square shaped, with a side length of 100 mm. Each material has been tested with a thickness of 1, 2, 3 and 4 mm.

The sample is placed between two electrodes inside a container filled with silicone oil (Fig. 2). The upper electrode is spherical, with a diameter of 12.5 mm, and it is connected to the high impulse voltage generator. The lower electrode is cylindrical with rounded edges, with a diameter of 70 mm, and is connected to ground. The purpose of the silicone oil is to increase the electrical breakdown of the media around the specimen, in order to prevent side flashovers.

The test follows the procedure described in [5]. It consists of applying a high voltage impulse with a rise

time and decay to half value of 1.2 and 50 μ s respectively, according to [6]. The test starts at relatively low voltage, where there is no risk of breakdown, and it is increased progressively until the breakdown of the material is reached.

This procedure is repeated 6 times. Each time, the peak value of the voltage impulse that produces breakdown and the peak value of the withstand voltage previous to breakdown are measured. The breakdown and withstand voltages of each material found in section 3 correspond to the average value of the measurements.

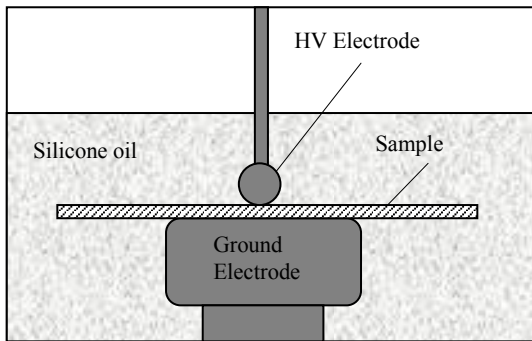


Fig.2 – Breakdown test setup: rubber sample placed between the high voltage and ground electrodes, inside a container filled with silicone oil.

2.2. Tracking resistance tests

The setup arrangement and the test procedure follow the standard setup described in [7]. The specimens are mounted on an insulating support, which stands at an angle of 45 degrees from the horizontal. Two electrodes are placed on the top and the bottom of the sample, connected to high voltage and ground respectively (Fig. 3). The specimens are arranged in sets of 5 samples. Each sample is 50 x 120 mm, with a thickness of 2 mm (Fig. 4).

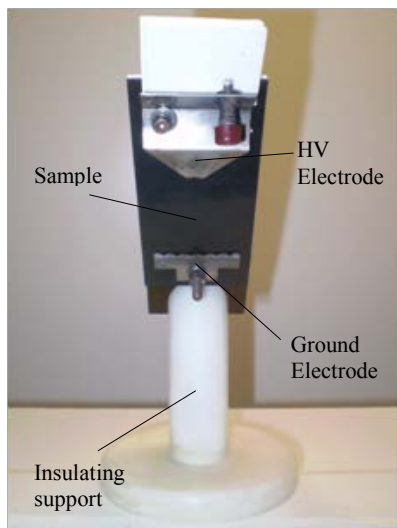


Fig.3 – Tracking resistance test setup. Sample of rubber material mounted on the insulating support with the electrodes.



Fig.4 – Tracking resistance test setup. Set of 5 samples mounted on the supports.

The procedure follows the Method 2, according to [7]: stepwise tracking voltage. It mainly consists of applying a sequence of AC voltage levels across the sample while a contaminant solution based on NH_4Cl is flowing over the sample lower surface. The initial voltage is chosen in such a way that no sample will fail during the three first steps, and is increased by 250 V every hour. The end-point criterion used in this test is “End-point criterion A: the value of current through the specimen exceeds 60 mA”. In order to determine when the current is over the maximum value allowed, a fuse is installed in the HV circuit of each sample.

3. Tests results

This section summarizes the results of the breakdown strength and the tracking resistance tests on the rubber materials.

3.1. Breakdown strength tests

The breakdown strength tests were performed on 6 samples of each thickness, for the four different rubber materials. The average breakdown and withstand voltages for each material and thickness are displayed in Fig 5.

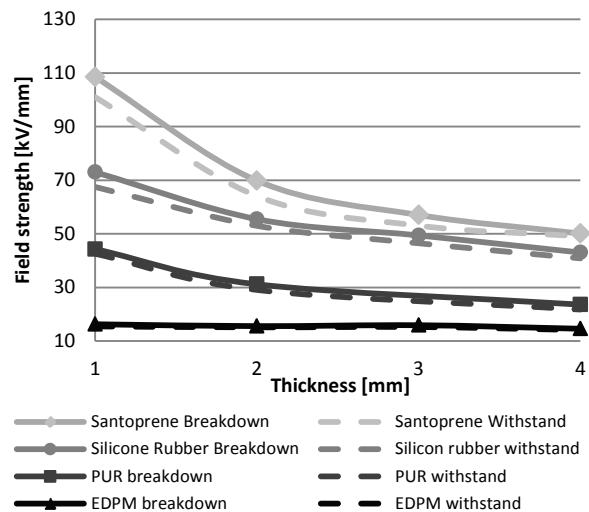


Fig.5 – Breakdown and withstand field strength of the tested materials, for thicknesses from 1 to 4 mm.

According to the test results, the Santoprene material presents the highest breakdown field strength of 110 kV/mm, followed by silicone rubber showing 72 kV/mm. It is also observed that the breakdown strength decreases when increasing the thickness of the sample. This can be explained by the so-called volume effect, where an increase of the material thickness involves a higher probability of impurities or microscopic defects. These inhomogeneities, normally small particles and air bubbles, enhance the electric field around or inside them, and lead to an earlier breakdown of the material. The volume effect can be found in all the tested materials except the EPDM. Considering that this material shows a very low breakdown strength, the negative influence of possible impurities is less dominant.

In order to study further the volume effect and the influence of interfaces, additional tests were performed to Santoprene, the material showing the highest breakdown strength. These tests consisted of testing two layers of material together. The results were compared to the breakdown strength of a single layer with the same total thickness and with the theoretical calculation of the breakdown strength obtained from the independent layers.

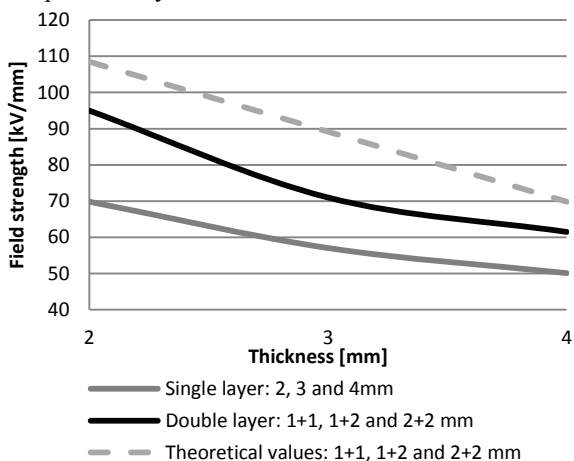


Fig.6 – Comparison of breakdown field strength between single-layer setup, double-layer setup and theoretical values for the double layer setup calculated from the breakdown strength of the independent layers.

The test reveals that the double-layer setup has higher breakdown strength than the single-layer setup. At a first glance, this may be surprising, since we have an additional interface in the material. On the other hand each layer of the double-layer setup presents fewer impurities per volume than the thicker single-layer, which makes the result more plausible. It is also found that the breakdown strength of the double-layer setup is lower than the value calculated from each independent layer. This fact indicates that in the double-layer setup, the breakdown occurs first in the weakest layer, directly followed by the other layer. Therefore, the weakest layer determines the breakdown of both layers. This phenomenon is more evident in the case of mixed thickness (1+2 mm), where the difference between the

calculated and the actual breakdown strength of the double-layer is greater.

3.2. Tracking resistance tests

The tracking resistance tests were performed on sets of five samples of the four different materials. Table 1 summarizes the results. The initial and the final voltages are the voltage level applied to the samples at the beginning of the test and the voltage level where the first sample failed, respectively. The classification of the material according to [7] corresponds to IEC Class – Method used to apply the voltage/end-point criterion/maximum level of voltage withstood.

Table.1 – Tracking resistance tests: classification of the material according to the test results.

| Material | Initial voltage [kV] | Final Voltage [kV] | IEC Class |
|-----------------|----------------------|--------------------|------------|
| Santoprene | 3.5 | 4.5 | 2A 4.25 kV |
| Silicone rubber | 3 | 4.5 | 2A 4.25 kV |
| PUR 8070-3 | 3 | 4.75 | 2A 4.5kV |
| EPDM 2165-1 | 1 | 1 | Failed |

The PUR material reached the highest voltage level before failure, followed by the Santoprene and silicone rubber, which show similar results. The EPDM material failed at the lowest level of voltage, and it is therefore out of the range of the IEC classification.

The end-point criterion chosen for the tracking tests depends only on the level of current flowing through the sample. Still, it is relevant for this investigation to look at the erosion of the samples after the tests, since it varies considerably in materials that withstand a similar level of voltage. Figs. 7 to 10 show the surface erosion of the samples after the tests.

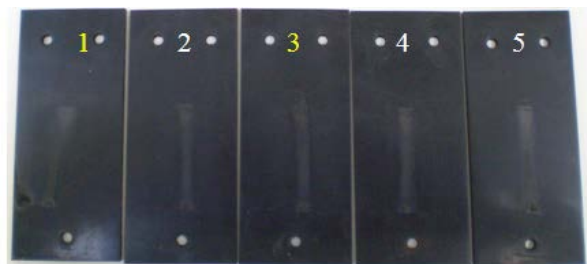


Fig.7 – Surface erosion in Santoprene rubber material after the tracking resistance tests. Samples 1 and 3 failed.



Fig.8 – Surface erosion in Silicone rubber material after the tracking resistance tests. Sample 1 failed.



Fig.9 – Surface erosion in PUR rubber material after the tracking resistance tests. Sample 1 failed.



Fig.10 – Surface erosion in EPDM rubber material after the tracking resistance tests. All samples failed.

It is seen in the pictures (Figs. 7-10) that all the samples show a matt appearance between the electrodes. However, this band is different in each material, and only some materials present a deep track. The Santoprene and EPDM materials have a narrow track. The Santoprene samples present erosion only next to the bottom electrode, while the EPDM samples have severe erosion in the whole path between the electrodes. The silicone and PUR materials have a wider dry band and no significant erosion. A failed sample of each material is shown in Fig. 11.



Fig.11 –The surface erosion (marked in yellow) and dry band can be compared in failed samples of each material. From left to right: Santoprene, Silicone rubber, PUR, EPDM.

4. Discussion

In this paper, the assessment of materials is done by comparison of the tests results regarding break down and tracking. Though being relevant for wind turbine flap application, the tests themselves do not directly provide information to determine if the material is suitable for the flap application with respect to interaction with lightning discharges. The breakdown strength tests show that the Santoprene material performs better than the other rubber materials, and its performance is comparable to the fiberglass materials used in wind turbine blades [3]. It is also observed that

the thickness of the sample has a significant impact on the breakdown strength of the material due to the volume effect. Regarding the tracking resistance tests, all rubber materials reach similar levels of voltage, except the EPDM material, which failed at the beginning of the tests. Furthermore, significant differences in erosion are observed in the materials that withstand the same level of voltage. Finally, it has to be considered that a rubber flap installed in a blade in service will be subjected to mechanical fatigue. Therefore mechanical tests should be done with the tested samples in order to evaluate how the erosion due to tracking affects the performance of the material in general.

5. Conclusions

Breakdown and tracking tests were performed on a selection of rubber materials following the same procedure as in GFRP materials for wind turbine blades. The tests results show that the Santoprene material performs better than the other materials, and has comparable properties to the fiberglass material used in blades with respect to tracking resistance and breakdown strength. Therefore, it can be considered as a suitable candidate for wind turbine blade flaps application, regarding its performance in interaction with lightning discharges.

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Author index

| | | | |
|-------------------------|------------------------|----------------------------|-------------------|
| Aakervik, Jørund | 53 | Ildstad, Erling | 15, 43, 112, 202 |
| Aarseth, Simon Årdal | 43 | Ingebrigtsen, Stian | 191 |
| Alam, Shahid | 18 | Jaeverberg, Nadja | 165 |
| Andersson, Johan | 161 | Janus, Patrick | 157 |
| Arevalo, Liliana | 116 | Jensen, Bogi | 123 |
| Bengtsson, Karl Magnus | 197 | Johansson, Kenneth | 23 |
| Bengtsson, Tord | 71 | Jonsson, Lars | 165 |
| Blennow, Jörgen | 29, 71, 94 | Josefsson, Staffan | 3 |
| Borg, Daniel | 23 | Joshi, Abhishek | 94 |
| Chen, Xiangrong | 29 | Ketonen, Marjo | 3 |
| Doiron, Charles | 23 | Kiiza, Respicius Clemence | 85, 108, 183 |
| Edin, Hans | 85, 108, 157, 165, 183 | Kjær, Søren Valdemar | 75 |
| Ekh, Johan | 169 | Krivda, Andrej | 57 |
| El-Khatib, Walid Ziad | 187 | Kubevoor-Ramesh, Deepthi | 98 |
| Englund, Villgot | 161 | Kumar, BVMP Santhosh | 140 |
| Evagorou, Demetres | 157 | Kumara, Sarath | 149 |
| Faleke, Håkan | 116 | Källstrand, Birgitta | 23 |
| Fantana, Nicolaie | 63 | Lahti, Kari | 33, 131, 179 |
| Faremo, Hallvard | 43 | Larsson, Mats | 116 |
| Friberg, Andreas | 161 | Lehtonen, Janne | 39 |
| Furuheim, Knut Magne | 3, 136 | Leibfried, Thomas | 103 |
| Fälth, Fredrik | 140 | Li, Ming | 116 |
| Garolera, Anna Candela | 175 | Li, Yan | 127 |
| Geißler, Daniel | 103 | Liland, Knut Brede | 197 |
| Geyer, Harald | 79 | Linhjell, Dag | 89, 191 |
| Ghorbani, Hossein | 140 | Logakis, Emmanuel | 57 |
| Gielniak, Jarosław | 67 | Lundgaard, Lars | 89, 191 |
| Graczkowski, Andrzej | 67 | Mantsch, Adrian | 29 |
| Gubanski, Stanislaw | 18, 29, 71, 149 | Mauseth, Frank | 15, 53, 202 |
| Hagstrand, Per-Ola | 161 | Metsäjoki, Jarkko | 131 |
| Hansen, Jens | 49 | Misteli, Kurt | 79 |
| Hellesø, Svein Magne | 136, 197 | Mohaupt, Peter | 79 |
| Henriksen, Matthew | 123 | Moraña, Hubert | 67 |
| Henriksen, Mogens | 49, 175 | Nguyen, Dung Van | 89 |
| Hinrichsen, Volker | 7 | Niasar, Mohamad Ghaffarian | 85, 108, 157, 183 |
| Hjortstam, Olof | 11, 98, 116 | Niittymäki, Minna | 131 |
| Ho, Chau Hon | 57 | Nikjoo, Roya | 108 |
| Holbøll, Joachim | 49, 75, 175, 187 | Nilsson, Susanne | 136 |
| Hvidsten, Sverre | 53, 136, 197 | Nuorala, Tomi | 39 |
| Härkki, Outi | 3 | Olsen, Pål Keim | 202 |
| Høidalen, Hans Kristian | 89 | Olsen, Rasmus | 49 |
| | | Olsson, Carl-Olof | 161 |

| | |
|--------------------------------|----------|
| Paulsson, Göran | 169 |
| Pelto, Jani | 3 |
| Petersson, Linnea | 169 |
| Przybyłek, Piotr | 67 |
| Ranta, Hannes | 179 |
| Rasmussen, Tonny W. | 187 |
| Runde, Magne | 112 |
| Ryen, Arve | 197 |
| Rytöluoto, Ilkka | 33, 179 |
| Schiessling, Joachim | 11, 98 |
| Secklehner, Maximilian | 7 |
| Serdyuk, Yuriy | 18, 98 |
| Sonehag, Christian | 11 |
| Sonerud, Björn | 3 |
| Späck, Yvonne | 149 |
| Steennis, E. Fred | 127 |
| Stromsten, David | 169 |
| Støa, Bendik | 112 |
| Suhonen, Tomi | 131 |
| Sæternes, Hans-Helmer | 53 |
| Takala, Markus | 39, 153 |
| Taylor, Nathaniel | 183 |
| Tenzer, Michael | 7 |
| Unge, Mikael | 89, 191 |
| Ve, Torbjørn Andersen | 15 |
| Venkatesulu, Bandapalle | 165 |
| Wagenaars, Paul | 127 |
| Walczak, Krzysztof | 67 |
| Walfridsson, Lars | 23 |
| Wang, Xiaolei | 108, 183 |
| Wei, Kun | 169 |
| Wielen, Peter C. J. M. van der | 127 |
| Wouters, Peter A. A. F. | 127 |
| Wu, Dong | 116 |
| Xu, Xiangdong | 71 |

