MULTISTRESS AGING OF POLYMERIC INSULATORS

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ABSTRACT

Weathering polymeric insulators in the lab under environmental conditions, similar to that experienced in the actual field, has the merit of simulating the actual service environment in the lab. This permits a better understanding of the ongoing mechanisms related to aging and longevity of insulators.

This paper presents the results of a one year environmental multistress aging study of polymeric insulators in a US Northeast coastal environment. Weather cycles simulating summer and winter weather conditions were developed based on Boston data. Field aging was also done for one year. Field and lab aging correlate well exemplifying the validity of the multistress weathering performed in the lab.

INTRODUCTION

Weathering and photodegradation of polymeric materials cause billions of dollars of product damage and power outages each year [1]. Insulator damage includes color change, strength loss, cracking, chalking, erosion, and arcing. To make an informed choice of insulators, it necessitates knowing the weathering of polymeric insulators under actual field conditions.

The United States of America is positioned in the belt of disturbed westerly winds [2]. This causes the weather in most regions of the USA, for much of the year, to be affected by cyclonic storms, or depressions, with their associated warm and cold fronts. Most of these depressions move across the country from west to southwest to east to northeast (NE), bringing clouds, precipitation and disturbed, changeable weather.

The NE region can experience changeable weather around the year with moderate amounts of precipitation throughout the year. Towards the north, the winters are wet and snowy. The weather is also more extreme in other aspects: day to day changes of temperatures can be great and individual falls of rain and snow are often heavy. Daily sunshine hours on the coast at lower levels inland, average from four to five in winter and as much as nine or ten in summer. Locally, sunshine may be reduced on the coast by fog both in summer and winter; winter fog may reduce the sunshine inland.

AGING CYCLES

Summer and winter weather cycles have been developed to test insulators in their actual in-service environment per EPRI Florida and Idaho cycles [3-5]. Meteorological information, such as max/min temp, UV radiation intensity, number of clear days, amount of precipitation, has been used for this purpose [2, 6]. Boston was selected as the representative city for the NE.

The aging cycles essentially identify the duration, and sequence of various stresses of interest. The weather cycles for Boston are as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Days</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>Target Temperature* (°C)</td>
<td>34.6</td>
<td>18.6</td>
</tr>
<tr>
<td>UVA Exposure (h)</td>
<td>0-12.75</td>
<td>0-6.5</td>
</tr>
<tr>
<td>Rain</td>
<td>5 times, 30 min each time</td>
<td></td>
</tr>
<tr>
<td>Salt Fog (h)</td>
<td>5000 µS/cm</td>
<td>8-8.5</td>
</tr>
<tr>
<td>Clean Fog</td>
<td>8 times, 30 min each time</td>
<td></td>
</tr>
</tbody>
</table>

*The temperatures include +11°C towards the heating of the insulator surface.

EXPERIMENTAL

28 kV (Line) Silicone rubber, distribution/dead end insulators were used for both field and lab aging. Complete details of the insulator, the environmental chamber, and the experiments are available in the 1999 CEIDP paper [7].

FIELD AGING
On April 1999, two insulators were installed in the NE region, by the Town of Hull Municipal Lighting Plant, MA, at the following locations, at 13.8 kV (Line).

1. Pole #3 Manomet Avenue
2. Pole #4 Channel Street

Insulator one was removed on May 2000 to compare with the lab aged insulator. This is done by calculating ESDD, NSDD, visual observation, hydrophobicity classification, and a material diagnostic technique, ESCA.

RESULTS & DISCUSSION

(1) Leakage Current & Surface Charge Data- Lab

Fig. 1 shows the cumulative charge during one year aging in the multistress chamber. Insulators 1 and 2 have almost the same amount of charge in the beginning, and slowly start to have some differential as time increases. This is in line with previous results published, where similar variation was obtained between two insulators in the same cycle [2]. The charge changes are in steps similar to EPRI results.

Fig. 2 shows the number of leakage current pulses accumulated for one year of aging. The magnitudes of current pulses are mostly around 1 mA. The peak mA was also detected and there were peaks up to 30 mA occasionally. But no arcing was observed. It might be an isolated event, for instance, when the salt fog is on, initially there will be some current bursts.

(2) Visual Observation

The field aged insulator looked very lightly contaminated. The contamination was very uniform as it is usually observed in the field [8]. There is a slight color change compared to the lab aged insulator and compared to the virgin insulator. This can be attributed to the natural exposure of the field insulator compared to the lab insulator. The lab insulator had patches of white areas where salt was dried off, but no significant color change.

(3) ESDD/NSDD Data

The ESDD and NSDD of the field and lab insulators were calculated in the traditional method [9]. Table 1 shows a comparison of the lab and field data. Both ESDD and NSDD are low, which is expected for an aging period of one year.

The ESDD was 0.0032 mg/cm² for the field sample and 0.0027 mg/cm² for the lab sample. This is a very good correlation between the field and the lab samples, especially considering the nature of the problem.

The NSDD of the field insulator is 70.7.10⁻⁶ mg/cm² and that of the lab sample is 7.8.10⁻⁶ mg/cm², an order of magnitude difference between the two. However the values are very low. Considering the sensitivity of these measurements, it can be safely concluded that there is good correlation between the lab and field aging.

Table 1: ESDD & NSDD of Field & Lab Samples

<table>
<thead>
<tr>
<th>Item</th>
<th>Field</th>
<th>Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESDD, mg/cm²</td>
<td>0.0032</td>
<td>0.0027</td>
</tr>
<tr>
<td>NSDD, mg/cm²</td>
<td>70.7.10⁻⁶</td>
<td>7.8.10⁻⁶</td>
</tr>
</tbody>
</table>
(4) Hydrophobicity Classification

Lab Insulator
Fig. 3 shows the lab insulators immediately after the test in the chamber and the field insulator tested for HC. Fig. 3a shows insulator #1 and Fig. 3b shows #2. It can be seen that the water droplets on both insulators look almost similar. Using STRI guide [10], the hydrophobicity classification (HC) is HC1(-) or HC2.

Field Insulator
An ordinary spray bottle filled with DI water, was squeezed 10 times on to the insulator. From the nature of the water droplets and wetting, the HC was identified. A look at the field aged insulator (Fig. 3c) indicates that the HC is almost the same as that of the lab aged insulator, that is HC1(-).

Fig. 3d shows a close up view. There were some big droplets, causing it not fall in the HC1 classification. There are some dry portions where a patch of salt can be seen.

(5) Material Diagnostic Technique

ESCA (XPS) was performed on the field and lab aged samples. The spectra were obtained using Kratos XSAM 800 using a Mg source. Figs. 4 and 5 show the results obtained.

Fig. 4 shows the atomic composition of the surface using wide scan. It can be seen that the field and the lab samples show similar composition.

Fig. 5 shows the Si2p narrow scan obtained for the lab and field samples. Table 2 shows a comparison of silicon, carbon and oxygen atoms for the field and lab samples. The HV portions of the field and lab samples correlate well for Si and C. The Si and C in the LV spectra of the field sample are 50% of that of HV, while that of the lab sample do not have such relationship.

Both in the lab and field samples, there is a change in the HV data compared to the LV data, indicating that different phenomena may be occurring in those portions.

The Si, C and O peak shifts indicate the change in the atomic composition due to aging compared to that of the virgin. A comparison with previous studies indicates that this might due to hydroxyl groups, making it more hydrophilic relative to the virgin [11].

<table>
<thead>
<tr>
<th>Item</th>
<th>Field</th>
<th>Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si2p (eV)</td>
<td>1.33</td>
<td>1.49</td>
</tr>
<tr>
<td>Cls (eV)</td>
<td>1.52</td>
<td>1.135</td>
</tr>
<tr>
<td>O1s (eV)</td>
<td>-0.18</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Table 2: ESCA Peak Shift For Field and Lab Samples

**SUMMARY**

- Multistress accelerated aging of polymeric insulators simulating actual service conditions is demonstrated for the NE environment.
- Summer and winter weather cycles were developed based on Boston meteorological data.
- One year lab aging compares well with one year field aging, indicating the validity of the weather cycles developed.
- This chamber can enable comparing long term performance of a number of insulators at a given environment or comparing performance of a given insulator under varying service conditions.

**REFERENCES**

ACKNOWLEDGMENTS

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(a) Insulator 1  (b) Insulator 2  (C) Field Sample  (d) big Droplets - Lab

Fig. 3: Hydrophobicity Classification of Lab and Field Samples

(a) Field  (b) Lab

Fig. 4: XPS Spectrum Comparison of Field and Lab Samples
Fig. 5: Si2p XPS Spectrum Comparison of Field and Lab Samples

(a) Field Sample

(b) Lab Sample