Investigation of Surface Modifications in ADSS Cables
Due to Dry Band Arcing

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Abstract – In the present work dry band arcing phenomena on ADSS (All-dielectric-self-supporting) cables has been studied using chemical analysis. To determine the degradation level and behavior after IEEE 1222 Electrical surface degradation test, several test methods, such as Oxidative Induction time (OIT), Differential Scanning Calorimetry (DSC), Thermogravimetric Analysis (TGA), Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscope (SEM) analysis were used. The results of these physico-chemical analyses reveal that, dry band arcing IEEE 1222 test standard is a surface degradation test method which only affects the sample surface get carbonized. Copyright © 2010 Praise Worthy Prize S.r.l. - All rights reserved.

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I. Introduction

The information transmitted with fiber optic cables is reliable and external electrical field has no any affect to the signal. ADSS cables are mainly used on HV transmission lines operating at voltages 150 kV or more [1] and installed 3-6 m below the high voltage conductors [2]. Since the cables are exposed to the strong electrical field environment, failures are usually caused by electrical phenomena, such as corona, sparking and dry band arcing. Discussions and previous studies indicate that the failure of ADSS cables caused by dry band arcing in high electric field environments is a common problem in industry [1],[3].

This paper reports the surface degradation level of HDPE ADSS cables which are subjected to dry band arcing test according to IEEE 1222 test standard [4]. Physical and/or chemical changes on the insulator surfaces have been analyzed using OIT/DSC, TGA, FTIR and SEM analysis.

II. Experimental

II.1. Test Samples and Facility

The test samples were prepared by cutting the ADSS cables used in electrical industry in pieces with a maximum length of 457 mm. Both of the ends were sealed to prevent water penetration. Two electrodes made of aluminum foil are wrapped on the sample with a distance of 102mm between each other [2].

All tests were performed in Istanbul University in HV test laboratory. Figure 1 shows the electrical connection diagram of the ADSS cable test facility.

The samples were suspended in a fiberglass chamber and periodically sprayed by salt water. Simultaneously the samples are energized up to 25 kV by a high voltage test transformer (220V/33kV, 400 VA). The voltage of the transformer is regulated by an autotransformer, where the current through sample is limited up to 1.3 µA by a RC circuit, connected in series.

A 50 ohm resistance is connected in series to sample. The voltage across the 50 ohm resistance, which is proportional to the current flowing through the sample, is measured and recorded using a digital oscilloscope. The RC limiting impedances, R and C are selected as 13.1 MΩ and 200 pF respectively and both of them are installed on a board at the side of the tank next to the test sample. Insulators are placed at the top of the fiberglass tank. Bare wires or insulated cables connect the transformer to the limiting impedances and to the test samples.

The components of the flow control equipment consist of a spraying system, a salt water storage bucket, pump, control valve, filter, flow meter, rain nozzles, and plastic tank with test samples. Salt water is mixed in a plastic bucket and pumped to 3 parallel connected spray nozzles. The flow rate is adjusted by the control valve.
The flow rate and water salinity are kept constant during the test. Water with 1% salinity is used for spraying the cables. The energized samples are sprayed by salt water for 2 minutes and allowed to dry for 28 minutes. During the drying period, the high voltage produced arcing on the samples [2].

When the cable is new, the water forms discrete droplets on the hydrophobic surface of fiber optic cable. The high voltage produces sparking between these water droplets. After several cycles the surface of the sample becomes hydrophilic; hence a continuous water layer appears on the jacket surface which eventually leads a current flow and dry bands. The flashover of the dry band produces hot spots on the surface of the specimen, which can seriously decrease the service life of the cable [5].

Figure 2 shows the typical current waveform of a dry band arc. If the arc is visible, the level of arc current is limited by the RC impedance, but if the arc is extinguished (not visible), the current is near zero due to the high impedance of the dry band.

![Typical current waveform during the dry band arcing](image)

Tests were performed under normal room temperature (23°C) and humidity conditions. In order to dissolve salt completely in water, a sufficient quantity of the salt solution was prepared 24 hours prior to the test start-time.

The cable samples were installed in the test fixture and made the required electrical connections. The control valve was set to attain the desired flow rate from the nozzles. The energized cables were wetted for 2 min and allowed to dry for 28 min using the time-controlled pump. Dry-band arcing was observed mostly during the drying period.

Periodically the test samples were investigated after each cycle. The cable is classified as failed if the jacket was punctured. Some of the cables were ignited during the test. Once the cable catches fire, the test was stopped and the destroyed cable was removed. The remaining cables were re-energized. The number of on/off cycles to failure was recorded. The current (voltage on 50-ohm resistor) was periodically checked to verify proper operation and recorded. After each test, the cables were swapped among the different locations in the chamber.

II.2. Physico-Chemical Tests

The aim of physico-chemical tests is to determine the effect of electrical tests on cable material in detail. During electrical tests on ADSS cable, initially cable jacket is degraded; however if the degradation continues the fiber inside the cable is destroyed as well, which as a result causes the data communications to get corrupted. In this study, by using physical and chemical tests, the temperature and burning behavior of insulation material used in the cable jacket is investigated. To determine the degradation level and melting point DSC analysis has been performed [6],[7]. In order to investigate the effect of burning process TGA analysis is done both on virgin and damaged samples. Before and after dry band arcing test, to specify the ADSS cable jacket's chemical condition, small pieces taken upon the degraded surface of the samples are subjected to FTIR analysis. The variation on the sample surface can be identified by their chemical bonds with these results. Visible deformations on sample surfaces are verified with scanning electron microscope (SEM) by a scale of 50 μm [8].

Differential scanning calorimetry (DSC) provides valuable results for characterizing the thermal and thermo-oxidative properties of polyethylene base polymers. The technique measures heat flow into or out of a sample as the sample is heated, cooled or held isothermally. The measurement of oxidative induction times (OOT), which relies on basically measuring heat flow given to sample versus time, is a valuable characterization test for assessing the long-term stabilities of ADSS cable materials. By using a Mettler Toledo Model 822 DSC, measurements were carried out isothermally and with heating/cooling rates of 10 °C/min. Heating range was chosen between 20 to 400 °C and the sample mass was selected as approximately 10 mg to 15 mg [9].

FTIR analysis is used for identifying chemicals that are either organic or inorganic. The wavelength of the absorbed light is a characteristic of the chemical bond which can be seen in this annotated spectrum. In this study to understand the burning process and identify the types of chemical bonds of HDPE ADSS cable FTIR analysis were done both on virgin and damaged samples. For measurements Perkin Elmer Precisely Spectrum One FTIR spectrometry was used. Infrared (IR) spectra were recorded in KBr pellets in Nujol mulls. To specify the bonds in HDPE cable the spectra is chosen between 4000 to 450 cm⁻¹.

Thermogravimetric analysis (TGA) is a type of testing method that is performed on samples to determine variation in weight versus variation in temperature. The weight loss curve can be used to specify the point at which degradation starts and for explaining the burning process. This test also used to define the level of inorganic and organic components in material. In our measurements, SI10 EXSTAR 6000 TG/DTA 6300 model type equipment was used. Temperature was increased with a rate of 10°C between 400°C and 750°C.
Finally scanning electron microscope (SEM) is used to take the images of the sample surfaces in micro scales. In this present work pictures of the ADSS cable samples before and after dry band arcing process were taken with JSM 5600 scanning electron microscope on specimens sputtered-coated with a thickness of 20 nm layer of gold.

### III. Results

#### III.1. OIT/DSC Analysis

For OIT/DSC analysis, when taking the sample mass upon the damaged area, due to the technical limitations the damaged mass comes together with part of the specimen which is not damaged during the dry band arcing test. The melting behavior of virgin and damaged sample results is given in Figure 3. Since HDPE is a crystallize polymer, there is only one peak which simulates the melting point at 130°C, hence similar results are taken for damaged and virgin samples, only with a difference of the exothermic energy level. With differential scanning calorimetry analyze a noticeable difference couldn't seen between the virgin and damaged sample, because of the analyze technique.

![Fig. 3. Melting behavior of virgin and damaged samples](image)

As shown in Figure 4, within 20 minutes (1500 cycles) the heat flow for non-damaged virgin samples settles down to a stable level. However for damaged samples the increase in heat flow continues even after the melting point which is experimentally not observed for virgin sample. Polymer melt temperatures were used to verify the temperature scale under oxidative operational conditions. A poor OIT reference polymer is considered with an OIT of < 8 min and a fair polymer has a OIT reference of 10 to 20 min. [10]. From measurements it is possible to claim that the tested ADSS cable has a fair OIT reference.

Figure 4 also shows that the inorganic particles (from carbonized part) in damaged sample still continue their burning process although most of the organic particles are already burned. The difference in OIT curve for virgin samples can be concluded as these inorganic parts are connected to organic parts of the commercial HDPE and burn with the organic particles.

![Fig. 4. OIT results for virgin and damaged samples](image)

#### III.2. FT-IR Analysis

FTIR analysis is used to determine the type of chemical bond at a certain frequency. According to FTIR analysis the OH bonds (3500- 3000 cm⁻¹) and OH group was not observed for damaged sample which can be seen in virgin samples (Figure 5). However in damaged samples, a peak is observed at 1900- 1600 cm⁻¹ which shows the carboxyl C=O bonds. With this analysis it is shown that during the arc process cable surface get heated which eventually lead these bonds to be broken and let the C=O bonds formed.

![Fig. 5. FTIR results for virgin and damaged samples](image)

#### III.3. TGA Analysis

The temperature behavior of virgin samples after TGA analysis given in Figure 6. Here degradation starts at 300 oC and continues through 450 oC. As seen from Figure 7 the degradation process for damaged samples occurred step by step. The results taken from TGA analysis
support the OIT/DSC results. The damaged samples which have inorganic particles degraded step by step.

In Figure 6 the first y-axis shows the virgin ADSS cable's mass variation versus temperature where the second y-axis is given for the Differential Thermal Analyses (DTA) variation. For virgin samples the degradation starts and ends between 400°C-450°C. This behavior also supports the TGA and FTIR analysis for this sample. Although the degradation in damaged sample supports the TGA and FTIR analysis too, for damaged samples the degradation process starts at 350°C and ends at 470°C (Figure 7). This temperature interval for damaged sample is very large compared to virgin sample. This behavior can be related to the OH bonds and alcohols as seen from FTIR analysis.

![Fig. 6. TGA analysis result for virgin sample](image1)

![Fig. 7. TGA analysis for damaged samples](image2)

III.4. SEM Analysis

Before dry band arcing test, all samples taken from the HDPE cables were studied under SEM analysis. The SEM picture taken upon from the sample has no protrusions or any other micro defects which will be a reason to start the dry band arcing process (Figure 8).

The damaged area after dry band arcing process is shown in Figure 9. Here the place where the degradation occurs enlarged 25 times. Blasted part of the polymer is like a water channel. When the channel picture is enlarged (Figure 10(a)) 500 times, the spongy carbonized area becomes clear. The picture taken upon the folded area shown in Figure 10(b) is different than the incinerated channel. Here the micro protrusions were observed. We assume that during the dry band arcing process polymer get heated then heated part folded near the water channel.

![Fig. 8. SEM picture of virgin sample, enlarged 500 times](image3)

![Fig. 9. SEM picture of damaged sample, enlarged 25 times](image4)

![Figs. 10. SEM picture of damaged sample, enlarged 500 times](image5)

(a) picture of damaged area upon the folded area
(b) picture of damaged zone upon the tracked area

Picture taken upon the folded part of the ADSS cable is given in Figure 10(a) the micro protrusions are clear. In Figure 10(b) on the water channel, carbonized, spongy like structure is left after the dry band arcing process.
IV. Conclusion

In this study it has been tried to explain that one of the popular artificial aging test of dry band arcing process on ADSS cables is a surface degradation process. IEEE 1222 test method is used as dry band arcing test standard. Samples which were affected by dry band arcing test are compared with virgin samples by using several physicochemical test methods. Initially to understand the burning process under oxidative conditions OIT/DSC analysis is performed. The results indicate that the commercial virgin sample has a fair OIT reference. However DSC analyze couldn’t make a sensible difference between virgin and damaged samples. This is because here when taking samples upon the surface of the ADSS cable, not just the carbonized area come also the cable which is not damaged is also come to analyze.

With FTIR analyze the infrared spectroscopy of virgin and damaged samples is taken. For damaged samples OH bonds are gone during the dry band arcing process because of the heat produced by electrical arcs. After this arcing process sample surface get carbonized and C-O bonds are come which also proves the damage on this zone. At the later stage, in order to evaluate the burning process more precisely, TGA method, which can operate at temperatures higher than the DSC, is used. The heating of analyze is extended up to 750°C, which allowed to indicate the difference in damaged and virgin samples more precise. The carbonized surface after dry band arcing test is burned step by step not just with a clear cut as seen in virgin samples. This behavior is attributed to burning of carbonized parts on damaged ADSS cable. After dry band arcing process observable changes occur on the ADSS cable sample. To investigate physical change on sample surface, SEM analyze is done. Initially virgin sample surface is studied by enlarging 500 times with a 50 µm scale. It is observed that virgin sample surface is smooth and has no micro defects which can cause damage rather than water flow between electrodes. After dry band arcing test damaged zone is removed carefully and studied under SEM microscope. One of the observable differences is that between high voltage and ground electrodes a channel is occurred where the conductive liquid flows. The other difference is the folded insulation observed next to the water channel. By enlarging these two different areas it is possible to see that upon the channel surface, carbonized spongy like surface is occurred after dry band arcing test. For the folded surface near the channel like structure, protrusions and micro defects are formed.

This study on ADSS cable shows that dry band arcing IEEE 1222 test standard is a surface degradation test method which only effects the sample surface get carbonized. In this study the severe degradation conditions which continues through to conductor in the cable material is not take into consideration.

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References


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