Behavior of Low Density polyethylene Aged Under UV Radiation.

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Abstract: Low density polyethylene (LDPE) is a usual material used within high voltage insulation systems. Like all polymers, this material may be aged after working under high voltage for a long time. The ageing process of this material is essentially caused by external factors. The exhibition to ultraviolet (UV) radiation is one of these factors. This work investigates the effect of this constraint on the electrical and mechanical properties of LDPE after UV-ageing. This paper includes the sample preparation process, the ageing of samples under identical conditions for up 380 h and finally the analysis of electrical and mechanical properties after the ageing process. The obtained results show that these properties are considerably affected by the ultraviolet radiation

Keywords: polyethylene, dissipation factor, ultraviolet radiation.

1 Introduction

Transport of electrical energy from power plant to clients can be made in urbanized area with underground cables. In such cable the insulation part is assured by polymeric materials [1]. Since 1940, polyethylene (PE) has been and continues to be widely used in the manufacture of cables, due to its low cost, high resistance to chemical degradation and easy recycling. This excellent insulation material, commonly used in high-voltage cables, is characterized by a very high dielectric strength and low dielectric losses [2].

Low density polyethylene (LDPE) is widely used as power cable insulation because of its excellent insulating and mechanical performance. However, the properties of the polymer degrade when it is subjected to environmental stresses such as UV radiations [3]. Indeed, crucial degradations in the dielectric, mechanical, physico-chemical properties of the polymer are caused by UV irradiations [5].

Recent studies have reported that UV radiations can lead to several changes in polymers dielectric properties such as breakdown strength, dielectric loss factor, dielectric constant, and mechanical characteristics [4].

As a consequence of these changes, the insulating systems lifetime will significantly decrease [4].
This paper provides experimental results of mechanical properties (elongation at break and tensile strength) and dielectrics properties (dielectric loss factor tgδ and dielectric constant **ε**') of virgin and irradiated LDPE.

2 Experimental setup

2.1 Materials

LDPE plates of 130×130 mm with 2 ± 0.2 mm thickness have been obtained from DFDA-4850NT granules produced by the Dow Chemical Company.
DFDA-4850 NT is a thermoplastic compound designed to be compatible with power cable insulation compounds, it can withstand higher extrusion melt temperatures than vulcanizable melt extrusion temperatures is in the range of 116 to 140°C.It is 2.0 melt index, 0.92 density, high pressure LDPE resin that has been stabilized with an antioxidant system.

2.2 UV ageing

The UV ageing of LDPE samples was carried out in an accelerated UV-ageing chamber. The samples irradiation is accomplished using eight low-pressure vapor 36 watt fluorescent lamps characterized by wavelength irradiation ranging mostly (98%) from 350 to 400nm. The lamps were placed 10 cm above the LDPE's top surface, every 48 hours, a set of samples are removed to undergo the various tests. The maximum ageing time is 384 hours.

2.3 Mechanical tests - Elongation at break and tensile strength measurement

The mechanical tests were carried out to determine the elongation at break, tensile strength as well to assess the general relaxation behavior of the material under mechanical load.
According to IEC 60811.1.1 (International Electrotechnic Committee) standard, the elongation at break and tensile strength tests is performed using a Schnek-Trebel testing machine.
Sample in the form of dumbbell-shaped of 5 cm length were tested under a crosshead speed of 50 mm/min, at ambient temperature. Elongation at break and tensile strength were measured simultaneously.

2.4 Dielectric tests

The dielectric measurements (dielectric loss factor and dielectric constant **ε**') were performed with an LCR-meter (Instek-LCR 817 type); able of measuring the materials properties at frequencies ranging from 12 to 10 000Hz, the measurement voltage of the apparatus did not exceed 2V.

2.4.1 Dissipation factor and permittivity measurements

The dissipation factor is obtained by direct lecture on the apparatus, while dielectric permittivity was calculated using the formula:

$$\varepsilon' = \frac{C.e}{S.\varepsilon_0}$$

Where C is the capacitance of the sample sandwiched between electrodes, e is the spacing between electrodes which equal to the sample thickness, S is the electrode area.

$$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F}.m^{-1}$$

2.4.2 Breakdown test

The AC breakdown test system can provide power frequency AC voltage continuously adjustable from 0 to 5
0 kV. The flat electrode of 6 mm diameter and the LDPE square specimen of 60mm × 60mm are all immersed in the transformer oil to avoid flashover. The breakdown tests are performed at room temperature under evenly increasing voltage. The increasing rate of the AC voltage is 2 kV/s and for each ageing point six specimens were tested.

3 Results and discussion

3.1 Dielectric properties

3.1.1 Dielectric strength

The evolution of the dielectric strength as a function of the UV exposure time is shown in the figure 1.
As can be seen from the figure 1, the material dielectric strength, decreases gradually with the increasing of the UV exposure time. This property decreased from 33.37 kV/mm to 26.44 kV/mm only after 144 h of UV exposure and reached the value of 28.45kV/mm at the end of exposure.

This variation of the dielectric strength may be attributed to the ionization of the material and the creation of charge carrier inside the material.

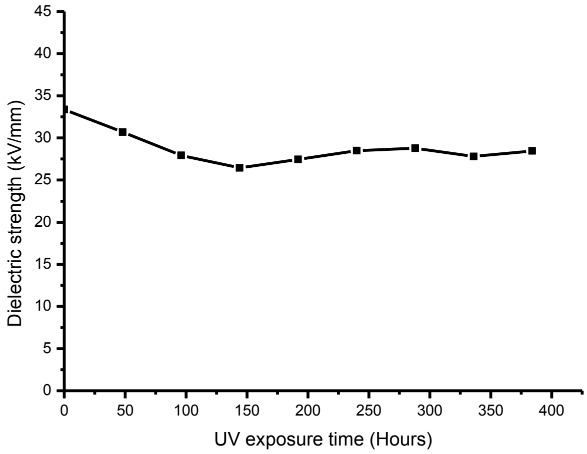

Fig.1. évolution of the dielectric strength as a function of the UV exposure time.

3.1.2 Dielectric dissipation factor

The dielectric dissipation factor tanδ as a function of UV exposure time and frequency is shown respectively in the figures 2 and 3.

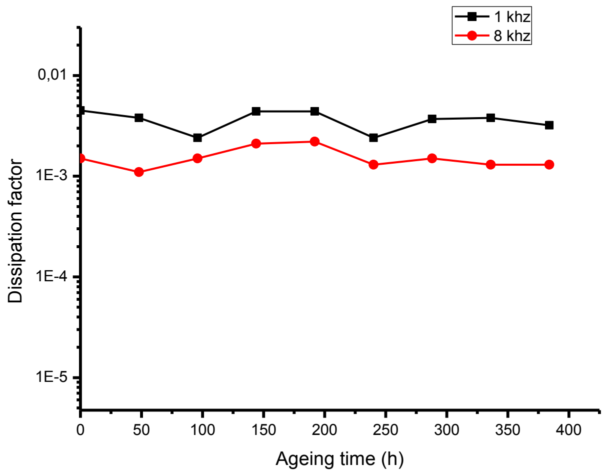

Fig.2. Evolution of dielectric dissipation factor as a function of UV exposure time.

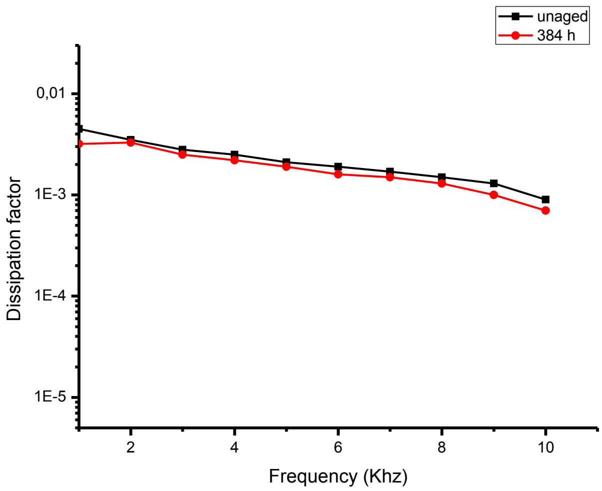

Fig.3. Evolution of dielectric dissipation factor as a function of frequency.

The dissipation factor measurement is an important tool for testing the reliability of high voltage cable insulation. It can serve as a representative indicator of other insulating material properties relevant to the ageing phenomena [6].
In figure 2, we observe that tanδ does not presents significant variations according to ageing time. The appearance of occasional peaks can be explained by probable movements of segments of the LDPE macromolecules [7].
The obtained results in the figure 3 show that tanδ decreases according to frequency. This behavior can be assigned to the polarization, namely space charge polarization, caused by charges accumulation on the dielectric interface / electrodes [8].

3.1.3 Dielectric constants

The dielectric constant ε' as a function of ageing time and frequency is shown respectively in the figure 4 and 5.
The variation of ε' as a function of the aging time shows that, in the range 0 to 100 h, ε' increases considerably and then stabilizes. These results may be explained by the changes in the structure of the polymer caused by ageing.
Figure 6 shows that dielectric constant ε' presents no monotonic variation according to frequency. We observe that this property is pratically constant both before and after ageing.

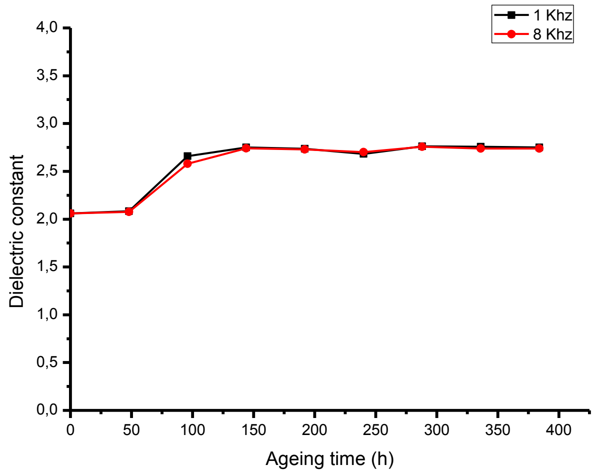

Fig.4. Evolution of dielectric constant as a function of ageing time.

3.2 Mechanical properties - Tensile strength and elongation at break

The mechanical properties evolution is respectively shown in figures 6 and 7.

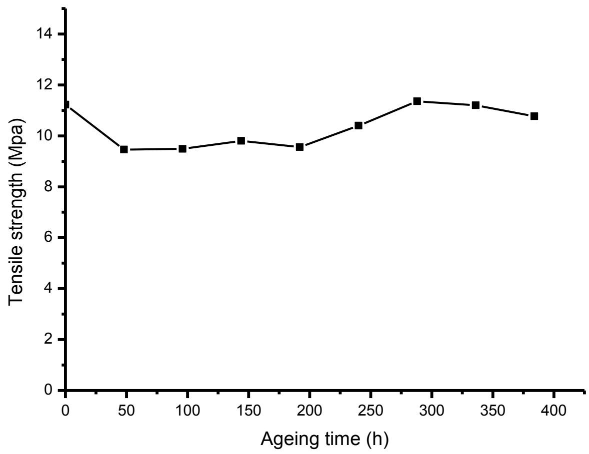

Fig.5. Evolution of tensile strength according to ageing time.

As can be seen from the results, both tensile strength and elongation at break decrease with UV exposure.

Firstly, the figure 6 shows that the tensile strength decreased from 11.23 MPa to 9.46 MPa only after 48 hours of UV exposure , between this instant and 192 hours this property presents a very slight variation. Next, the tensile strength increased extensively until reaching a peak (11.36 MPa) at 288 hours, after that this property decreased slightly and reaches the value of 10.77 MPa at the end of the exposure.

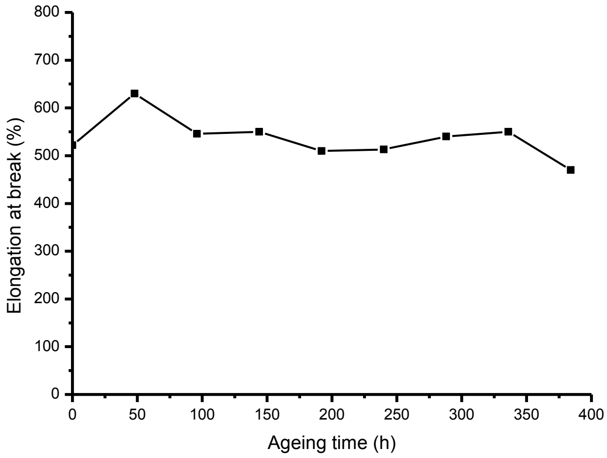

Fig.6. Evolution of elongation at break according to ageing time.

Secondly, the figure 7 shows that the elongation at break increased significantly and reaches a peak (630 %) at 48 hours of exposure, after that, this property decreased until reaching 470 % at the end of the exposure.
This behavior is similarly reported in the literature [9, 10].These variations can be attributed to the LDPE insulation photo-degradation which is followed by chemical changes such as chain scission. These alterations lead to the decrease of both amorphous region size and molecular weight. Indeed, these modification cause weakness and embrittlement of the material [4].

4 Conclusion

In this work we have presented results of mechanical and dielectric studies in low density polyethylene, subjected to UV constraint.
The obtained results show that UV radiation affects considerably the LDPE characteristics. It has been reported that all the caracteristics (elongation at break, tensile strength, dissipation factor, dielectric constant and dielectric strength) are clearly sensitive to UV constraint. Generally, it was showed that UV irradiations leads to serious decrease of some LDPE insulation properties.
In order to make a better evaluation of the insulation degradation, long duration tests followed by physico-chemical analyses would be made.

5 References

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