Impact of Thermal Constraint on The Low Density Polyethylene (LDPE) Properties

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Abstract: Nowadays, Low density polyethylene (LDPE) is increasingly used as voltage cable insulating material. Owing to its excellent mechanical and electrical properties, LDPE may undergo degradation under service conditions. The focus of this work is to investigate the eventual impact of temperature on the LDPE characteristics. For this purpose, dielectric properties (Breakdown strength, Dielectric loss factor and dielectric constant); and mechanical characteristics (tensile strength and elongation at break) were studied. Aim of this work is the investigation of possible changes in some Low density polyethylene (LDPE) properties subjected to thermal constraint. The obtained results show that all the properties are widely affected by thermal constraint.

Keywords: polyethylene, dissipation factor, thermal constraint.

1 Introduction

Since their appearance, polymeric materials have been widely used in many fields. Thanks to their excellent insulating properties, these materials are increasingly used in the electrical engineering [1, 2].The huge field application of polymers increased academia and industrial interest, which brought to the underlining of new features and possible applications of these materials.

Since 1940, polyethylene (PE) has been and continues to be widely used in the manufacture of cables, due to its low cost. This excellent insulation material, commonly used in high-voltage cables, is characterized by a very high dielectric strength and low dielectric losses [3]. However, it is well known that this material may undergo dramatic effects on its properties when exposed to stress conditions.

Temperature is one of the most aggressive constraints which can affect the basic characteristics of the insulation [4]. Any polymeric material gradually degrades during its

life application particularly under the effect of temperature. Under heat conditions, thermal ageing occurs and causes irremediable failure of the cable insulation.
Thermal ageing is an irreversible chemical and /or morphological change that may reduce strongly the material properties and produce a limit to the effective service life of the electrical power cable by thermal breakdown mechanisms [5].
Aim of this work is the investigation of possible changes in some Low density polyethylene (LDPE) properties subjected to thermal constraint. To monitor this work, mechanical tests namely tensile strength, elongation at break and dielectric measurements such as dielectric loss index, dielectric permittivity and dielectric strength have been performed.

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. The number of sample tested for dielectric breakdown is 6 while, this number is between 6 and 9 samples for mechanical tests.

2.2 Thermal ageing experiments

Thermal ageing experiments were carried out in a thermo-ventilated oven that could maintain the average temperature ± 2°C. The temperature of ageing was 90°C. Square samples of 60×60 mm (dielectrics measurements), and dumbbell-shaped samples of 50 mm length (for mechanical test) were vertically suspended and exposed to the thermal constraint during 2500 hours inside the oven. After each 500hours of exposure, samples were removed and subjected to the different tests.

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 Dielectric loss index and permittivity measurements

The dielectric loss index is the product of the dielectric permittivity and the dissipation factor, which is obtained by direct lecture on the apparatus, while 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.

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

2.4.2 Breakdown test

The AC breakdown test system can provide power frequency AC voltage continuously adjustable from 0 to 100 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 Mechanical properties - Tensile strength and elongation at break

The mechanical properties evolution, are respectively shown in figures1and 2.
Figure 1 shows that tensile strength decreases from 11.23 MPa to 10.34 MPa only after 500 hours of thermal constraint exposure. After this instant the characteristic presents a very slight variation until the end of exposure.

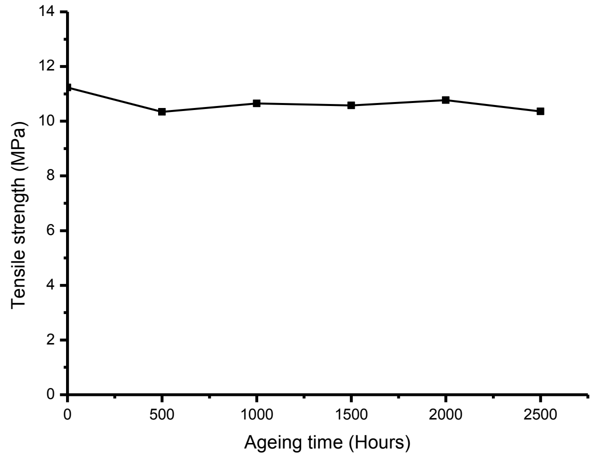

Fig.1. Evolution of tensile strength according to ageing time.

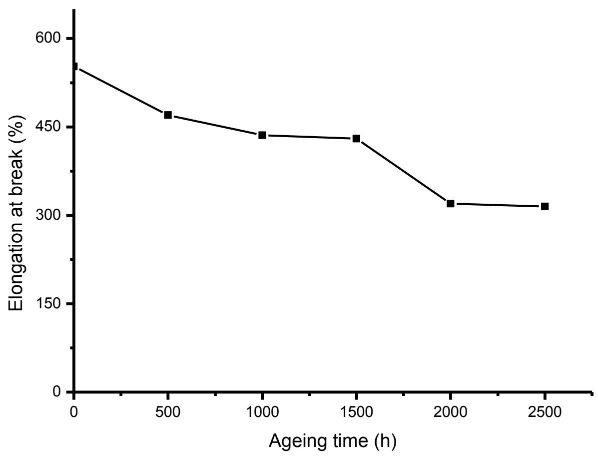

Fig.2. Evolution of elongation at break according to ageing time.

Figure 2 shows that the elongation at break decreases considerably with the increasing of the thermal constraint exposure time, where this property attain the value of 315 % at the end of thermal constraint exposure, while this value was 552 % in the beginning of exposure.

This decrease of the two properties with the increasing of thermal constraint exposure can be essentially explained by the thermo-oxidative degradation of the material which is followed by chains scission which the speed increase with the increasing of temperature [6, 7].

3.2 Dielectric properties

3.2.1 Dielectric loss index

The dielectric loss index evolution as a function of ageing time and frequency is shown respectively in the figures 3 and 4.

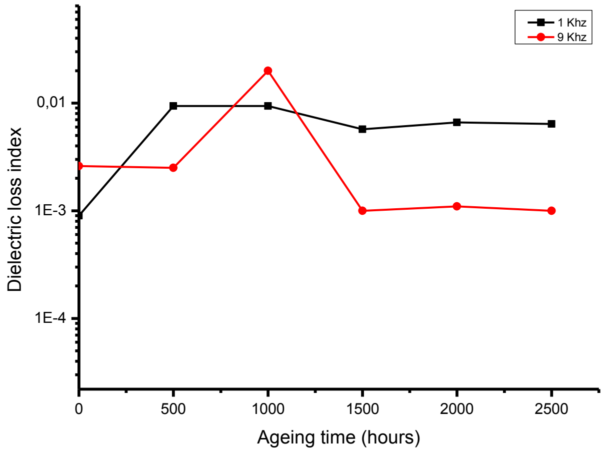

Fig.3. Evolution of dielectric loss index as a function of ageing time.

As can be seen from the results shown in figure 3, the dielectric loss index presents non monotonic variations. It is well known that the dielectric loss index is the product of the relative permittivity and the dissipation factor. The evolution of this property, tells us about the power lost in the polymer [8]. Therefore, any increase or decrease of the dielectric loss index corresponds to an increase or decrease of the power lost in the material [9-11].

Figure 4 shows that the dielectric loss index decreases with frequency increasing. This decrease is more accentuated in low frequencies which can be explained by the originating dipolar relaxation phenomenon in the material [8].

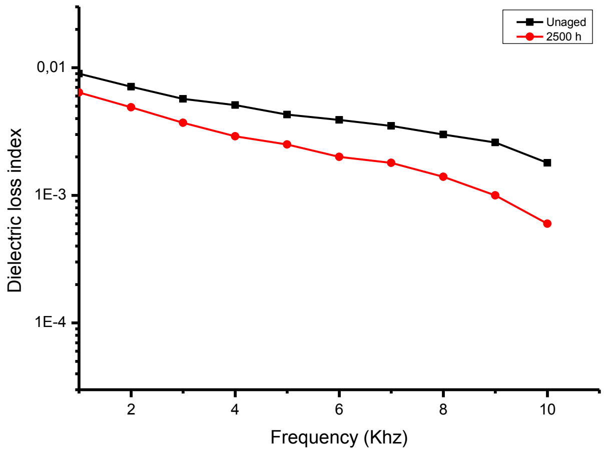

Fig.4. Evolution of the dielectric loss index as a function of frequency

3.2.2 Dielectric constant

The dielectric constant variation as a function of ageing time and frequency is respectively shown in the figures 5 and 6.

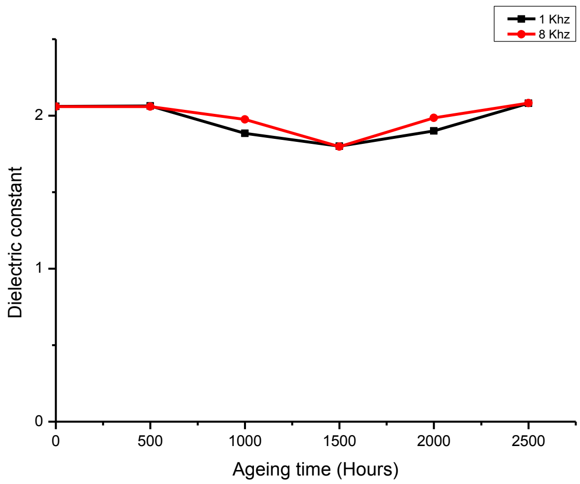

Fig.5. Evolution of dielectric constant as a function of ageing time.

Figure 5 shows that the dielectric constant does not change practically with the aging time [12]. The property value was 2.06 in the beginning while this value doesn't exceed the value of 2.081 in the end of the thermal constraint exposure.

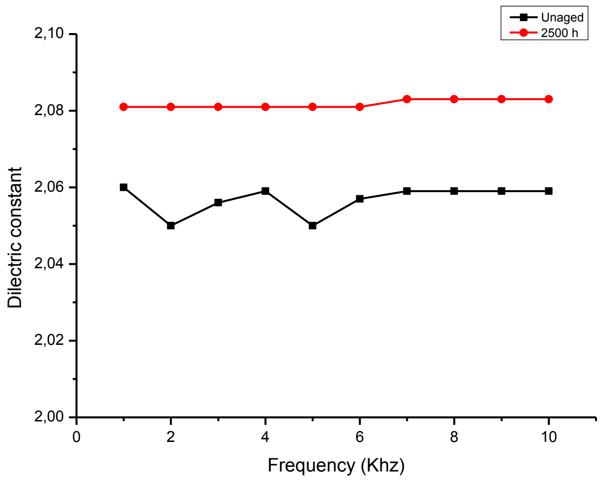

Fig.6. Evolution of dielectric constant as a function of frequency

The figure 6 shows that, the dielectric constant presents no monotonic variation according to frequency. We observe that this poperty is pratically constant both before and after ageing.

3.2.3 Dielectric strength

The evolution of the dielectric strength as a function of ageing time is shown in the figure 7.

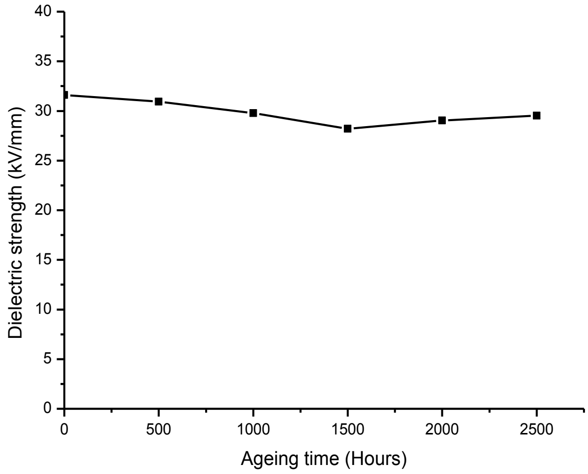

Fig.7. Evolution of the dielectric strength as a function of the ageing time.

As can be seen from figure7, the material dielectric strength, decreases gradually with the increasing of the ageing time. This property decreased from 31.61 kV/mm to 28.20 kV/mm only after 1500 h and reached the value of 29.52kV/mm at the end of exposure.
This variation may be attributed to the thermo-oxidative degradation which is followed by ionization of the material and creation of charge carrier inside the material.

4 Conclusion

This paper presents results obtained from research carried out with the purpose of characterizing LDPE degradation under thermal aging. These results show that the thermal constraint affects considerably the dielectric and mechanical properties of the material. It has been reported that all the material characteristics (elongation at break, tensile strength, dielectric loss index, dielectric constant and dielectric strength) undergo a significant variations.
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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