Central Power Research Institute
Vol. 14(2)/143-147, December 2018
ISSN (Print) : 0973-0338
DOI : 10.33686/pwj.v14i2.144712
Power Research

Study of the Effects of Fluorescence UV Radiation and Low Temperature on PVC Cable Outer Sheaths

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Abstract

Underground Polyvinylchloride (PVC) sheath power cables are exposed to the atmospheric condition during installation. Depending on the atmospheric conditions the cable sheath is facing extreme environmental stresses such as ambient temperature (high and low), direct sunlight (UV) radiation, rain or water accumulation etc. The life of PVC cables is reduced by being exposed to harsh environmental conditions and can subsequently damage the unprotected cables. This work is aimed to the study of the effects of UV radiation and low temperature on PVC cable outer sheaths. Three commercially available PVC cable were chosen for the study. UV exposed PVC insulations become brittle after UV exposure and in low temperature. UV exposure eventually results in material degradation, diminishing the performance characteristics of the material. Thermogravimetric Analysis (TGA) was used to characterize the thermal behavior of PVC cable insulation materials before and after UV ageing. In addition, Fourier-transform infrared spectroscopy (FTIR) was used to reveal the chemical processes that caused the UV degradation of the sample. A good agreement between results of the methods was found. Exposure to low temperature resulted in a reduction in stiffness of the polymeric structure caused embrittlement which transformed the PVC structure from a flexible material capable of undergoing large strain elastic behaviour to a stiffer material with higher yield behaviour.

Keywords: Cold Elongation, UV Radiation, FTIR, PVC, TGA

1. Introduction

Polyvinyl Chloride (PVC) is one of the most widely used plastics that has been extensively used in the wire and cable industry as the main constituent of insulation and sheathing due to its very properties like good electric insulation, desired mechanical properties, flame retardant effect, easy to process, etc.,[1]. Power cables laid in underground are normally PVC sheathed and which are not faced to atmosphere normally. But the cable drum lay in atmosphere for longer period of time during installation process and the material faced extreme weathering condition. PVC is a very hard plastic material. Therefore, plasticizer is added to PVC to makes it flexible, processable, resilient and easy to handle[2]. Apart from that weathering stabilizer, fillers, flame retardant are also added in PVC during compounding process. Long duration weathering leads to change in chemical composition and structure of the base polymer as well as other additives materials.

Weathering mostly occurred in PVC due to the UV component of the sunlight and temperature. The sun is the principal natural source of UV radiation on the earth. It emits radiation, consisting of electromagnetic rays including ultraviolet A (UVA) in the radiation range of 315-400 nm and ultraviolet B (UVB) in the radiation range of 280-315nm. The energy of a photon corresponds to UVA and B are 3.10 to 3.94eV and 3.94 to 4.43eV respectively and this enourmous energy can cause most bond dissociation in polymers. As a consequence, development of cracks, brittleness and color changes in the exposed cable insulation are reported many times by the utility companies even within one year of laying which leads to poor electrical properties[3]. Another reason of crack development and brittleness is low temperature. In this paper, the effects of 313nm fluorescence UV radiation

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and low temperature on the mechanical, physical and thermal properties of PVC cable outer sheath were discussed.

2. Materials

Three commercially available PVC cable outer sheaths removed from the cable were considered for this study and designated as PVC1, PVC2 and PVC3.

Figure 1. Accelerated weathering tester using fluorescent UV lamps.

3. Experimental Study

3.1 Fluorescent UV Ageing

Three commercially available PVC cable sheath samples were subjected to accelerated Fluorescence UV exposure facility with irradiance according to ASTM G 154 – 2016 in Accelerated weathering instrument from Q-Lab Corp i.e. a chamber using UVB-313nm fluorescent lamps with a set irradiance value of 0.71 W/m2 at 313 nm, with a chamber temperature of 60±3°C with 4hrs dry and 4hr water spray at a chamber temperature of 50±3°C per cycle for 500 hrs. The instrument is shown in Figure 1.

3.2 Thermogravimetric analysis (TGA)

The TGA was performed with TGA Q500 model of TA Instruments, USA operated in the dynamic mode from room temperature to 700 °Cat heating rates of 10 °C/min in inert medium (Nitrogen gas medium) with nitrogen gas flow rate of 60ml/min and initial weight of the each specimen was around 20mg.

3.3 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR analyses of PVC samples were measured in Laser injected Thermo scientific FTIR analyzer.

3.4 Mechanical Properties

Tensile Strength and Elongation was measured as per IS:10810 (Part 7)-1984 (RA 2016) by using Universal Testing Machine, with load cell of 500N at 250mm/min rate of separation of jaw with a gauge length of 20 mm. Low temperature Tensile Strength and Elongation was measured at -25±2°C.

4. Results and Discussion

4.1 Physical Properties

Figure 2. Colour change of PVC1 before UV ageing.

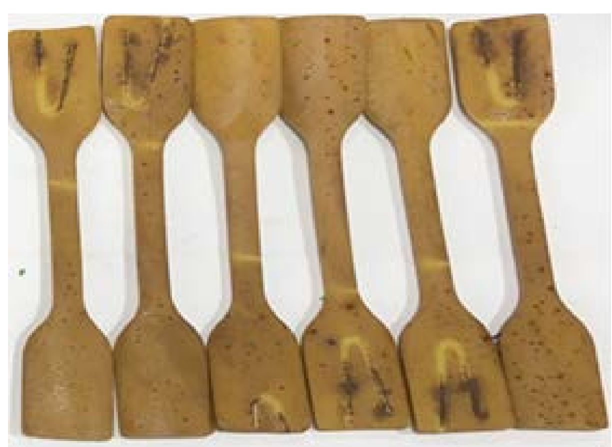

Figure 3. Colour change of PVC1 after 500 hrs UV ageing.

The colour change from yellow to brown was observed after 500 hrs UV ageing as shown in Figures 2 and 3 due to oxidation process.

4.2 TGA Analysis

TGA was used to evaluate the degradation properties of commercially available PVC cable sheath designated as PVC1, PVC2 and PVC3. Figure 4 and 5 show typical TGA curves and the corresponding derivative thermogravimetric (DTG) curves obtained at a heating rate of 10 °C/min. TGA thermograms correspond to two stage degradations indicating that more than one component is lost from the samples in the tested temperature range. Figures 4 and 5 depict the TG and DTG results of the PVC samples before and after UV ageing measured during heating from room temperature to 700°C at the rate 10 °C min^{-1} in nitrogen. It was observed that maximum mass loss occurred in the range 290 to 320 °C depending on samples. It is assumed that dehydrochlorination from the PVC backbone and evaporation of some additives (e.g. plasticizer) had been taken place at this first stage of degradation[2]. Second stage of degradation occurred at 400 to 525 °C corresponds to total burning/degradation of the residual polymer backbone[4]. Maximum degradation temperature of PVC1 is 312 °C whereas; the same for PVC2 is 290°C. TGA/ DTG after 500 hrs UV ageing also confirms that PVC1 is thermally more stable than the other two.

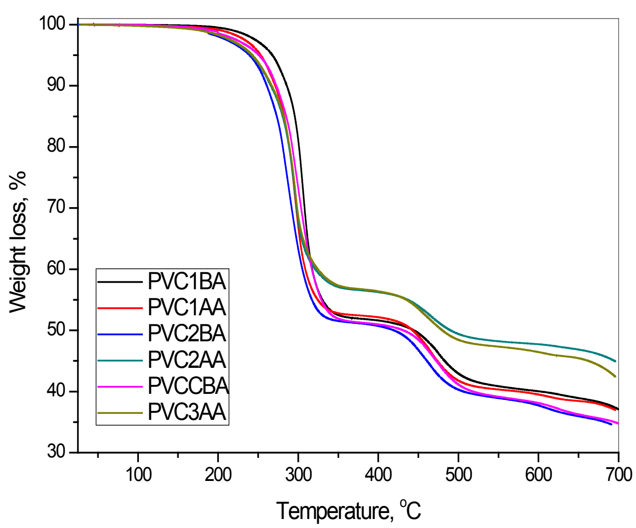

Figure 4. TGA Curve of PVC cable outer sheaths before and after 500 hrs UV ageing.

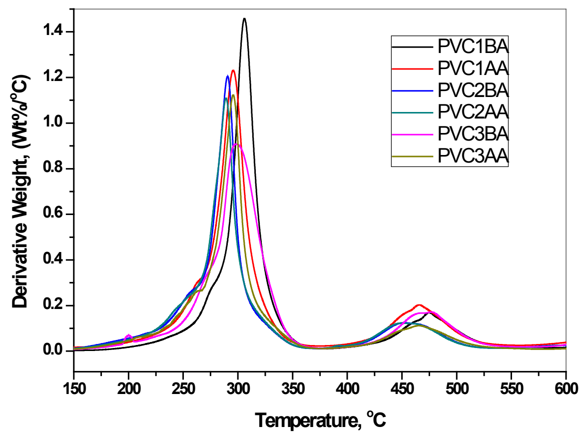

Figure 5. DTG Curve of PVC cable outer sheaths before and after 500 hrs UV ageing.

4.3 FTIR Analysis

FTIR spectra as shown in Figures 6 and 7 for PVC1and PVC2 respectively, reveal some chemical functional groups of the cable sheaths before and after ageing. For before ageing samples, the spectra in the range of 800- 600 cm^{-1} indicate C-Cl vinyl group. The spectra were sharp and great at around 1420 cm^{-1} indicates a hydrocarbon group (C-H) of CH_2 [5]. The spectra at 1720-1730 cm^{-1} indicates a carbonyl (C = O) group. Spectra at around 2970 - 2920 cm^{-1} indicates aliphatic C-H. These results indicate that cable sheaths are composed of vinyl chloride, ester, methyl and methylene (aliphatic hydrocarbons). But after ageing the intensity of C-Cl vinyl group, hydrocarbon group (C-H) of CH_2 and aliphatic C-H decreased abruptly. The carbonyl peak shifted to lower wavelength range of 1635 cm^{-1}. All these phenomena confirmed the polymeric degradation due to 500 hrs Fluorescent UV ageing.

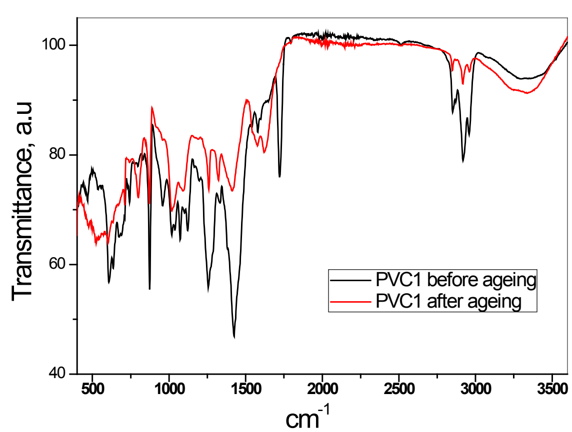

Figure 6. FTIR of PVC1 before and after 500 hrs UV ageing.

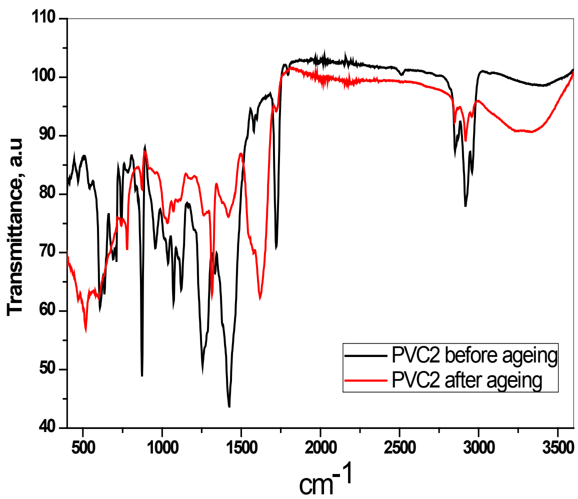

Figure 7. FTIR of PVC2 before and after 500 hrs UV ageing.

4.4 Mechanical Properties

Tensile Strength and Elongation behaviors of the samples before and after UV ageing were presented in Tables 1 to 3. Tensile Strength and Elongation of PVC1 retains good. But other two samples became very stiff after ageing due to loss of plasticizer. Cold elongation results given in Table 4 that indicated that at -25°C the molecular movement of the plasticizer became restricted caused material stiffness[2,3].

Table 1. Tensile strength and elongation of PVC1 before and after 500 hrs UV ageing

PVC1	Before UV radiation	After UV Radiation	Retention (%) Observed Value
Tensile strength (N/mm^2)	18.06	15.58	86.26
Elongation at break (%)	375.45	281.7	75.02

Table 2. Tensile Strength and Elongation of PVC2 before and after 500 hrs UV ageing

PVC2	Before UV radiation	After UV Radiation	Retention (%) Observed Value
Tensile strength (N/mm^2)	13.78	12.61	91.51
Elongation at break (%)	301.35	86.08	28.56

Table 3. Tensile Strength and Elongation of PVC3 before and after 500 hrs UV ageing

PVC3	Before UV radiation	After UV Radiation	Retention (%) Observed Value
Tensile strength (N/mm^2)	15.38	13.84	89.99
Elongation at break (%)	406.45	211.90	52.13

Table 4. Tensile Strength and Elongation of PVC cable sheaths at -25°C

	PVC1	PVC2	PVC3
Tensile strength (N/mm^2)	18.20	22.00	19.65
Elongation at break (%)	43.88	37.876	49.82

5. Conclusion

The experimental investigations presented in this paper reveal that the physical properties of the PVC cable sheaths degrade drastically after 500 hrs Fluorescent UV ageing. The low-temperature deterioration is dominated by loss of plasticizer by migration. All the experiments confirm that PVC1 is more stable after 500 hrs UV ageing than the other two. Plasticizer is a very important component of PVC cable outer sheath compounding. The properties of PVC cable outer sheath depend on the quality of the Plasticizer used during service. Therefore, selection of proper plasticizer is very important.

6. Acknowledgement

The authors wish to thank the management of Central Power Research Institute (CPRI), Bangalore for permitting to publish this paper. The facility provided by Dielectric Materials Division, CPRI is greatly acknowledged.

7. References

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