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## **In-Service and Weather Station Exposure of Grey and Black PVC Covered Conductors**

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### **ABSTRACT**

The weathering characteristics of grey and black PVC-covered conductors from several manufacturers were investigated after long-term exposure under both in-service and weather station conditions. Visual examination and physical testing revealed significant deterioration of light grey and dark grey conductor samples provided by one manufacturer. Accelerated weathering tests confirmed these results. Molecular weight distributions as determined by gel-permeation chromatography indicated that surface degradation by chain scission of the PVC resin had occurred in the deteriorated samples. The prime cause of this deterioration is believed to be the absence of suitable UV blocking properties, in these cases insufficient quantities of titanium dioxide.

### **INTRODUCTION**

The State Electricity Commission of Victoria uses plasticized PVC covered conductors for the purpose of supplying consumers with electrical energy from the nearest power line pole. For many years,

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carbon black was considered to be the only satisfactory pigment to protect PVC in exterior use owing to its superior UV blocking properties. However, in 1971 Griffiths [ 1 ] reported on the weathering properties of orange colored PVC and indicated that satisfactory formulations for plasticized PVC were becoming available in colors other than black.

It seemed desirable to use grey instead of black polymer insulated conductors for consumer connection because the grey one operates at a temperature 5-10°C lower than the black, and it is aesthetically more pleasing. Therefore, trial batches of light grey (designated LG) and dark grey (DG) colored plasticized PVC insulated conductors were purchased from three cable companies (designated 1, 2, 3) for analysis and long-term trials under in-service and weather station conditions. The specification for these trial batches included the following main points:

- |                     |                                      |
|---------------------|--------------------------------------|
| 1. Plasticizer      | Based on phthalate esters only       |
| 2. Stabilizer       | Tribasic lead sulfate (TBLS)         |
| 3. Titanium dioxide | Pigment grade, 10 parts php of resin |

This paper reports the results of visual examination, physical, and chemical testing after 6 years of exposure. The reasons for failure of some samples are discussed in relation to the original specification.

## EXPERIMENTAL

Samples of the grey, and for comparison, a black PVC insulated conductor (designated 2BL) were erected for in-service trials (house connections) at Sunshine, a light industrial area in Melbourne. Similar sets of samples were exposed on racks at a weather station at Merbein, an inland country area which receives sunshine in excess of 3000 h/year. Lengths of each conductor were retained in closed cupboards to serve as control samples, and to provide specimens for accelerated aging.

The samples were visually examined for appearance, color, and gloss retention at approximately yearly intervals. The same criteria were used for evaluating the results of accelerated aging under UV light [ 2 ].

Standard methods were followed in determining physical properties [ 3, 4 ], and a simplified version of the standard method [ 5 ] was used for the analysis of components as follows.

The samples were dissolved in tetrahydrofuran (THF), and the inorganic components separated by centrifugation. The PVC was precipitated with methanol and separated by filtration. From the filtrate, the plasticizer was recovered by evaporation. The components were weighed, then identified by IR spectroscopy. Titanium

TABLE 1. Results of Visual Examination of Plasticized PVC-Covered Conductor Exposed at Merbein

Cumulative solar radiation (MJ/m <sup>2</sup> )	Cumulative rainfall (mm)	Comments
3,825	170	Appearance, color, and gloss unchanged on all samples
9,675	700	Incipient fading on Samples 1LG, 3LG, 3DG, reduced gloss on 2BL
23,560	1,560	1LG, 1DG: still glossy 2LG: loss of color, losing gloss; 2DG: losing gloss 3LG: losing color and gloss, exudation on top surfaces 3DG: exudation on top surface 2BL: loss of gloss, chalky top surface
25,260	1,730	1LG, 1DG, 2LG, 2DG: no change 3LG, 3DG: dirt and sand adhering to exuded material on top surface; 2BL: unchanged
33,160	1,960	All samples: no further change.
42,750	2,380	Continued loss of color on 1LG, 2LG, and 3LG. Continued loss of gloss on all samples, total loss of gloss on 3LG, 3DG, and 2BL

<sup>a</sup>At the last inspection after just 6 years exposure, 1LG and 1DG were in very good condition. Samples 2LG, 2DG, and 2BL were in good condition (under the chalky surface of 2BL the insulation was still intact). Samples 3LG and 3DG were in very poor condition.

dioxide content was determined on separate sample aliquots by colorimetry.

For the estimation of molecular weight distribution, the top surface of the insulations was scraped to a depth of 1 mm and the material dissolved in UV grade THF for gel-permeation chromatography (GPC). Chromatograms were obtained using a Waters Associates HPLC system incorporating a Model 401 differential refractometer, a Model 440 UV absorbance detector, and a Model 730 data module. Three  $\mu$ -Styragel columns ( $1 \times 10^4$ ,  $1 \times 500$ , and  $1 \times 100$  Å) in series were used.

TABLE 2. Visual Examination of Plasticized PVC-Covered Conductor Exposed in Service at Sunshine

Cumulative amount of solar radiation (MJ/m <sup>2</sup> )	Cumulative rainfall (mm)	Comments
3,590	380	Foreign matter and dust present on all samples. 3LG, 3DG show loss of gloss and exudation, particularly on top surface, and adherence of dust and other particles
10,760	1,610	3LG, 3DG no further change. 1LG, 1DG, 2LG, 2DG still glossy. 2BL loss of gloss on top surface
16,100	2,320	3LG, 3DG condition deteriorating fast. 1LG, 1DG, 2LG, 2DG loss of gloss commenced. 2BL complete loss of gloss on top surface
21,325	2,820	No further change at either inspection
26,580	340	
31,850	4,300	Samples 1LG, 1DG still have some gloss, 2LG, 2DG almost no gloss. 3LG, 3DG dust and dirt adhering to top surface, particularly where exudation took place. 2BL top surface dull and chalky.

## RESULTS

Results of visual examination of the conductors exposed at Merbein and Sunshine are given in Tables 1 and 2. Exudations were observed on Samples 3LG and 3DG at both places. However, at Sunshine this occurred 6 months after installation for domestic service, while at Merbein exudation on the same brand of conductor only appeared 3 years later. This indicated that exudation of the plasticizer was promoted by the possibly higher temperatures prevailing in the current-carrying conductor at Sunshine.

Accelerated aging of unexposed specimens under UV light resulted in exudations on Samples 3LG and 3DG after 10 d. Prolonged exposure (41 d) produced no change in Samples 1LG, 1DG, and 2BL and only discolorations in Samples 2LG and 2DG.

Physical tests performed on samples after 6 years of weathering showed reduced breaking strength (83% of control) and reduced

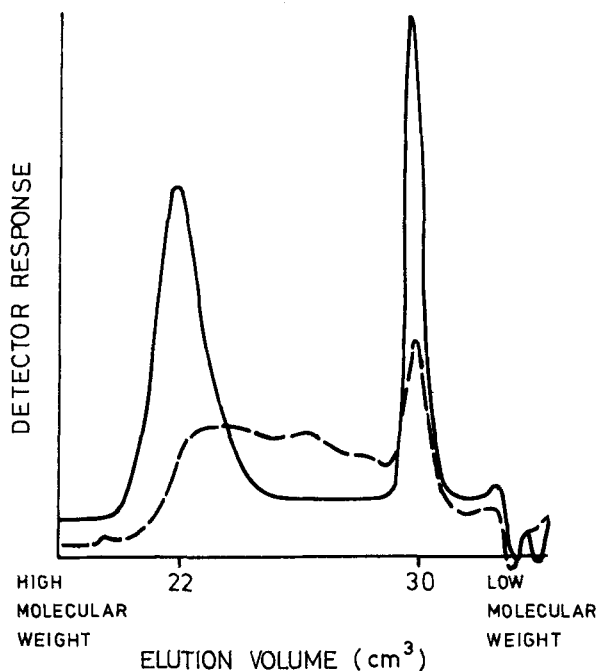


FIG. 1. GPC chromatograms obtained by differential refractometer for Sample 3LG. Control (—) and exposed (- -).

elongation for Samples 3LG and 3DG. These two samples also failed in the cold bend test and showed increased capacity to absorb water after weathering. The physical properties of the other brands did not change markedly.

Chemical analysis revealed no significant difference between exposed and control samples. In terms of compliance to specification the following were noticed:

- a. Samples 2LG and 2DG contained dibasic lead phosphite (DBLP) in addition to the required TBLS stabilizer
- b. The stabilizer in Samples 3LG and 3DG was a basic lead sulfate, other than the TBLS found in the other brands
- c. Samples 3LG and 3DG contained only 2.6 parts of  $\text{TiO}_2$  per 100 parts of resin, i.e., much less than the specified 10 pphp of resin

GPC chromatograms of Samples 1LG and 2BL indicated no significant differences between the molecular weight distributions of exposed and control samples. This proved the virtual absence of PVC degradation after 6 years of weathering.

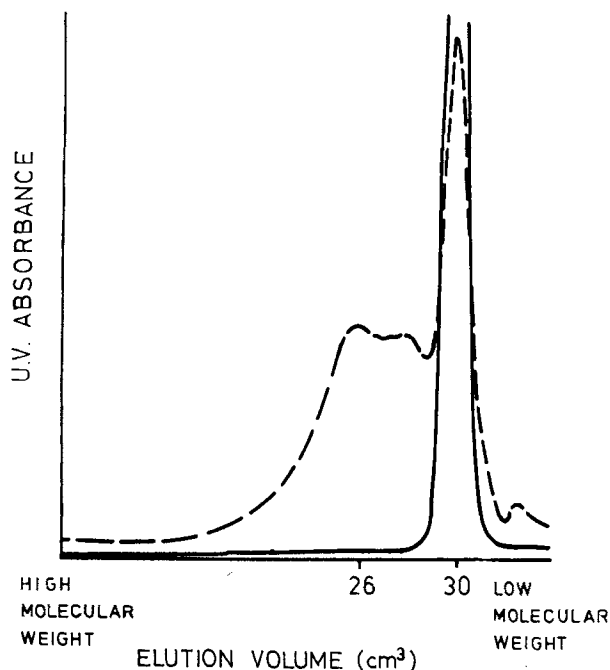


FIG. 2. GPC chromatograms obtained by UV absorbance detector at 254 nm for Sample 3LG. Control (—) and exposed (- -).

Figures 1 and 2 show the molecular weight distribution of Sample 3LG before and after weathering. The effect of exposure at Merbein can be clearly seen on both chromatograms. In Fig. 1, well-defined peaks indicate the composition of the control sample; the polymer component at 22 cm<sup>3</sup> elution volume and the low molecular weight plasticizer peak at 30 cm<sup>3</sup>. The exposed sample has a lower average molecular weight than the control and an increased dispersity (between 22 and 30 cm<sup>3</sup> elution volume), indicating that surface degradation in the form of chain scission has occurred during exposure.

The lower molecular weight material produced as a result of this degradation has a significant UV absorbance at 254 nm, whereas the control sample shows no UV absorbance at 254 nm apart from the plasticizer peak (Fig. 2). This suggests the presence of groups such as C=C, C=O, and/or conjugated systems in the exposed polymer which were not present in the control.

## DISCUSSION

Numerous papers deal with the thermal and photochemical degradation of PVC resins. Results of a study of the weathering problem published in 1955 [6] already emphasized the need for correct PVC formulations. The advantages of TBLs and DBLP stabilizers were recognized; the former as primarily a processing stabilizer, the latter as additional protection against light and/or oxidation. However, the present study did not confirm the enhanced stability expected from the presence of DBLP in Samples 2LG and 2DG. Both in accelerated and natural aging modes these samples were slightly inferior to 1LG and 1DG.

It has been shown that dehydrochlorination is the dominant reaction in thermal degradation while autoxidation plays a major role in photochemical attack [7]. Production of free radicals on the surface of polymers during weathering, generating peroxy radicals from reaction with oxygen, is well known [8]. It is postulated [9] that oxygen quenches energy-rich polyenes and reacts in the singlet state, yielding carbonyl groups which themselves absorb light and accelerate the photoreaction.

Our experimental results suggest two possible causes for the degradation of Samples 3LG and 3DG:

- a. Insufficient titanium dioxide loading
- b. Inefficiency of the stabilizer (which in these samples was not considered to be TBLs)

The surface degradation induced by solar radiation of the samples (3LG, 3DG) exposed at Merbein is clearly indicated on the GPC chromatograms. This photochemical deterioration manifested itself in exudation of the plasticizer, cracking of the surface, and failure to pass physical tests. Similarly, early degradation of Samples 3LG and 3DG in accelerated aging under UV light seems to confirm the view that photochemical processes have occurred. The accepted protection against photochemical degradation is incorporation of titanium dioxide pigment in the PVC resin. In these two samples insufficient amounts of the pigment were incorporated. However, contribution of thermal effects to the degradation cannot be ruled out in view of the uncertain composition of the stabilizer in Samples 3LG and 3DG.

## CONCLUSIONS

Visual examination of weathered, PVC-insulated conductors can easily detect the signs of degradation. Changes in physical properties, particularly the decrease in elongation, may help to assess the degree of deterioration.

Changes in the molecular weight distribution of Samples 3LG and



3DG indicated that surface degradation by chain scission has occurred during natural aging at Merbein. The products of degradation absorbed UV radiation at 254 nm, indicating unsaturation and, possibly, oxidation.

The prime cause of the observed degradation is believed to be the insufficient protection against UV light; that is, the low titanium dioxide content of the affected samples.

The observed tendency toward thermal degradation was attributed to the unsatisfactory stabilizer system in Samples 3LG and 3DG.

Given satisfactory formulation, light-colored, plasticized PVC insulated conductors may replace black ones for outside use.

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