PREDICTION DE LA DURée DE VIE DE MATERIAUX ISOLANTS À BASE D'EPR ENTRANT DANS LA COMPOSITION DE CABLES ELECTRIQUES

LIFE PREDICTION OF ELECTRICAL CABLE EQUIPMENT EPR INSULATING MATERIAL

Pages: 7
SYNTHÈSE :

Les câbles des centrales nucléaires subissent, en conditions d'utilisation, des contraintes thermiques et irradiatives. Une étude des influences respectives de la température et des irradiations donne une évaluation précise des processus de dégradation du matériau d'isolation de câbles EPR (caoutchouc éthylène propylène). Toutefois, afin d'être vraiment complète, l'étude prend en compte les effets combinés irradiation-température.

Les principaux mécanismes de la dégradation de ces matériaux ont été étudiés par l'analyse des propriétés sensibles au vieillissement.

Afin de prédire le comportement à long terme, notamment au-delà de 30 ans, nous avons mis au point un modèle de prédiction reposant sur l'évolution de l'elongation à la rupture, critère le plus sensible au vieillissement en fonction du temps, de la température et des irradiations.

L'originalité de cette recherche repose sur le fait qu'il a été possible de quantifier les effets de synergie sur la base de l'analyse de la constante de vitesse de réaction déterminée par le modèle cinétique.

Les conclusions de l'étude suggèrent que la dégradation, au bout de 50 ans, de l'EPR employé comme matériau d'isolation de câbles électriques est faible dans l'environnement d'une centrale nucléaire.
EXECUTIVE SUMMARY:

Cables in nuclear power stations are submitted to thermal and radiation stresses in their operating conditions. A study of the respective influences of temperature and radiation affords an accurate appreciation of the degradation processes of the insulating cable material (EPR: Ethylene Propylene Rubber). However, to be completely comprehensive, the study takes into account of the effects of the combined stresses irradiation-temperature.

The main processes of degradation of these materials were studied by analysing sensitive properties to aging.

In order to predict long-term behaviour, particularly beyond 30 years, we attempted to devise a prediction model based on the variation of the ultimate elongation, the most sensitive criterion to aging. The conclusions of the study suggest the degradation of the EPR as electrical cable insulators insulating material is low in nuclear power stations environment after 50 years.

This study provided an opportunity of modelling the behaviour of the ultimate elongation versus time, temperature and irradiation. The originality of this research is based on the fact that it was possible to quantify the synergy effects on the basis of the analysis of the rate constant determined by the kinetic model.
Introduction

EPR (Ethylene propylene Rubber)/CSPE (Chlorosulfonated Polyethylene) LOCA (Loss Of Coolant Accident) cables are critical components for life cycle managements. In order to extend their service life in nuclear power stations (PWR), Electricité de France decided to study the main degradation effects of these materials in term of physico-chemical changes versus time and environmental contraints. On the basis of the experimental results, a kinetic equation expressing the dependence of ultimate elongation on temperature, dose rate and time was obtained. It allowed us to predict the life expansion of these components in power stations.

In this paper, the insulating materials (EPR) results are proposed.

Experiments

Materials:

The cables concerned have a 3*1mm² copper conductors.

Experimental conditions:

Accelerated aging tests on cables (30cm length) were studied under the following conditions:

<table>
<thead>
<tr>
<th>Phenomenon</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal aging</td>
<td>135-125-110-100-90-70°C Gas : air in a ventilated oven</td>
</tr>
<tr>
<td>Irradiation</td>
<td>β source 60Co Dose rate : 10-100-500-100-2200 Gy/h Total dose : 5-10-20-50-75-100 kGy Temperature : 40°C Gas : air</td>
</tr>
<tr>
<td>Thermal irradiation</td>
<td>β source 60Co Dose rate : 100 Gy/h Total dose : 10-20-50-75-100 kGy Temperature : 50-90°C Gas : air</td>
</tr>
</tbody>
</table>

The duration of the aging process ranged from several days to several months (2 years).

Mechanical testing:

After aging, the EPR insulation materials were carefully stripped, and jackets and copper conductors removed. Mechanical characteristics of the tubular samples were determined by means of a testing machine (Instron - Model 1193) according to the NFT 46-002 conditions. Samples were strained at ambient temperature (20°C) at 45 mm/mn.

Experimental results[1][2]

*Thermal stresses*

The thermal aging of EPR mainly brings about the oxidation of the materials after the induction period. The oxidation is reduced by the presence of anti-oxidants. After the induction period, the oxidation process causes a significant degradation of the material.
Irradiation stresses

A kinetic change is observed around a critical dose rate \( (d_c) \) of 500 Gy/h.

* if \( d > d_c \) : the degradation process is controlled by the oxygen diffusion and cross-linking predominates in the center of the material.
* if \( d < d_c \) : the oxidation process leads to a chain scission and predominates over the cross-linking process. In this case, the degradation is homogenous.

The existence of \((d_c)\) was observed when analysing the behaviour of the ultimate break versus time. This one increases considerably under high dose rate, whereas it remains virtually unchanged under low dose rate (Fig 1).

![Fig 1](image)

**Behaviour of the EPR ultimate break at different dose rates versus time.**

Combined effect temperature-irradiation

When cables are exposed to dose rates of 100 Gy/h, the degradation is considered as homogeneous and is not controlled by the oxygen diffusion. According to the operating conditions, when temperature factor is taken into account, one of the main conclusions is that the temperature has only a limited influence on the lifetime.

Kinetic model. Lifetime prediction[3]

In order to assess the life duration of cables, a kinetic model based on the expression of the ultimate elongation variation versus time has been developed. We have used the kinetic equation for aging suggested by Menlow and Dakin [4], eg :

\[
\frac{de}{dt} = -K e^\beta
\]

where \( e \) is the property whose time variations are correlated to aging process of the material, \( t \) is aging time, \( K \) the pseudo-reaction rate constant, and \( \beta \) the overall order of the degradation process.

This law supposes that \( \beta \) is the same in the studied condition ranges. This assumes that only one predominant process causes degradation in the given condition range and that ultimate elongation is directly related to this process.

The resolution of this integral for different values of \( \beta \) and at the boundary conditions \((e = e_0 \text{ at } t = 0)\) leads to the expressions :

\[
\beta = 0 \quad \left(\frac{e}{e_0}\right) = 1 - Kt
\]

\[
\beta = 1 \quad \left(\frac{e}{e_0}\right) = \exp(-Kt)
\]

\[
\beta \neq 0, \beta \neq 1 \quad \left(\frac{e}{e_0}\right) = (1 + (\beta - 1) K t) \left(\frac{1}{1-\beta}\right)
\]

The analysis of the curves shape \( e/e_0 \) leads to a positive \( \beta \) value.

Each experimental aging curve was fitted according to equations (2) by using the Sigmaplot software [5], which gives the corresponding \( K \) and \( \beta \) values.

Then, the dependance of the rate constant versus temperature and dose rate was determined.

Modelling results

The parameters of the model were determined according to the expression of \( e/e_0 \):

\[
\left(\frac{e}{e_0}\right) = (1 + (\beta - 1) K t) \left(\frac{1}{1-\beta}\right)
\]

The simplest hypothesis consists in considering that the rate constant is defined as the sum of the thermal and irradiative contributions[6][7][8] :

\[
K = K_{th} + K_I
\]

\[
K_{th} = K_{th0} \exp \left(\frac{-E_a}{RT}\right)
\]

\[
K_I = K_{I0} d e^\gamma \exp \left(\frac{-E_I^0}{RT}\right)
\]

The results obtained for EPR are listed on the following table [9][10] :
The analysis of these results is on good agreement with the experimental part:

- at low dose rates, the degradation seems to be different because the $\beta$ value is not equal to the $\bar{\beta}$ obtained for high dose rates,
- the kinetic model finds a transition for a dose rate of about 500Gy/h (slope break observed in a diagram $\ln K_{\tau} = f(I)$ at $T_1$),
- the dependence of $K_{\tau}$ obeys to the Arrhenius law in the range of temperatures considered and allows us to extrapolate to the lowest temperatures (typically 40°C).
- evidence suggests that, within the exposure conditions in power stations (30-40°C, 0.01-0.001 Gy/h), radiolysis is the predominant mechanism which leads to the material degradation.

The knowledge of the six parameters ($\alpha$, $\beta$, $K_{\tau}$, $K_{\bar{\tau}}$, $E_a$, $E_{a'}$) allows us to give the general expression of the ultimate elongation versus time in the conditions of exposure in nuclear plants. The simulation is based on the lowest initial value admitted for the qualification [11] procedure (200%). It leads to the ultimate elongation value reached after 50 years of exposure (Fig 2). In any case, the lifetime criterion (50% absolute) is never reached before 50 years.

### Conclusions

This study provided an opportunity to describe the behavior of the ultimate elongation versus time, temperature and irradiation. The originality of this research is based on the fact that it was possible to quantify the influence of the combined effect of temperature and irradiation. We could describe with a relatively high degree of accuracy the predominant mechanism and the ultimate elongation values for EPR according to exposure conditions.

### Acknowledgments

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### References

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