NUCLEAR CABLES: LIFETIME SIMULATION AND NEW APPROACH FOR THE STUDY OF POLYMER AGEING

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ABSTRACT

The aim of our studies is to assess the lifetime expectancy of cables installed inside the building reactor of French nuclear power plants. From a material standpoint, the cable ageing is associated to the ageing of the polymer jacket and insulation of the cable. To simulate the nuclear cable ageing, we develop two different approaches: an empirical approach with a model based on a behaviour law and a kinetic approach based on a description of the polymer at the molecular scale. The first comparisons between numerical and experimental results are quite relevant and very encouraging and have jointly confirmed the good behaviour in time of French nuclear cables.

KEYWORDS

Nuclear cable, lifetime estimation, kinetic model

INTRODUCTION

The study of the ageing of electric cables installed inside the building reactor of nuclear power plants has been one of EDF's main concerns for many years, in particular within the framework of the lifetime extension of the installations.

From a material standpoint, cable ageing is related to the ageing of polymers constituting the jacket and the insulation of the electrical conductor. The ageing processes of a polymer linked to its exposure to different environmental factors such as irradiation or temperature are very diverse and complex. Thus, despite extensive literature on the subject over more than a half a century, there is still no model capable of exhaustively representing such diversity.

The first approaches developed to address the issue raised are empirical approaches but they are not industrially perennial and suffer from many limitations.

That is why, in recent years EDF in partnership with ENSAM Paris, has developed a more generic approach based on the understanding and kinetic modelling of polymer ageing by thermo and radio-oxidation.

This article will start by giving a short summary of the main results derived from studies using conventional empirical approaches. Then the new kinetic approach and the first numerical results will be presented. At last, the current developments of this new approach are exposed.

1. THE EMPIRICAL APPROACH

The empirical model developed by EDF in the 1990s, is based on the chemical kinetic laws and expresses the time dependency of a physical property according to the variables temperature T and irradiation dose rate I [1]. For the monitoring of elongation at break, this time dependence is expressed, in first approximation, as follows:

$$\frac{\varepsilon}{\varepsilon_0} = [1+(\beta-1).K_t(T,I).t]^{\frac{1}{1-\beta}} \qquad \text{for } \beta \neq 0;1$$

$$\frac{\varepsilon}{\varepsilon_0} = \exp\,[-K_t(T,I).t] \qquad \text{for } \beta=1$$

with $K_t(T,I) = K_{th}(T)+K_r(T,I)$

and :

- ε the elongation at break at t, ε_0 the initial value,
- β characterizes the process of degradation responsible for ageing.

$K_t(T,I)$ corresponds to the constant of speed; it is a function of thermal K_{th} and radiative K_r contributions:

$$K_{th}(T) = k_0.\exp(-E_a/RT)$$

$$K_r(T,I) = k'_0.I^{\alpha}.\exp(-E'_a/RT)$$

with:

- E_a and E'_a the energies of activation ($kJ.mol^{-1}$),
- k_0 and k'_0 the coefficients pre-exponential (J^{-1}).

The simulations were performed for CSPE (Chlorosulfonated Polyethylene) and EPR (Ethylene Propylene Rubber), respectively for jacket and insulation of typical French nuclear cables, for average conditions of temperature and dose rate, bounding by the upper values the conditions inside the building reactor (temperature of 50℃ and dose rate 0.1 Gy/h) and with a set of valu es determined in previous studies in our laboratory.

Figure 1 presents the calculation performed for the insulation material EPR. The previous studies done on this type of material showed that the results are dependent on the formulation and also of the crystallinity ratio. Two sets of extreme values were defined for the model, for crystallinity ratio of 5 and 40-50% (blue curves). These simulations were then compared with results stemming from analyses of cables taken in a building reactor after several years (until 30 years) of in-service conditions [2]. Experimental results show that elongation at break is significantly higher than the predictions established by the model.

The differences between the modelling and the experimental results can be attributed to several factors such as:

- the difference of formulation / cristallinity between the cables taken on nuclear site and cables used to fit the model parameters,
- the conditions of ageing especially oxidation, which are probably different between a cable on- installed site and cables samples studied in laboratory.