An Experimental Study on the Effects of Thermal and Radiation Aging on Cable Fire

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1. Introduction

Cables are widely installed in a nuclear power plant(NPP). The most important criterion for cable performance is its ability to withstand a design-basis accident[1]. Class 1E cables, one of the cables used in a nuclear power plant, are used in essential electrical equipments and systems for emergency reactor shutdown, containment isolation, reactor core cooling and reactor heat removal[2]. Class 1E cables must pass certain fire resistance tests. These include IEEE-383[2] in accordance with NUREG-0800[3], which the regulatory guidelines of the Nuclear Regulatory Commission(NRC). However, cable sheath and insulation may age due to radiation and heat in the power plant. This aging may lead to a change in the components constituting the cable and cause a decrease in the performance of flame retardant[1,4].

The purpose of this study was to investigate the combustion characteristics and smoke emission of thermal and radiation aged cables. Combustion characteristics were analyzed using a cone calorimeter.

2. Materials and Methods

2.1 Materials

In this study, CSP/EPR cable was used as test specimens. The cable was subjected to accelerated aging test and radiation aging test. CSP/EPR cable consist of three components: Chlorosulfonated Polyethylene rubber (CSP) Sheath, Ethylene Propylene rubber (EPR) insulation layer, and copper cores. Table. 1 presents the specifications of the cable specimens.

Table I: Specification of experimental cable specimens

Division		Detail
Application		Power/control
Voltage [V]		600
Material properties	Sheath	Chlorosulfonated Polyethylene rubber (CSP)
	Insulation	Ethylene Propylene rubber (EPR)
	Conductor	Copper

2.2 Radiation Aging of Cables

In the radiation aging test, a radiation aging model was applied that considered only the effects of absorbed dose.

In this study, a cobalt-60 gamma ray was used, and the absorbed dose was irradiated under the condition 1.94×10^6 Gy. The combustion characteristics of the irradiated cable (IR cable) and the Non-irradiated cable (Non-IR cable) were compared.

2.3 Accelerated Aging of Cables

In the accelerated aging test, a thermal aging model was applied considering only the time and temperature relationships. For aging test, the activation energy was calculated through the Thermogravimetric Analysis (TGA). The accelerated aging period was calculated using the Arrhenius equation, Eq (1).

$$\ln\left(\frac{k(T)}{k(T_{ref})}\right) = \left(\frac{E_a}{R}\right) \times \left(\frac{1}{T_{ref}} - \frac{1}{T}\right) \qquad (1)$$

$k(T)$: *Reaction rate at temperature* T
$k(T_{ref})$: *Reaction rate at temperature* T_{ref}
E_a : *Energy of activation* (eV)
R : Boltzmann constant(eV/K)

The energy of activation calculated through the TGA test was 1.35eV, and the condition of T:363K, T_{ref} : 423K were applied to Eq(1) to obtain the required accelerated aging time. In this study, the accelerated aging test was conducted only for the IR cable. The cable was subjected to accelerated aging for interval of 10 years :10, 20, 30 and 40 years. Table. 2 shows the required accelerated aging time.

Table II: Required Accelerated aging time calculated by the Arrhenius equation

Aging Period [year]	Required Accelerated aging time [hour]
10	194
20	387
30	580
40	773

2.4 Cone Calorimeter Test

Cone calorimetry is useful for evaluating flammability performance of an organic material[5]. The cone calorimetry is based on the principle that 13.1 MJ of heat release when burning 1 kg of oxygen[6]. Variable parameter can be obtained from cone calorimetry including the heat release rate (HRR), the total heat release (THR), the mass loss rate (MLR), the smoke production rate (SPR), the total smoke release (TSR). Table. 3 presents cone calorimeter test conditions.

Table III: Cone calorimeter test conditions

Division	Details
The size of specimens [mm^3]	100×100×30
Test running time [s]	2400
Heat flux [kW/m^2]	50
Exhaust flow [m^3/s]	0.024±0.002

3. Results

Fig. 1-2 presents the HRR curves and THR values for all specimens. The flame of the Non-IR aged cable (Non-IR 0year cable) was extinguished in 910 to 930 s, and the IR Non-aged cable (IR 0 year cable) be in about 1200 s. The IR aged cables were tested until 2400 s, and showed two peaks. The first peak of heat release rate ($PHRR_{1st}$) was the lowest for the Non-IR 0 year cable, and tended to decrease as the aging period increased. This is considered to be the main cause of removal of volatile components present in the cables during the thermal accelerated aging test. In addition, it was confirmed that the heat release rate increased at 800 s for the IR 20 year cable, and increased after 1150 s for IR 40 year cable. This was due to the internal thermal penetration and pyrolysis as the char layer decomposes on the materials surface[7]. Thereafter, the highest THR value for the IR 20 year cable was measured.

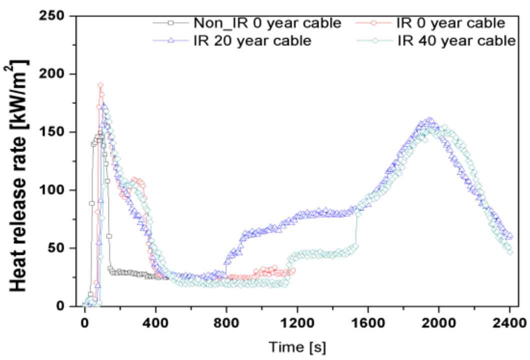

Fig. 1. HRR curves with respect to time for specimens

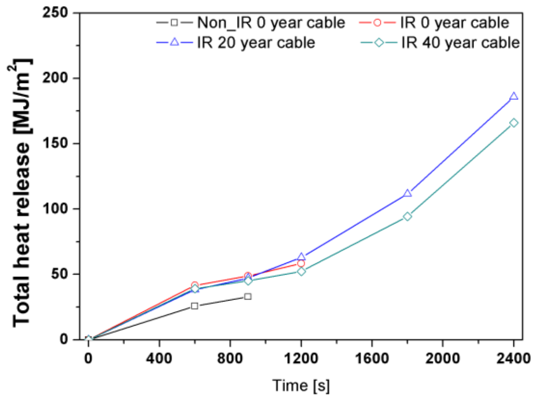

Fig. 2. THR values with respect to time for specimens

4. Conclusions

The cone calorimeter test was performed to confirm the combustion characteristics of IR cables and accelerated aging ones. It was confirmed that thermal and radiation aging are the causes of increasing the first PHRR. Thermal aging caused unstable formation of the char layer, causing internal thermal penetration and pyrolysis due to the decomposition of the char layer. However, as the aging period increased, the tendency for the overall fire risk to increase was not clear, but it was confirmed that the risk of aging cables increased after 1200 seconds. Therefore, since the deterioration of flame retardant performance with respect to aging, studies on combustion characteristics due to aging must be additionally conducted.

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