Evaluation of heat and radiation effects on mechanical properties of fluoroelastomer under normal operation environment of nuclear power Plants

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1. Introduction

Polymeric materials are widely used in equipment in nuclear power plant (NPP) system for cable, switch seal. Among the polymeric materials, fluoroelastomers have been widely used as sealing materials due to high radiation and thermal resistance and mechanical properties. However, polymeric materials including fluoroelastomer are aged during normal operation period of NPP and experience degradation of mechanical properties. The cause of these degradations is known to be dominated by the effects of heat and radiation. In such environment, phenomena such as scission of the molecular chain, crosslinking, and reaction between scissioned molecular and oxygen in atmosphere occur. These phenomena show that the mechanical properties of the polymeric materials are degraded.

Polymeric materials used in NPP vary in their type and composition, and their degradation behaviors are different and difficult to predict. But, previous study on the mechanical degradation of these materials has focused on the effect of UV light, ionizing radiation, and ozone. However, to understand mechanical degradation of polymeric materials caused by heat and radiation is very important to ensure the safety of NPPs. [1-2]

Therefore, in this study, to investigate the mechanical degradation behavior of fluoroelastomer used in sealing materials in NPP, accelerated thermal aging test and radiation test were performed. To evaluate the mechanical degradation, hardness was measured and fourier transform infrared spectroscopy (FT-IR) analysis was performed.

2. Experimental

2.1 Accelerated thermal aging test

In order to evaluate the mechanical degradation of fluoroelastomer caused by heat and radiation, serial experiments were performed. First, an accelerated thermal aging test was performed to simulate the heat degradation of polymeric materials during long-term NPP operation period as shown in Fig. 1. Test conditions of accelerated thermal aging were determined by Arrhenius equation as shown in equation (1).

$$t_2 = t_1 \, exp\left\{\frac{E_a}{k}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right\} \qquad (1)$$

Whereas, t_1 is operation time, t_2 is test time, T_1 is operation temperature, T_2 is test temperature. The decomposition activation energy of fluoroelastomer used in this study is 1.09 eV. The accelerated thermal aging test conditions using the eq (1) were as shown in table 1. The test were performed at 140 ℃ for 176.1 hours.

Fig. 1. Accelerated thermal aging test

Table I: Accelerated thermal aging test condition

Activation energy	Operation temperature (T_1)	Accelerated thermal aging temperature (T_2)	Accelerated test time (t_2)
1.09 eV	54.4 ℃	140 ℃	176.10 hours (7.34 days)

2.2 Irradiation test

In this study, to evaluate the mechanical degradation in radiation environment, irradiation test in KAERI ARTI (Korea Atomic Energy Research Institute Advanced Radiation Technology Institute) was performed using gamma-ray (Co^{60}) at room temperature and in the air.

The test was performed at an irradiation time of 22.25 hours at a dose rate of 9 kGy/hr and a total absorbed dose of 2.0 x 10^6 Gy. [3]

3. Result and discussion

3.1 Hardness measurement

To investigate the degradation of fluoroelastomer caused by heat and radiation, durometer shore A hardness was measured according to ASTM D2240 as shown in fig 2.

Durometer shore A hardness of as-received specimen was 74.1. The hardness of specimens exposed only to radiation and specimens exposed to radiation and heat were 80.4, and 81.7. These results of hardness measurement were increased by 8.5% and 10.1%, respectively. [4]

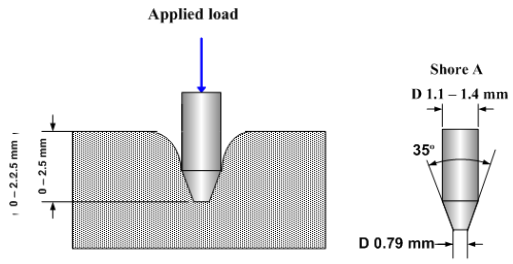

Fig. 2. Durometer hardness test indenters

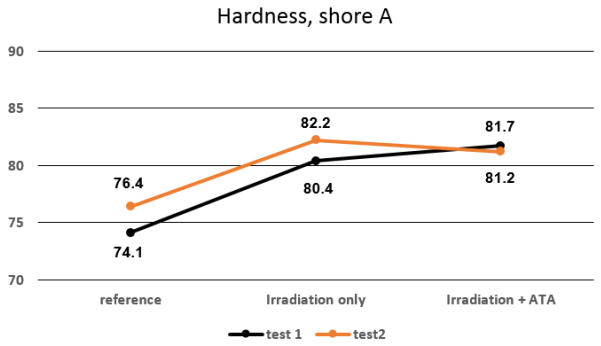

Fig. 3. Hardness change of fluoroelastomer

3.2 Fourier transform infrared (FT-IR) analysis

FT-IR (Nicolet iS50) analysis was carried out to identify structural changes in materials caused by heat and radiation. The FT-IR spectrum of the fluoroelastomer is shown in Fig. 4

Compared with the as-received specimen, the specimen degraded in heat and radiation showed a new peak at a wavelength of 1710 cm^{-1}. This peak in the FT-IR spectrum appears due to the formation of C=O bonding caused by heat and radiation. And, the peak at 1640 cm^{-1} increased with exposure to heat and radiation. In addition, the increase of C=C bonding was found through the wavelength of 1640 cm^{-1}. [5]. The peak of C-H bonding is reduced by the degradation test, however C-F bonding is unchanged due to the difference of the bonding energies of C-F bonding (453 kJ/mole) and C-H bonding (347 kJ/mole)

Based on these results, C=O and C=C bonding concentration plays an important role in hardness change of fluoroelastomer caused by heat and radiation.

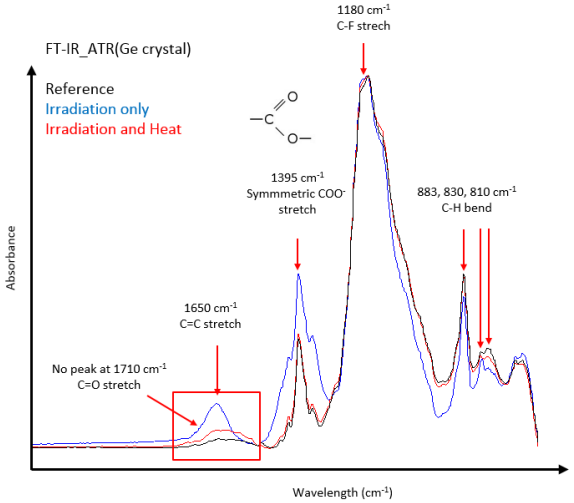

Fig. 4. FT-IR spectrum of fluoroelastomer

4. Conclusions

To understand the effects of heat and radiation during the normal operation condition of NPP on mechanical property of polymeric materials, accelerated thermal aging test and irradiation test were performed with fluoroelastomer. And to evaluate the degradation of mechanical property, hardness measurement was carried out.

1) Shore A hardness in cases of radiation exposure only and radiation/heat exposure were increased 8.5% and 10.1%, respectively, compared with the reference specimen

2) FT-IR analysis showed a peak a 1715 cm^{-1} wavelength, which was formed by the reaction of the scissioned main chain and oxygen in atmosphere. The 1640 cm^{-1} peak appears that the main chain of the polymer is scissioned to form C=C bonding within the polymer.

3) The increase in hardness is similar to the increase in C=O and C=C bonding peaks. Therefore, it is considered that C=O and C=C bonding affects the mechanical degradation of fluoroelastomers due to heat and radiation during the normal operation period in NPP.

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