Analysis of nuclear power plant cable using DMA

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1. Introduction

Qualification of the polymer which should be used as main cable materials of nuclear system is very important for safety of nuclear. Especially, cables connected with operation of safe valves or pumps for LOCA (Loss of Coolant Accident) are highlighted more remarkably. We are taking information on thermal aging-decomposition of polymer from Wyle Lab. in USA, but are deficiency for activation energy of various cables using nuclear system. So we will perform qualification of polymer from inducing activation energy using DMA (Dynamic Mechanical Analyzer) equipment in KIMM (Korea Institute of Machinery and Materials).

2. Methods and Results

Commonly, Aging test of polymer is that measuring activation energy from UTM (Universal Tensile Machine) while inserting a lot of specimens into electrical furnace. But, these methods require lots of labor and time. So, we determined very easily and accurately activation energy from experimental datum of temperature, modulus and frequency in DMA.

2.1 Arrhenius equation

Arrhenius equation is a common equation which can get activation energy from rate constant and temperature.

$$k = A\exp(-\frac{E_a}{RT})$$

Which is k : rate constant , A : pre-exponential factor, E_a : Activation energy, R : gas constant, T : temperature we can convert rate constant as the time. That is

$$\ln\frac{t}{t_o} = \frac{E_a}{R}(\frac{1}{T} - \frac{1}{T_0})$$

Also, we can convert as frequency.

$$\ln\frac{f_o}{f} = \frac{E_a}{R}(\frac{1}{T} - \frac{1}{T_o})$$

Which is t : time, f : frequency.

2.2 DMA analysis theory

Dynamic mechanical properties refer to the response of a material as it is subjected to a periodic force. These properties may be expressed in terms of a dynamic storage modulus, a dynamic loss modulus. Typical values of dynamic modulus for polymers range from 10^6~10^{12} dyne/cm^2 depending on the type of polymer, temperature and frequency.

Basic principles for studying long-term behavior of polymers have been well established by Williams, Landel and Ferry. The methods of time-temperature superpositioning (i.e. reduced variables) are used to accelerate the mechanism of a relaxation or molecular event by either increasing the temperature or increasing the stress, in the experiment. WLF equation is associated with the transition, plateau and terminal regions of time scale[1]. That is,

$$\log\alpha_T = \frac{-C_1(T - T_g)}{C_2 + (T - T_g)}$$

Which is α_T : shift factor (f_o/f), T_g : glass transition temperature. The shift factor, α_T represents the magnitude of shifting along the x-axis, necessary for a specific isotherm to superimpose on its neighbor in the final master curve with respect to a given reference temperature. The log α_T vs. temperature plot should be a smooth monotonic curve same as Fig 2. provided the mechanism of relaxation remains the same during the process. We can connect this equation with Arrhenius equation. It is clear that activation energy can be taken plot of log α_T vs. ($1/T - 1/T_o$) as value of f_o/f is equal to α_T

2.3 Experiment

We used DMA analysis system as Pyris Diamond DMA of Perkin Elmer Instrument. A specimen size is 50(W)×16(D)×50(H) mm as the standard size of ASTM D 412. Experimental method is that measured modulus depending on various frequency under uniform temperature. Polymer was selected as EPR of class 1E polymer which used be in nuclear power plant.

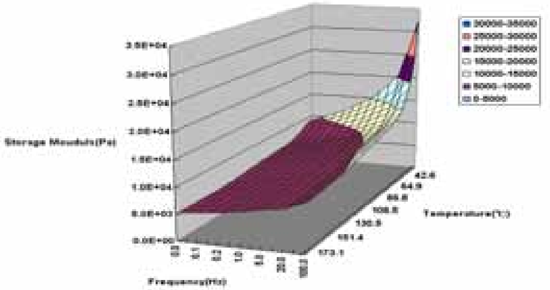


Figure 1. Modulus as a function of temperature and frequency.

Temperature is 25 ~ 600 ^{o}C, frequency is 0.5~20 Hz. We can know that the storage modulus decreases as a temperature, but increases as a frequency same as Fig 1. To get the activation energy, data in Fig 1. is modified as of ln α_T vs. (1/T – 1/T$_o$) under uniform modulus same as Fig 2.

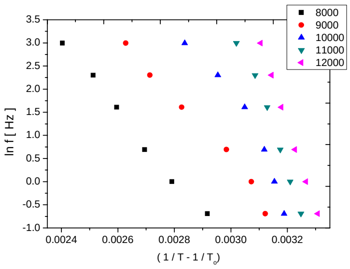
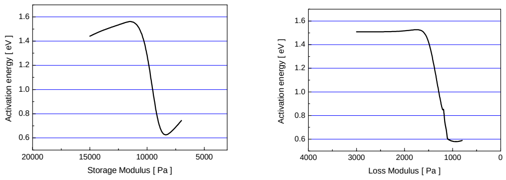


Figure 2. Plot about ln α_T vs. (1/T – 1/T$_o$) under uniform modulus

2.4 Results

We obtained the activation energy as a function of modulus in previous data [Fig. 3] and selected 50% activation energy between maximum and minimum modulus. Resultantly, Storage modulus is 1.24 eV, loss modulus is 1.13 eV. This value is very closed to Wyle lab. data.



(a) (b)

Figure 3. Activation energy considering as (a) storage modulus and (b) loss modulus.

3. Conclusion

When it is compared with the DMA and the 1.23 eV of thermal aging test on the Wyle Lab. , it makes no difference between 1.24 eV and 1.13 eV in the activation energy. If it carries out the examination by thermal aging test, it takes the enormous time. But if it executes the one by the only DMA, it takes the opportunity that is able to reduce the examination time and it will be able to secure the trust on the repeat test for the many polymer materials.

Acknowledgement

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