A Study on Shelf Life Evaluation of Rubber O-ring

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1. Introduction

Non-metallic materials stored in warehouses in nuclear power plants have shelf life. The shelf life means the maximum storage time allowable such that the install life of the material is not affected. Materials whose shelf lives expire are generally discarded, unless the shelf lives of these materials can be extended by reducing the install life. Examples of this case are rubber materials.

Rubber materials are widely used for sealing of various machines [1]. There are various life evaluation methods for rubber material. For example, the compression set is generally used for evaluating the aging condition of rubber materials used for sealing. A compression set value can be calculated according to the ASTM D395. We have tried the compression set test by using specimens with 6.99mm diameter O-ring even when ASTM D395 recommends the use of bar specimen. Test results and comparison between O-ring and reference data of EPRI NP-6608 [2] are presented below.

2. Methods and Results

2.1 Measurement of Compression Set

2.1.1 Test Method

The compression set test is intended to measure the ability of rubber compounds in retaining elastic properties after being subject to compressive stresses for a long period of time. The calculation of the compression set, expressed as a percentage of the original deflection, is as follows;

$$C = [(t_0 - t_1)/(t_0 - t_2)] \times 100$$

Where; C denote the compression set expressed as percentage of the original deflection(%), t_0 the original thickness of specimen(mm), t_1 the final thickness of specimen(mm), and t_2 the thickness of the spacer bar used(mm).

2.1.2 Test Result

The compression set test consists of the periodical compression set measurements of O-rings that had been compressed in fixtures and the aging treatment at elevated temperatures. In this study, the O-rings were subject to a 25% squeeze by the test fixture [3]. The accelerated aging at the temperature of 80℃, 100℃, and 120℃ were performed for a period ranging from 24 to 888 hours. From the results as shown in Figure 1, we can see an increase in the compression set. The time that take for the compression set to reach the limit value of 50% was 208.3 hrs when the temperature was 120℃, 475.4 hrs when the temperature was 100℃, and 1002.8 hrs when the temperature was 80℃, respectively.

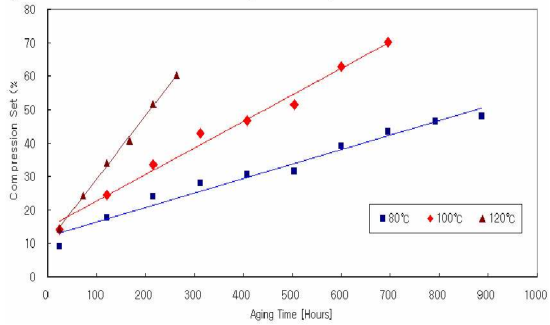

Figure 1. Compression Set for NBR O-ring

2.2 Arrhenius Model for Calculation of Activation Energy

Arrhenius equation is well known as a physical model for predicting lifetime in accelerated thermal aging condition. The plant environment is monitored throughout the lifetime of the plant to calculate the thermal aging value with monitoring results, heating is continued to foster accelerated aging to prove that accelerated aging equals natural aging. It is assumed that the rate of the thermal aging decrease in an inverse manner to temperature, such that the rate constant "k" can be expressed as follows;

$$k = A \exp (- (E_a / k_B T)) \qquad (1)$$

where "k" is reaction rate, "A" is frequency factor, "E_a" is activation energy, "k_B" is boltzmann's constant, and "T" is absolute temperature(^oK). Life is assumed to be inversely proportional to the chemical reaction rate. In terms of life, and after is converted to Napierian base logarithms, Equation (1) becomes;

$$\ln (\text{life}) = (E_a / k_B)(1/T) + \text{Constant} \qquad (2)$$

Equation (2) can be expressed in an algebraic form as follows;

$$y = mx + b \qquad (3)$$

where "m" is slope(E_a / k_B), and "b" is intercept (constant). The slope is determined by the activation energy “ E_a ” and the activation energy controls the sensitivity of the degradation rate [4].

2.3 Calculation of Activation Energy by Arrhenius Model

The point of compression set failure 50% in three degree was shown in Figure 2. The slope of this graph is “m” in the equation (3). The activation energy was calculated as 0.47eV by equation (3).

2.4 Comparison and Analysis of Activation Energy

The activation energy value of the commercial specimen was 0.47eV which was relatively lower than 0.8eV of the N103 and 0.91eV of the N219 specimens as given in the EPRI NP-6608 report. The material tests in EPRI NP-6608 were conducted in accordance with ASTM D1414 [4]. Such difference in activation energy may be observed even though the generic activation energy of the nitriles is 0.92eV [5]. Despite the fact that these specimens are nitriles, their activation energies can show certain variations.

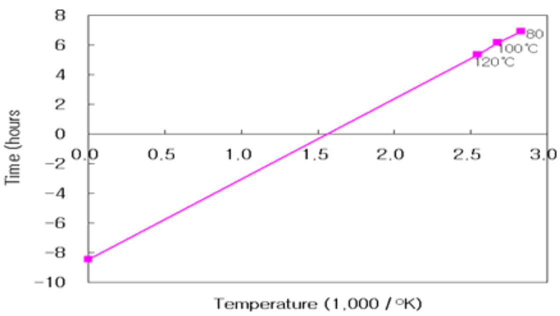

Figure 2. Compression Set Arrhenius Graph

2.5 Shelf Life Eevaluation

The shelf life for these three NBR O-rings whose degradation with temperature follows an arrhenius relationship can be evaluated using the equivalent storage time (EST).

$$\text{EST} = t_1 / \exp[(E_a / k_b)(1/T_1 - 1/T_2)] \quad (4)$$

Where:

EST = equivalent storage time (hrs) at temperature T_2

t_1 = accelerated aging time (hrs) at temperature T_1

exp = exponent to base e

E_a = activation energy (eV)

k_B = Boltzmann’s constant (8.617 X 10^{-5} eV / ^oK)

T_1 = accelerated aging temperature (^oK)

T_2 = average storage temperature (^oK)

In order to assure that the install life of an item is not affected by its time on the shelf, the shelf life was limited to 5% of the EST. This limitation ensures that there still remains 95% of the item’s install life. It should be noted that this 5% factor is considered conservative considering that the item had been stored in a benign environment and was not subject to any additional stresses of the in-service environment. In addition, the variability of most physical property testing was greater than 5% [5].

The experimental shelf life in the case of the NBR specimen was 0.8 years. The shelf life of N103 specimen is 2.4 years. The shelf life of N219 specimen is 5.7 years, while that of nitrile and NBR in MIL-HDBK-695C was between 3 ~ 5 years. According to EPRI report, the test results showed to vary according to the test method, specimens, experiment conditions, etc. This data can only be applied to the material management program if the shelf life is acceptable, but otherwise, other methods should be considered.

3. Conclusion

The shelf life evaluation of rubber O-ring was conducting using the compression set test. Install life of O-ring was evaluated in accordance with ASTM D 395 and EPRI NP-6608. We evaluated the aging degradation of O-ring by applying the compression set and arrhenius equation. We used NBR O-ring as test specimen even when ASTM D395 recommends the use of round bar specimen. We found that compression set of NBR O-ring showed relatively low activation energy compared with reference data in EPRI report. It was assumed that the test specimen of O-ring had more thermal impact due to low thickness of specimen compared with the specimen of ASTM D395.

Further study is required to confirm the difference of thermal impact due to specimen size.

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