Transactions, SMiRT-24
BEXCO, Busan, Korea - August 20-25, 2017
Division IX (include assigned division number from I to X)

LIFE-CYCLE EVALUATION AND PREDICTION OF NATURAL RUBBER IN LEAD RUBBER BEARING FOR NUCLEAR POWER PLANT

Hong-Pyo Lee[1], Myung-Sug Cho[2], Jeong-Su Choi[3], Kwang-Seok Jang[4], and Ki-Chul Sim[5]

[1] Senior Researcher, Plant Const. & Eng. Lab., KHNP-Central Research Institute, Korea
[2] Principal Researcher, Plant Const. & Eng. Lab., KHNP-Central Research Institute, Korea
[3] Associate Researcher, R&D Center, UNISON eTech Co. Ltd., Korea
[4] Senior Researcher, R&D Center, UNISON eTech Co. Ltd., Korea
[5] Senior Researcher, R&D Center, UNISON eTech Co. Ltd., Korea

ABSTRACT

In order to accurately evaluate the life of a product, it is necessary to estimate the life of the product from the failure data in the actual environment. However, this method has a disadvantage that it takes a long time. Therefore, in this study, life expectancy under service conditions is estimated by using accelerated life test method which shortens the failure time by applying harsher conditions than actual use environment or conditions.

INTRODUCTION

Background

Recently the demand for product performance, quality and reliability of a product’s life cycle is increasing, especially in the case of foreign countries in Europe and Japan. As the consumer lifestyle patterns rapidly grow, the development period of the product is shortening, which in turn increases the element of the unknown. Over time, consumers will complain more and damage will be done to business if the company fails to provide accurate solutions for consumer product complaints.

Reliable estimates for the life expectancy of rubber products are highly complex and Korea’s field data are sparser than other countries. Therefore, it is not easy to predict the life expectancy of rubber products. In addition, the performance and longevity of rubber products are dependent on factors such as temperature, humidity, oil, ozone, mechanical and electrical stresses. Other products are equally difficult to test, but it remains difficult to design tests with similar conditions to the actual environment. To solve these problems the tests were conducted based on reliability, and stability according to time with in a usage conditions of the product.

Research object and method

In this study, the accelerated thermal aging test has been conducted to assess the lifespan of the elastic support made of natural rubber. From the results of the test, we estimated the product's life distribution and statistic as well as the usefulness of the elastic bearing as it has been predicted. The best way to estimate the life of a product is to test it in a real-life environment. However, the drawback to this approach is that the development phase takes too long. Therefore, this study used a method of accelerated testing which reduces fault time by creating conditions that are harsher than actual real-life conditions to estimate the life span.

The basic concept of the acceleration test is to increase the level of deterioration or performance of the product, which will affect the deterioration of the product's characteristics, thereby promoting deterioration of the rubber product. The method used in this experiment is to increase temperature to speed up the aging process of the rubber product by increasing the concentration of ozone to speed up the cracks.

In this study, select the temperature which is the most important factor influencing the performance degradation of rubber then accelerated heat aging testing was applied at higher temperatures than actual use environments.

TESTING METHOD

Failure criteria

In case of high molecule materials or chemical materials as rubber, breakages occur after flames rather than sudden breakage that the breakage judgment standards of the chemical material need to be regulated accurately. Generally, according to ISO 11346, in case of chemical substances, the point in which the early physical properties are lowered to 50% of the original physical property value as the point of breakage.

However, in case of rubber equipment, the points of breakage regulated by ISO22762-3 (base support for construction purposes) or EN1337-3 (base support for bridge) are regulated differently. In this test evaluation, the test evaluation method and criteria applying building construction standards of ISO22762-1, 3.

Acceleration

In the field of chemical materials, the Arrhenius model generally used in acceleration heat aging test using stress standards as temperature based on ISO 11346 and related literature.

Physical property test

A Uniaxial tension test was conducted for the physical property test. The uniaxial tension test was conducted by applying road cell of 5KN capacity on the material tester, and extensometer was used to measure the change rate of the specimen. The test specimen utilized the dumbbell-shaped No.3 specimen according to the standards of ISO 37 to measure the tensile strength and elongation ratio.

Figure 1. Test specimens.

The compound was prepared by mixing natural rubber and compounding agent in kneader, vulcanizing it in 18" open roll, and then processing it into rubber sheet. After appropriately cutting the rubber sheet, it was molded at a temperature of 140℃ and a suitable vulcanization time in a test heating press. A tensile test piece was produced using a molded rubber sheet with a dumbbell type No. 3 blade of ISO 37.

Accelerated thermal aging test

Most of the rubber parts terminate their lives due to heat aging due to environmental influences and fatigue damage accumulation due to repeated weight. In this study, the acceleration testing method of heat-aging in aging tester of higher temperature than where the actual test is used by considering the temperature, the main factor is considered among various characteristic-lowering factors. The aging condition according to temperature change was aging for 180 days at 70℃, 80℃, and 90℃, and the specimen aged during a specific duration was taken out of the oven and left in room temperature for 24 hours before physical characteristic test.

Table 1: Aging test conditions.

Aging temperature (℃)	Test period (Days)	Properties	Chang rate of properties (%)
70, 80, 90	Non, 1, 4, 7, 14, 30, 45, 60, 75, 90, 120, 150, 180	Tensile strength	-15
		Elongation at break	-25

Figure 2. Aging oven and Universal Test Machine.

LIFE PREDICTION

Arrhenius's equation

The data obtained by heating acceleration aging test was predicted the expected life by using the Arrhenius's equation. Arrhenius model is determined by life span when initial characteristics of rubber products changes at various temperatures. And time-temperature is expressed as a master curve and a relational expression. From this relationship, predictable life estimates can be calculated at certain temperatures and data can be predicted useful-life by using data obtained from the acceleration test results by natural ageing at room temperature. In order to identify the Arrhenius equation, the characteristic value of the rubber is referred to as P, It can be expressed as follows.

$$-\frac{dP}{dt} = kP, \left[\frac{P}{P_0}\right] = -kt \tag{1}$$

where P is the rubber property value, P_0 is the rubber property value at before aging, t is the time and k is the reaction rate.

In the equation (1), the reaction rate constant is an integer representing the aging reaction of the characteristic value. In 1889, Arrhenius obtained empirical equations such as in the equation (2) and equation (3).

$$k = A \cdot e^{-E/RT} \tag{2}$$

$$\ln k(T) = -\frac{E}{RT} + C \tag{3}$$

where A, C is constant, E is the activation energy (J/mol), R is the gas constant (8.314 J/mol·K), T is the absolute temperature (K).

In (3), ln k(T) shows a linear relationship between 1/T and inclination E/R. If the point at which the characteristic value p is aged in equation (1) is the lifetime, the lifetime (t) at that point can be obtained from (4).

$$t = -\ln(P/P_0)/k \tag{4}$$

In the equation (4), the lifetime t is expressed by the relationship of the temperature from the reaction rate constant relation (2), and the temperature can be converted to the lifetime.

The lifetime at temperature with the characteristic value P is equal to the lifetime at the temperature, which can be expressed by equation (5).

$$\ln\left[\frac{t_1}{t_2}\right] = \frac{E}{R}\left[\frac{1}{T_1} - \frac{1}{T_2}\right] \tag{5}$$

In other words, it is possible to evaluate the change over several years at room temperature with a high-temperature accelerated aging in a short period of time, which is similar to a change in low temperature-long time and a change in high temperature-short time.

Lifetime prediction

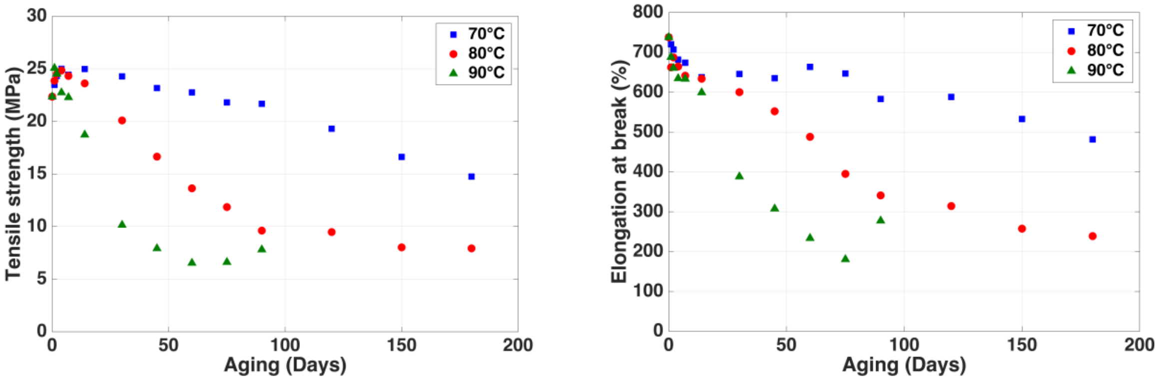
Through hardness and tensile tests, it is expected that the aging properties for the aging days at various aging temperatures will increase with increasing temperature and aging days. The Arrhenius curve can be obtained from the relationship between temperature and time, which corresponds to the failure life of the rubber material set in this study, and the Arrhenius's equation can be obtained from the trend line. The Arrhenius's equation, a time-temperature relation, can be used to obtain a usable lifetime at any temperature.

EVALUATION OF LIFE ESTIMATE

Test results

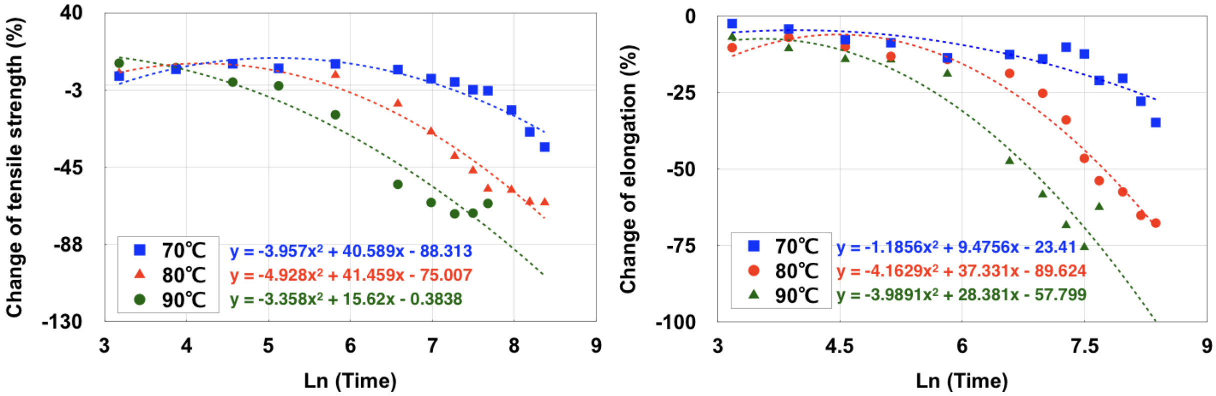
To determine the ageing characteristics of the natural rubber, the tensile characteristics was measured at 70℃, 80℃, and 90℃ for 180 days at a temperature higher than the actual use temperature.

Fig. 3 shows the aging characteristics of tensile strength and elongation. At low temperature, the characteristic value changed slowly. When the temperature was high, the aging progressed rapidly. Fig. 4 shows the horizontal axis represents the logarithm of the number of aging days of aging and the vertical axis represents the rate of change of physical properties.



(a) Tensile strength curves for aging days (b) Elongation at break curves for aging days

Figure 3. Tensile strength of natural rubber according to aging.

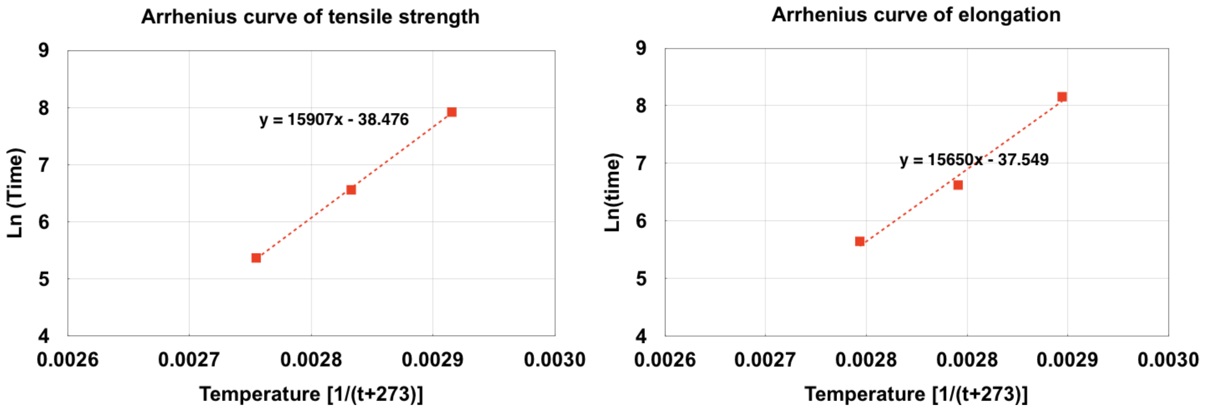


(a) Tensile Strength rate of change for Ln(time) (b) Elongation at break of change for Ln(time)

Figure 4. Elongation of natural rubber according to aging.

Life time prediction

The vertical axis represents the logarithm of the lifetime and the horizontal axis represents the inverse of the absolute temperature. Fig. 3, the Arrhenius curve can be represented. From this slope, the activation energy can be obtained. The tensile strength was predicted to be 339 years and the elongation rate at 361 years at room temperature 25 ℃ using the predicted life expectancy.



(a) Tensile Strength (b) Elongation at break

Figure 5. Arrhenius curves by temperature and time.

Using the activation energy, the following relationship can be used to determine the age of use relative to the following formula.

$$\ln(t_y) = \frac{E_a}{R} \times \left(\frac{1}{T_1} - \frac{1}{T_0} \right) + \ln(t) \tag{6}$$

where t_y is the accelerated aging time, T_y is the Accelerating temperature, T_0 is the Operating temperature, t is Deterioration time of operating temperature.

Table 2: Prediction of the life time of rubber materials.

Temp. (℃)	Properties change	Life prediction equation	Life-time (Years)	Activation energy[E_a] (J/mol)
25	Tensile strength (-15%)	ln(t) = -38.48+15,907/(T+273)	339	130222.182
	Elongation at break (-25%)	ln(t) = -37.55+15,650/(T+273)	361	132658.184

CONCLUSION

This research predicted the aging life due to the heat of shear modulus (G=0.5MPa) rubber by utilizing Arrhenius model. The aging life limit standard of the elastic base utilized the point of the tensile strength lowered by 15% and elongation ratio lowered by 25% according to the EN-1337.

The conditions of aging temperature were conducted at 70℃, 80℃, and 90℃, and in predicting the actual usage temperature of the natural rubber as 25℃, it was verified that the anticipated life of the two physical characteristics was 100 years or longer. Because the cover rubber of elastomer is protecting the product, it is anticipated that the inner laminated rubber would be slower in aging compared to the anticipated life value.

Also, it is considered that the interaction formula in low temperature as well as high temperature would be deducted, and if there are many breakage mechanism analysis of the rubber product and the physical trait and characteristic change are accumulated, the life anticipation and credibility enhancement of rubber products will be assisted greatly.

REFERENCES

EN. (2005). Structural bearings. British Standard, EN-1337, London.

Han, S. W., Kwak, S. B. and Choi, N. S. (2014). “Accelerated Life Prediction of Ethylene-Propylene Diene Monomer Rubber Subjected to Combined Degradation,” *J. Korean Soc. Mech. Eng. A, Trans., 38,* 5, 505-511.

ISO. (2004). Rubber, vulcanized or thermoplastic - Estimation of life-time and maximum temperature of use. ISO 11346:2004(E), International Standard.

ISO. (2005). Rubber, vulcanized or thermoplastic — Determination of tensile stress-strain properties. ISO 37:2005(E), International Standard.

ISO. (2010a). Elastomeric Seismic-Protection Isolators - Part 1: Test Methods. ISO 22762-1:2010(E), International Standard.

ISO. (2010b). Elastomeric Seismic-Protection Isolators - Part 3: Applications for Buildings. ISO 22762-3:2010(E), International Standard.

Park, K. H., Park, J. H., Lee, H. H. and Kwon, Y. I. (2004). “Accelerated Heat Aging Test for Predicting Useful Lifetime of Elastomeric Bearing,” *J. Reliability and applications, 4,* 2, 73-90.

Woo, C. S. and Park, H. S. (2006). “A Study on the Lifetime Prediction of Rubber Mount for Refrigerator Component,” *J. applied reliability, 6,* 2, 135-150.

Woo, C. S., Park, H. S., Kim, K. S., Yang, S. C., Jang, S. Y. and Kim, E. (2009). “Useful lifetime prediction of Rail pad for High Speed Railway,” *Proc., KSAE Spring Conference*, Jeju, Korea, April 2009, Korean Society of Automotive Engineers, Seoul, Korea.