Accelerated Thermal Aging Studies on Natural Rubber in Seismic Isolation Bearings

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1. Introduction

The long-term performance of rubber bearing isolation systems depends mainly on the deterioration of the rubber over time. The deterioration of rubber materials is likely to occur under severe environmental attacks such as thermal oxidation, ozone, and ultraviolet radiation. Most rubbers harden and eventually become brittle owing to the aging process.

The thermal aging is known to be the most significant factor in the deterioration of rubber materials. The ambient temperature substantially increases the stiffness and damping of the rubber bearings, even at room temperature. Under low temperature, a long duration of exposure increases both quantities. High temperatures have a significant effect on the mechanical properties of rubber bearings. This study focuses on the aging behavior of natural rubber material used in seismic isolation bearings by accelerated heat exposure tests.

2. Accelerated Test

The thermal aging of natural rubber specimens was carried out in a temperature-controlled air aging oven. The test specimens were exposed for a series of temperatures and times: the temperatures were 70°C, 85°C, and 100°C, and the aging times were 1, 2, 4, 7, 15, 30, 45, 60, 75, 90, 120, 150, and 180 days. Tests were carried out in accordance with the method of aging test indicated by ISO 22762-1 [1]. As the basic properties of the rubber material, hardness, elongation, and tensile strength were measured. For the shear properties, shear modulus and equivalent damping ratio were evaluated. To investigate a failure mode at the steel plate and rubber interface, a 90° peel test was conducted.

3. Results and Discussion

Fig. 1 shows the results obtained from accelerated thermal aging tests for the natural rubber specimens. The aging behaviors of rubber material are briefly described.

3.1 Hardness

Hardness increases with time but the change is not significant. The curves of hardness change were complicated. The hardness rises gently at the two lower temperatures, 70°C and 85°C. At 100°C, the increase of hardness rises gently until 30 days, but a sharp rise appears after 60 days.

3.2 Elongation

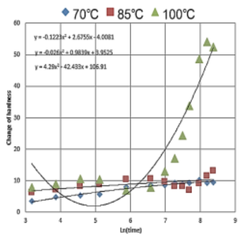
The curves of elongation change show a downward trend with the exposure time. This trend is similar to the case for natural aging. The elongation of rubber deteriorates rapidly at longer exposure times and at higher temperatures. The pattern of change was quite consistent at the three different temperatures.

3.3 Tensile Strength

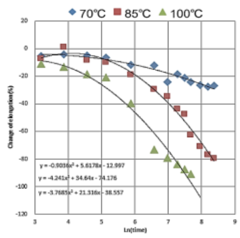
The tensile strength of rubber tends to decrease with an increase in time and temperature of the exposure. However, a slight increase was obtained in the specimens with short exposure times.

3.4 Shear Modulus

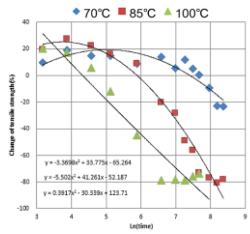
Shear modulus was determined using cyclic behaviors. When excluding some scattered results, the trend of change with time is relatively simple. The curves of change of shear modulus show an upward trend with time.



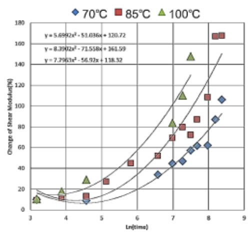
a) Hardness



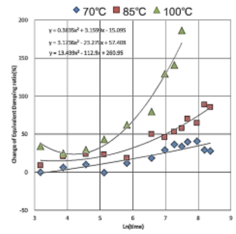
(b) Elongation



(c) Tensile Strength



(d) Shear Modulus



(e) Damping Ratio

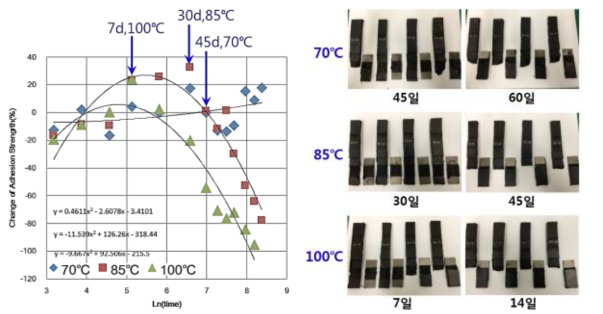
Fig. 1. Variation of property change of rubber material by accelerated heat aging.

3.5 Damping Ratio

The change of damping ratio tends to increase with time of exposure. A sharp rise appears after 4 days at 100°C.

3.6 Adhesion

The test results of adhesion between the rubber and the steel plates were complicated. The accelerated specimens under short exposure have failed at the interface between the rubber and the layer of the adhesive, while those under a long exposure have failed in the rubber, as shown in Fig. 2.
The specimens that had been exposed for 45 days at 70°C showed both adhesive and rubber failures, and those for 60 days at 70°C showed a rubber failure. The specimens that had been exposed for 30 days at 85°C showed adhesive failure but those for 45 days at 85°C showed a rubber failure. For a temperature of 100°C, a change in failure type appeared at 7 days.



(a) Adhesion Strength (b) Failure types

Fig. 2. Variation of adhesion strength and failure types at the rubber and steel plate interface by heat aging.

3.7 Lifetime Prediction

Long-term prediction of mechanical properties can be made through short-term material tests. The Arrhenius equation, which represents the relationship between the reaction rate and temperature, is used for assessing the lifetime. The reaction rate at any temperature is obtained from the change in the selected property with exposure time at that temperature. Using the accelerated thermal aging test results, the Arrhenius equations for the selected properties of rubber material were proposed, as shown in Table I. The limits of the property change for hardness, elongation, and tensile strength were in accordance with BS EN 1337-3 [2]. The change limits for the shear modulus and damping ratio were assumed to be based on the author's judgment.

Table I: Arrhenius Equations as a Function of Temperature

Property	Change of Property	Arrhenius Equation
Hardness	10%	$\ln(t) = -17.706 + 9066/(273+T)$
Elongation	-25%	$\ln(t) = -29.070 + 12679/(273+T)$
Tensile Strength	-15%	$\ln(t) = -33.156 + 14185/(273+T)$
Shear Modulus	25%	$\ln(t) = -11.861 + 6237/(273+T)$
Damping Ratio	25%	$\ln(t) = -23.168 + 10295/(273+T)$

Using the Arrhenius equations proposed in Table I, the long-term prediction of the selected material properties of rubber is evaluated as shown in Fig. 3. A significant deterioration can occur in the shear modulus owing to high temperatures. As the ambient temperature increases, the aging of the rubber proceeds rapidly. Table II shows that the lifetime of natural rubber will be quite different according to the ambient temperatures.

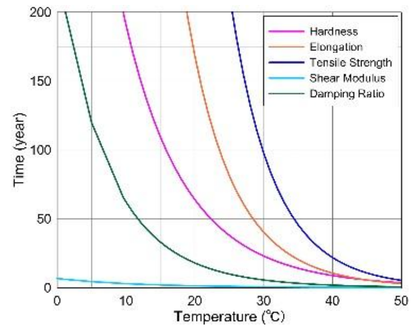


Fig. 3. Prediction of material properties at ambient temperatures.

Table II: Lifetime Prediction of Rubber Based on Mechanical Properties at Ambient Temperature

Temperature (°C)	Hardness (years)	Elongation (years)	Tensile Strength (years)	Shear Modulus (days)	Damping Ratio (years)
20	64	168	482	516	18
25	38	81	214	361	10
30	23	40	97	255	6

4. Conclusions

Accelerated thermal aging tests were carried out for a natural rubber material, and its lifetime was predicted. The deterioration of the rubber material is more significant at high ambient temperature. In addition, the deterioration of rubber influences the adhesion between the rubber and the steel plates. Dynamic properties of the rubber will be a critical factor for defining the service time of seismic isolation bearings.

Acknowledgement

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REFERENCES

[1] ISO 22762-1, Elastomeric Seismic-Protection Isolators – Part 1: Test Methods, 2010.
[2] BS EN 1337-3, Structural Bearings – Part 3: Elastomeric Bearings, 2005.