THERMAL AGING BEHAVIOR INSIDE HDR BEARING

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Abstract

Among various degradation factors, thermal oxidation plays the most significant role during the aging process of high damping rubber (HDR) material. However, as for HDR bearing, aging displays the feature of a diffusion-limited oxidation. Material properties develop heterogeneously from the bearing surface to the interior. In the accelerated thermal oxidation test, it is discovered that besides oxidation, temperature may also cause HDR to deteriorate. In order to distinguish the temperature effect from the oxidation effect, an accelerated aging test is designed and performed. In this test, specimens are divided into two groups. In one group, all specimens are directly exposed to air, while in the other group specimens are heated in an oxygen-free container. The oxidation group is thought to represent the HDR bearing surface, while the oxygen-free group represents the interior region. In each group, there are two types of specimens, one for uniaxial tension test, and the other for lap-shear test. The environmental temperature is set as 70℃ and the thermal aging time is divided into 7 stages, the initial state, 1, 2, 5, 10, 20 and 40 days. When aged to a certain time, the specimens are taken out, and the uniaxial tension test and the lap-shear test are performed. The comparison between the property variations in those two groups gives valuable insight into the thermal aging behaviors inside HDR bearings. In addition to these specimens, small sized HDR bearings are also put into the air-aging oven and accelerated aged. At the prescribed time, HDR bearings are sliced to pieces to verify the above test results.

INTRODUCTION

In the early 1980's, the development in rubber technology led to new rubber compounds, which were termed high damping rubber (HDR). HDR material possesses both flexibility and high damping properties. The bridge bearings made of HDR can not only extend the natural period of the bridge, but also reduce the displacement response of structures. Moreover, because of the inherent high damping characteristics of HDR, there is no need of additional devices to achieve the required levels of protection from earthquakes for most applications, so that the seismic isolation system becomes more compact.

All rubber materials are attacked by oxygen, even at room temperature, and heat, light, dynamic strain and liquids (Robert, 1988). The degradation process of physical properties is called aging. In order to evaluate the aging behavior of HDR material, a series of accelerated exposure tests were performed by Itoh et al. (2005, 2006a) It was found that the thermal oxidation is the most predominant degradation factor affecting the HDR material. Through accelerated thermal oxidation tests on HDR blocks, Itoh et al. (2006b) also found that the aging HDR bearing displays the feature of a diffusion-limited oxidation. Properties of the outer surface change most greatly and keep changing over the time. However, the interior region of HDR only shows a rapid change during the earliest time and then keeps invariable. Test shows that even at normal temperatures, the elongation at break (EB) of the whole HDR blosck decreases about 20% within only one year. Since generally aging is related to the oxidation process, the rate and extent of diffusion of oxygen through the rubber governs the change in properties due to aging. In the case of rubber bearings, oxygen ingress is generally limited to a thin layer of exterior edge surface because the aged rubber will inhibit the permeation of oxygen and the interior region cannot touch the degradation factors like oxygen, acid rain, ozone, etc. Therefore, it should be heat that causes HDR to deteriorate.

This paper tried to reveal the thermal aging behaviors inside HDR bearing through accelerated thermal test. In order to evaluate the influence of heat, the specimens are divided into two groups. In one group, all specimens are directly exposed to air, while in the other group specimens are heated in an oxygen-off container. Since it is hard for normal uniaxial tension tests to reflect the hysteresis behavior of HDR, one of the most important merits of this material, lap-shear tests are performed to give supplement information. Besides, small-sized HDR bearings are also accelerated aged and performances are tested. Then those bearings are sliced to pieces to investigate the property variations.

The HDR specimens are provided by Tokai Rubber Industries, Ltd. It is possible that when suffered by aging, the HDR from other companies may behave differently due to the difference of chemical compound.

ACCELERATED THERMAL TEST WITH AND WITHOUT OXYGEN

HDR Specimens

There are two types of specimens, one is No.3 dumbbell specimens, and the other is lap-shear specimens, as shown in Fig.1(a) and Fig.1(b), respectively. Usually the lap-shear specimens should adhere to the metal plates before aging test. However, if adhering to the metal plates, oxygen cannot permeate into the center region of the specimen, so that in the thermal oxidation test the lap-shear specimens are aged without adhering to the metal plates, as shown in Fig.1(c). After the aging test, the rubber specimens are adhered to metal plates using special glues. The lap-shear specimens with metal plates are only tested in oxygen-off test.

(a) No.3 Dumbbell Specimens (b) Lap-Shear Specimens (c) Lap-Shear Specimens without Metal Plates

Fig.1 HDR Specimens

Equipment of Test

In order to heat the HDR specimens in an oxygen-off environment, a lever band container CTL-30 produced by Nitto Metal Industries Co. is used, as shown in Fig.2. The container is airproof, and there are two valves on the cover, through which the oxygen in the container can be released. The accelerated thermal tests are carried out in a temperature-controlled air-aging geer oven, which is produced by Toyo Seki Seisaku-sho Co., as shown in Fig.3.

Fig.3 Lever Band Container CTL-30

Fig.4 Air-Aging Geer Oven

Test Conditions

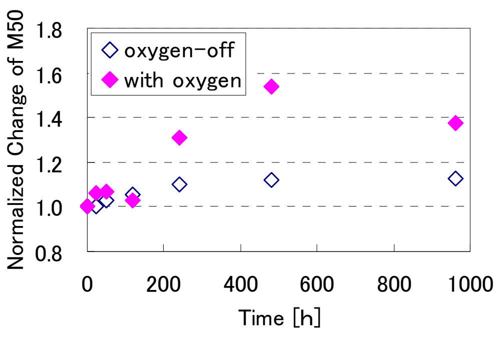
The specimens and the test conditions are presented in Table 1. There are 28 No.3 dumbbell specimens and 28 lap-shear specimens in each group. The test temperature is 70℃, and the thermal aging time is divided into 7 stages, the initial state, 1, 2, 5, 10, 20 and 40 days.

Table 1 Test Specimens and Conditions in the supplementary test

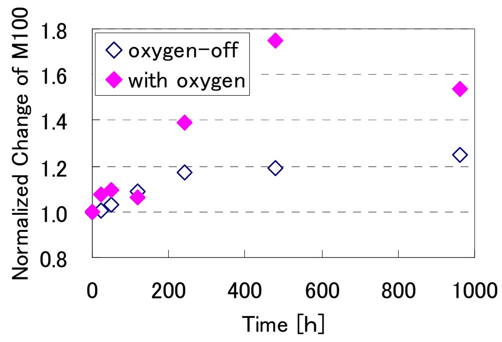
Specimen	Test Condition	Test Duration (days)	Number	Total
No.3 dumbbell specimen	Initial state	—	4	28
	70℃, oxygen free	1, 2, 5, 10, 20, and 40	4×6=24	
No.3 dumbbell specimen	Initial state	—	4	28
	70℃, oxidized	1, 2, 5, 10, 20, and 40	4×6=24	
Lap-shear specimen adhering to metal plates	Initial state	—	4	28
	70℃, oxygen free	1, 2, 5, 10, 20, and 40	4×6=24	
Lap-shear specimen without metal plates	Initial state	—	4	28
	70℃, oxidized	1, 2, 5, 10, 20, and 40	4×6=24	

Experimental Results

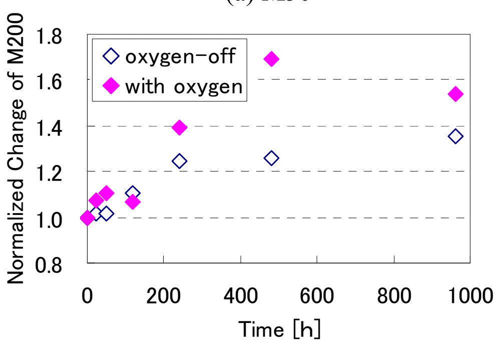
First, uniaxial tensile tests are performed on No.3 dumbbell specimens. The inspection method conforms to the quality inspection method specified by JH as well as the specifications in JIS K6251 and K6253 about the general rules of physical testing methods for vulcanized rubber. Since the stress-strain relationship of rubber material shows high non-linearity, it is difficult to calculate the stiffness using the secant method. For all the aged rubber samples, the stresses at 25%, 50%, 100%, 200% and 300% strain, i.e. M25, M50, M100, M200 and M300, tensile strength (TS) and the elongation at break (EB) are taken as the evaluation indexes. The normalized changes of those properties are compared in Fig.5. In this figure every point represents the average value of 4 samples. It is clear that in the oxygen state properties of HDR change faster than in the oxygen-off state.



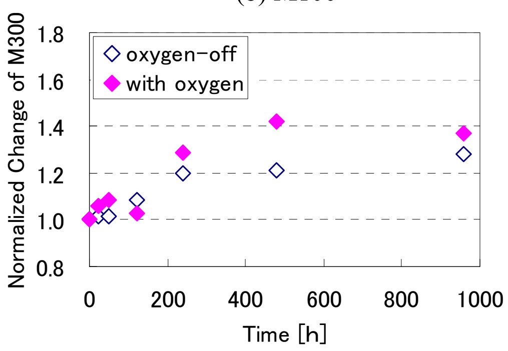
(a) M50



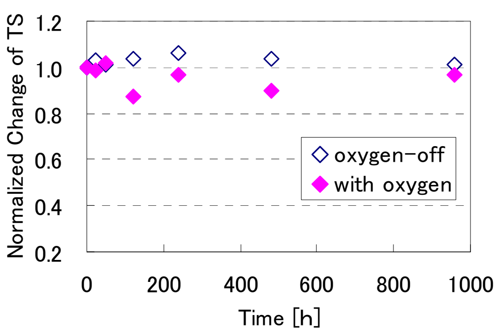
(b) M100



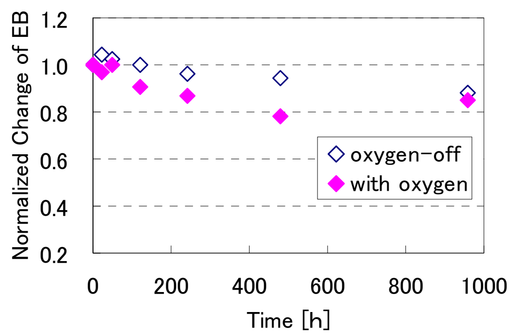
(c) M200



(d) M300

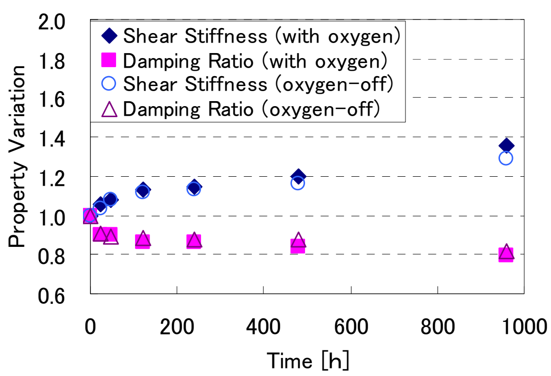


(e) TS

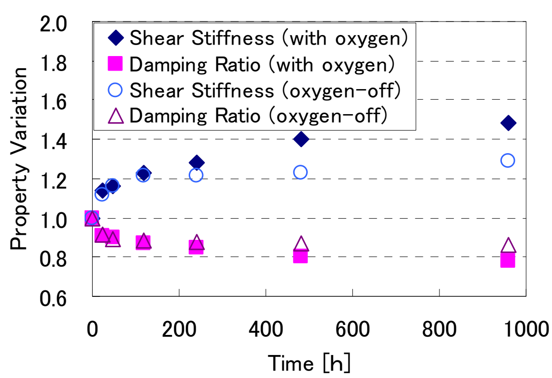


(f) EB

Fig.5 Uniaxial Tensile Test Results



(a) Shear Strain of 50%



(b) Shear Strain of 150%

Fig.6 Lap-Shear Test Results

Next, lap-shear tests are performed on lap-shear specimens. The shear stiffness and damping ratio are measured when the shear strain is 50% and 150%, as shown in Fig.6. Fig.6(a) shows that at low strain the differences between the oxygen state and the oxygen-off state are not very obvious. However, in Fig.6(b), at 150% shear strain both shear stiffness and damping ratio changes faster in the oxygen state than in the oxygen-off state. After heated for 960 hours, in the oxygen state the shear stiffness increases by 50%, while in the oxygen-off state only increases by about 30%. On the other hand, the damping ratio decreases by 20% in the oxygen state, and decreases by about 15% in the oxygen-off state.
Both the uniaxial tensile test and the lap-shear test prove that HDR deteriorates even in an oxygen-off environment. However, the existence of oxygen will accelerate the aging process.

ACCELERATED AGING TEST ON SMALL-SIZED HDR BEARING

Small-Sized HDR Bearing

Because normal HDR bearings used in bridges are too large for the chamber of the air-aging geer oven, in the accelerated aging test 4 small-sized HDR bearings are used. The dimension of the tested HDR bearing is shown in Fig.7. The bearing has a size of 300×300mm and a height of 101mm. The steel plates are 280mm square, the thickness of upper and bottom plates is 25mm, and that of the inner plates is 3mm. There are six rubber layers with a thickness of 6mm. The design specifications are presented in Table 2. Fig.8 shows the small-sized HDR bearing heated in the air-aging geer oven.

Table 2 Design Specifications of Small-Sized HDR Bearing

Dimension of Compression Area [mm]	280×280
Thickness of Rubber Layer [mm]	6
Thickness of Steel Plate [mm]	3
Thickness of Covering Rubber [mm]	10
Number of Rubber Layers	6
Number of Steel Plates	5
The 1st Shape Factor	11.7

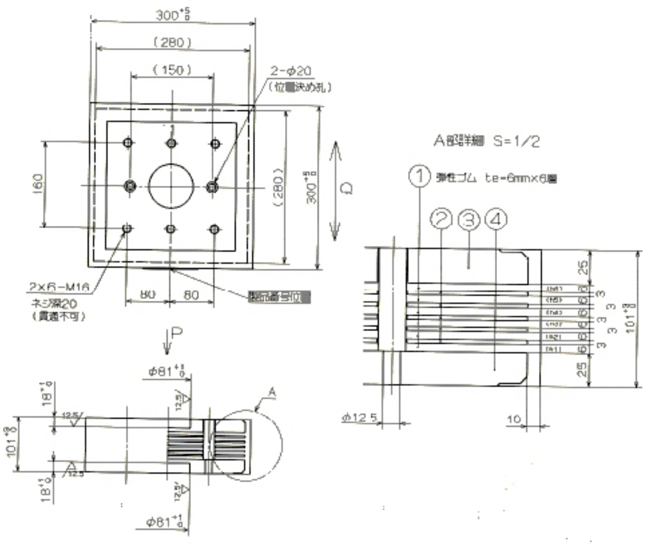


Fig.7 Dimension of Small-Sized HDR Bearing

Fig.8 HDR Bearing in Geer Oven

Test Conditions

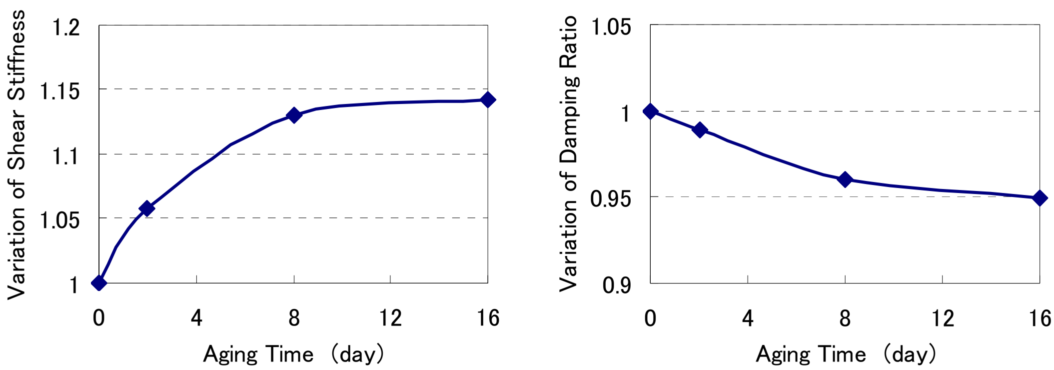
There are six small-sized HDR bearings provided by Tokai Rubber Industries, Ltd. First lap-shear tests are performed on 4 bearings in the initial state. In the lap-shear test, the compression force is 472kN (intensity of pressure: 6.0MPa), and in the horizontal direction amplitude is 63mm (shear strain: 175%). Sine waves with a frequency of 0.02Hz are inputted for 11 cycles. Then the shear stiffness and the damping ratio are measured. Since the first-time deformation of HDR bearing will influence the following mechanical performance, one HDR bearing is tested twice in the initial state to get the correction factor. Three bearings are heated at 80℃ for 2, 8 and 16 days. Then lap-shear tests are performed on those aged the bearings again and the shear stiffness and the damping ratio are compared with the original values. Besides, in order to investigate the property variation inside HDR bearing, two HDR bearings are sliced.

Experimental Results

The Test results are listed in Table 3. From the twice tests in the initial state it is calculated that the correction factors are 0.988 for shear stiffness and 0.968 for damping ratio. Using these factors to modify the test results after aging, the variations of shear stiffness and damping ratio are plotted in Fig.9. It is found that the shear stiffness of HDR bearing increases due to thermal aging, while the damping ratio decreases. After 16 days of heating at 80℃, the shear stiffness increases by nearly 15%, and the damping ratio decreases by about 5%.

Table 3 Shear Stiffness and Damping Ratio Before and After Aging

Aging Time	Shear Stiffness (kN/mm)		Damping Ratio (%)	
	Before Aging	After Aging	Before Aging	After Aging
Initial State	1.823	1.800	18.16	17.59
48 hours	1.831	1.912	18.16	17.39
192 hours	1.805	2.014	18.17	16.90
384 hours	1.789	2.019	18.30	16.83



(a) Shear Stiffness (b) Damping Ratio

Fig.6 Accelerated Aging Test Results of Small-Sized HDR Bearings (80℃)

Experimental Results

ACKNOWLEDGMENT

The authors wish to express their gratitude to Tokai Rubber Industries, Ltd. for the support of the HDR bearings and accelerated aging tests.

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