OZONE-INDUCED CRACK ON BASE-ISOLATED NATURAL RUBBER BEARING SUBJECTED TO EXTERNAL LOADS AND ITS REPAIR

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ABSTRACT

In order to investigate crack occurrence condition of natural rubber bearings of bridges, a series of accelerated exposure experiments applying the environmental degradation factors (temperature and ozone) and external loads on the rubber bearing specimen was carried out. The condition of ozone-induced crack occurrence was identified. That is, cracks occurred in the regions with local tensile strain on the surface of rubber bearing by 40 degrees Celsius of temperature and 100 pphm of ozone density. Furthermore, the cracks were repaired by coating with polyethylene material. The repaired cracks were not extended under the same experimental condition. The load carrying capacities of the virgin rubber bearing, the bearing with cracks and the repaired bearing were almost the same because the cracks were generated only in the surface rubber cover of specimen.

Keywords: Base-isolated natural rubber bearing, Crack, Ozone, Load, Repair.

1. INTRODUCTION

Natural rubber is widely used as a material for base-isolated bearings for bridges and buildings. However, the mechanical properties of natural rubber are changed due to several factors such as temperature, solar radiation, and ozone (Itoh et al., 2006). Recently, cracks induced by ozone are observed on the surface of base-isolated natural rubber bearings of bridges. These rubber bearings are relatively new being used only in a few years. Originally, the ozone-induced cracks occurred in the natural rubber bearings of bridges in cold region in Japan around 2000. It was estimated that the main cause of cracks was the low performance of anti-aging agent contained in the natural rubber under the cold environments. Then, the improved anti-aging agent was developed and its availability was confirmed (Sugimoto et al., 2001). Although the present natural rubber bearings contain the improved anti-aging agent, the cracks still occur in the natural rubber bearings not only in cold region but also normal temperature region. The load carrying capacity of natural rubber bearing is not decreased even though the cracks occur on the surface of rubber bearing. However, there is a possibility that the load carrying capacity of natural rubber bearing is decreased when the surface cracks reach the rubber layers inside the bearing. Furthermore, the serious damage is anticipated when the large load and uplift force by earthquake are applied on the natural rubber bearing with cracks (Yamada et al., 2013).

It is still unknown how the crack is initiated and propagated on the surface of natural rubber bearings. To solve this problem, a series of accelerated exposure experiments applying environmental degradation factors (temperature and ozone) and external loads on a natural rubber bearing specimen were carried out. A large experimental apparatus for the accelerated exposure experiments was newly developed. The rubber bearing specimen with external loads was subjected to several conditions of ozone density and temperature in the chamber. The condition of ozone-induced crack occurrence was identified by these experiments. Furthermore, a repair method was investigated for the generated ozone-induced crack and the repair performance was evaluated.

2. TEST SPECIMENS

2.1. Rubber material

Table 1 shows the compositions of natural rubber material used in this study. That contains the anti-aging agent of which the performance under the low temperature condition was improved. The natural rubber materials are provided by Kawakin Core Tech Co. Ltd.

Table 1: Components of rubber material (weight ratio)

Natural rubber	N330 Carbon	Naphthenic oil	Anti-aging agent (TMDQ)	Anti-aging agent (IPPD)	Wax	Oxide zinc	Stearic acid	Accelerator (CBS)	Accelerator (TMTD)	Sulphur	Total
100	40	10	1.5	1.5	1.5	5.0	1.0	1.5	1.5	0.5	163.5

2.2. Dumbbell specimens

For identifying the conditions of generating cracks in the natural rubber material, specimens shown in Figure 1 are used (Japanese Standards Association 2010). The shape of specimen is like a dumbbell, so called, a dumbbell specimen. The dumbbell specimens are lengthened by the metal rig shown in Figure 2. The dumbbell specimens applied pre-strain by the rigs are set in the chamber of accelerated exposure experimental system.

2.3. Bearing specimens

Figure 3 shows the natural rubber bearing specimen used in this study. 6 sheets of the natural rubbers with 8 mm thick and 5 sheets of steel plates (SS400) with 3.2 mm thick are layered alternatively. These rubber sheets and steel plates are square of 200 mm x 200 mm. The steel plates (SM490A) with 22 mm thick are set on the top and bottom of the bearing. The height of the

Thickness: 2 mm

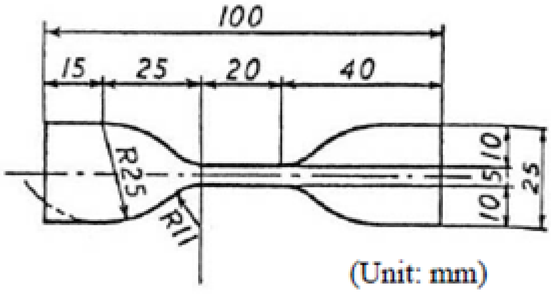


Figure 1: Dumbbell specimen

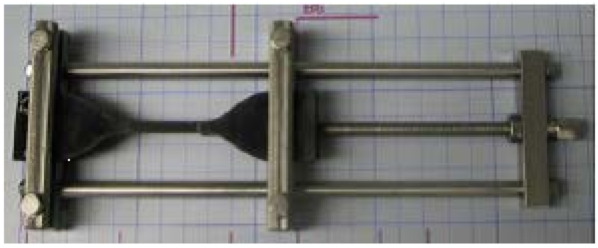


Figure 2: Dumbbell specimen with pre-strain

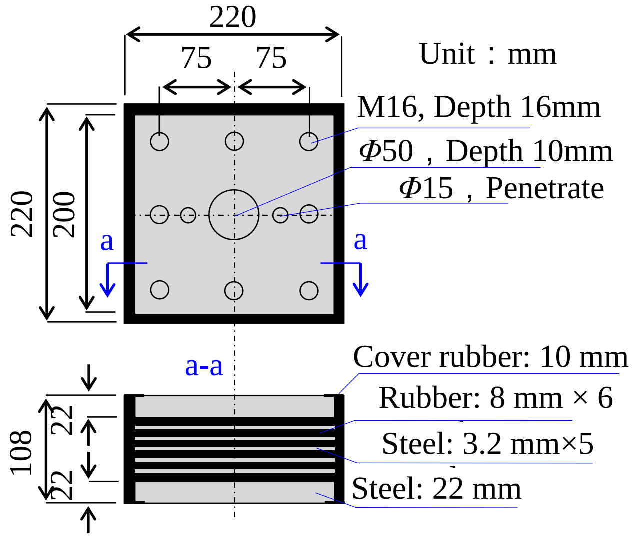


Figure 3: Bearing specimen

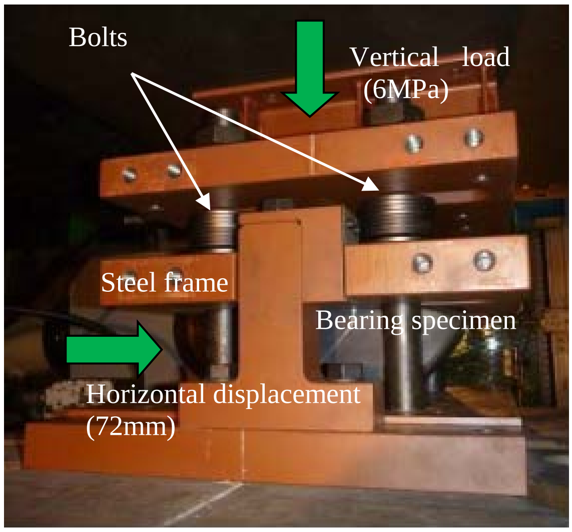


Figure 4: Deformation of bearing specimen by steel frame

bearing specimen is 108 mm. The surface of bearing is covered by the natural rubber with 10 mm thick.

For applying and locking the shear deformation on the bearing specimen, the steel frame shown in Figure 4 is used. The bearing specimen is set in the steel frame with bolt holes. The specified horizontal deformation of 72 mm, which corresponds to 150 % of the total thickness of rubber layers (8 mm x 6 sheets), is applied on the top of the steel frame. And then, the vertical pressure of 6 MPa is applied and the bolts are fixed for locking the horizontal deformation.

The bearing specimen with shear deformation is set in the chamber of accelerated exposure experimental system.

3. ACCELERATED EXPOSURE EXPERIMENTS

3.1. Experimental system

The dimension of chamber of the accelerated exposure experimental system used in this study is 1500 mm wide, 1000 mm long and 1000 mm high. The bearing specimen with the steel frame for applying the shear deformation can be set in the chamber. The number of the dumbbell specimens hanged on the top of the chamber is around 150. The temperature range is from -30 to 50 degrees Celsius. The maximum ozone density is 150 pphm (Japanese Standards Association 2004).

3.2. Accelerated exposure experiments on dumbbell specimens

In order to identify the condition of ozone-induced crack occurrence of the natural rubber material, a series of accelerated exposure experiments was carried out on dumbbell specimens. Table 2 shows the experimental conditions. The temperature conditions were -30, -15, 0 and 23 degrees Celsius which occur in the general situations. The crack occurrence was examined at every 24 hour by visual check and observation with microscope. Table 2 and Figure 5 show the experimental results. X in Table 2 means the crack occurrence or break of dumbbell specimens. On the other hand, the bar means that cracks could not be observed by visual checks and even the microscope.

Table 2: Experimental conditions and their results

Condition	(1)			(2)			(3)			(4)			(5)		
Temperature (degrees Celsius)	-30			-15			0			23			23		
Ozone density (pphm)	150			150			150			50			100		
Pre-strain (%)	0	40	75	0	40	75	0	40	75	0	40	80	0	40	80
Time (hour)	480	480	480	96	96	96	96	96	24	192	192	192	192	144	24
Crack or break	-	-	-	-	-	-	-	-	X	-	-	-	-	X	X

X: Crack occurrence

No crack could be observed after finishing 480 hours of the experiment under the condition (1). Furthermore, cracks were not observed after finishing 96 hours of the experiment although the temperature was heightened by the condition (2). The temperature was slightly arisen by the condition (3), then, cracks were generated and the dumbbell specimens were broken at 24 hours in the cases with pre-strain of 75 %. The results indicated that cracks easily occur by the not so low temperature condition such as 0 degrees Celsius rather than the low temperature condition of -30 degrees Celsius with the high ozone density and the large pre-strain. However,

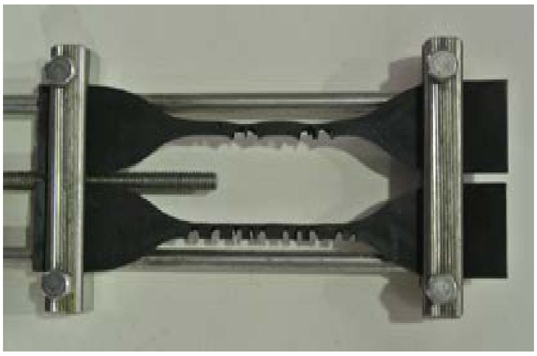


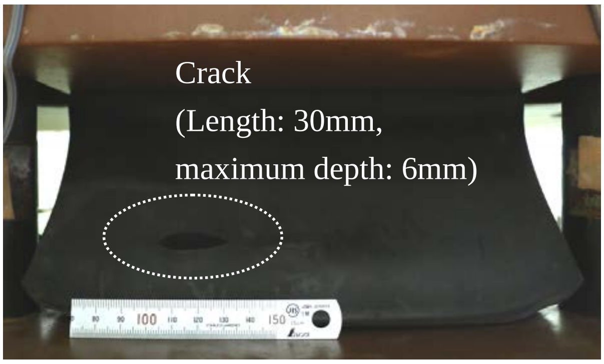
Figure 5: Damaged dumbbell specimen (condition (5), pre-strain 80%)

in the case that the temperature was more heightened to 23 degrees Celsius and the ozone density was decreased to 50 pphm, cracks did not occur regardless of the magnitude of pre-strain after the experiment of 192 hours (the condition (4)). Based on these results, the experiment was performed by the condition (5), of which the temperature was 23 degrees Celsius and the ozone density was 100 pphm. Then, cracks or breaking occurred earlier according to the magnitude of pre-strain.

3.3. Accelerated exposure experiments on bearing specimens

The accelerated exposure experiment was performed on the bearing specimen under the condition of which the temperature was 23 degrees Celsius and the ozone density was 100 pphm. However, cracks did not occur on the surface of specimen after the experiment of 96 hours. It might be thought that the resistance toward ozone attack of the bearing specimen was higher than that of the dumbbell specimens of which the thickness was just 2 mm and which is subjected to ozone attack from the both surfaces. Therefore, the temperature was heightened to 40 degrees Celsius and the experiment was carried out again. As a result, cracks were observed as shown in Figure 6 after the experiment of 384 hours. The crack occurrence positions were corresponded to the region in which the high tensile strain was locally applied. The maximum length and depth of crack obtained by this experiment were around 30 mm and 6 mm respectively. The cracks stopped in the surface cover rubber and they did not reach the rubber layers inside the bearing specimen.

(a) Front side



(b) Back side

Figure 6: Cracks of bearing specimen

4. CRACK REPAIR BY CSM COATING

4.1. Repair procedure

The cracks of bearing specimen generated by the accelerated exposure experiment were repaired by CSM (Chlorosulfonated polyethylene) coating. Figure 7 shows the flow of crack repair. Firstly, the steel frame for applying the shear deformation on the bearing specimen was removed. The region around the small cracks were cleaned and primed. And then, the cracks were covered by the CSM coating. In the case of the large crack, the crack was removed by grinding, and then the

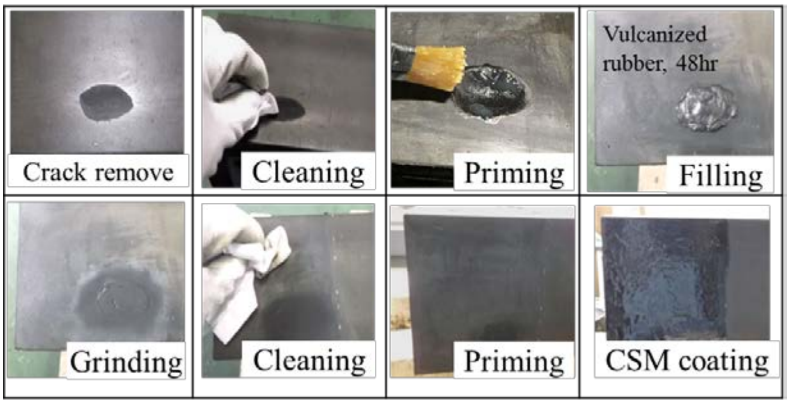


Figure 7: Crack repair flow

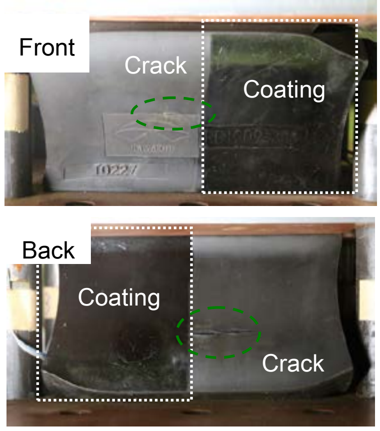


Figure 8: Cracks of repaired specimen

region around the crack was cleaned and primed. The hole due to removing the crack was filled with vulcanized rubber. 48 hours after, the surface of the part filled with the vulcanized rubber was smoothed, cleaned, primed. Finally, that part was covered by the CSM coating. The coating repair was performed on the half of the surface including the crack for examining the repair performance of the CSM coating by comparing the coated part and that without coating.

4.2. Accelerated exposure experiment on repaired bearing specimen

The accelerated exposure experiment was applied on the bearing specimen of which the cracks were repaired by the CSM coating. The experimental condition was the temperature of 23 degrees Celsius and the ozone density of 100 pphm. Figure 8 shows the appearance of specimen after the experiment. The new cracks were generated in the regions without coating after 192 hours of the experiment. However, no crack was re-generated in the repaired region by the CSM coating even after 384 hours of the experiment. The experimental results showed the repair performance of the CSM coating.

5. LOADING EXPERIMENTS ON BEARING SPECIMENS

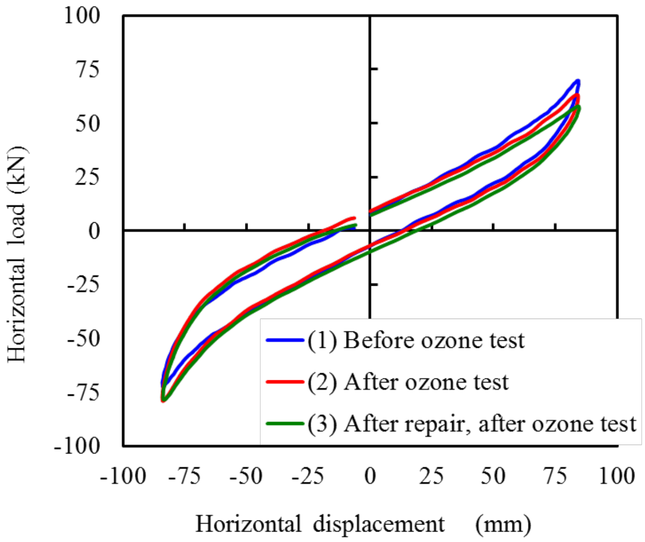
5.1. Experimental conditions

A series of loading experiments was performed on the bearing specimen for investigating the influence of cracks on the mechanical performances of the bearing specimen. The loading experiments were carried out on the bearing specimen of the following three states.

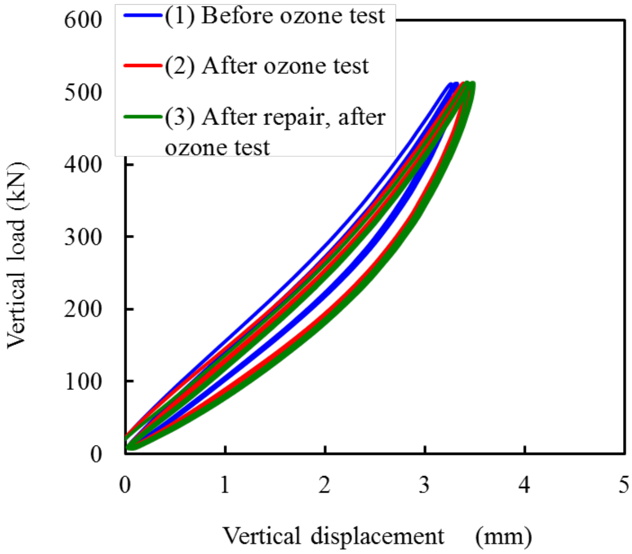
(1) Before the accelerated exposure experiment (Virgin state).

(2) After the first accelerated exposure experiment (With small and large cracks).

(3) After the crack repair and the second accelerated exposure experiment (With the CSM coating and new cracks).



(a) Horizontal loading



(b) Vertical loading

Figure 9: Results of loading experiments

A cyclic horizontal displacement of ±84 mm, which corresponded to ±175 % of shear deformation, was applied by 3 times on the bearing specimen with vertical pressure of 6 MPa. On the other hand, a cyclic compressive load from 0 MPa to 12 MPa was applied by 3 times during 20 seconds on the bearing specimen. The loading frequency was 0.5 Hz.

5.2. Experimental results

Figure 9 shows the results of loading experiments. The vertical displacement of the bearing specimen with small and large cracks occurred by the first accelerated exposure experiment (state (2)) increased by 4 % from that of the virgin state (state (1)). The vertical displacement of the bearing specimen of which the cracks were repaired and after the second accelerated exposure experiment (state (3)) increased by 3% from the virgin state (state (1)). The horizontal stiffness of them were almost the same as that of the virgin state. All of the three states satisfied the design specifications of vertical displacement and horizontal stiffness. No crack propagation could be observed by the loading experiment. It might be thought that the influence of cracks generated by the accelerated exposure experiments on the mechanical performances of bearing specimen was not so large because the cracks did not reach the rubber layers inside the specimen.

6. CONCLUSIONS

A series of accelerated exposure experiments applying the environmental degradation factors (temperature and ozone) and external loads on natural rubber bearing specimens was carried out for identifying the conditions which cause cracks on the surface of natural rubber bearing for bridges. Furthermore, a repair method was investigated for the generated ozone-induced crack and the repair performance was evaluated.

The main conclusions obtained are as follows.

(1) Ozone-induced cracks occurred in the dumbbell specimens with natural rubber material used for bridge bearing under the high temperature (23 degrees Celsius) and high ozone density (100 pphm) condition. Furthermore, the larger the magnitude of pre-strain was, the earlier the cracks or breaking occurred.

(2) Cracks occurred on the surface of bearing specimen under the high temperature (40 degrees Celsius) and high ozone density (100 pphm) condition. The cracks occurred in the region which the high tensile strain was applied on. The features of cracks were almost the same as that observed in the actual rubber bearing used during 10 or more years in the general temperature sites.

(3) The generated cracks on the surface of bearing specimen were repaired by CSM (Chlorosulfonated polyethylene) coating. Although the accelerated exposure experiment was performed on the repaired bearing specimen, no crack occurred from the repaired part by the CSM coating. The new cracks occurred from the part which the CSM coating was not applied on. The result indicated the repair effect of the CSM coating.

(4) The influence of cracks generated by the accelerated exposure experiments on the mechanical performances of bearing specimen was not so large because the cracks did not reach the rubber layers inside the specimen. No crack propagation could be observed by the cyclic loading experiment.

7. ACKNOWLEDGMENT

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