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EFFECT OF THERMAL AGING ON THE FATIGUE BEHAVIOR OF NATURAL RUBBER

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Abstract—This paper investigates the thermal aging effects on the fatigue life duration of natural rubber using volumetric test specimens under uniaxial loading condition. All samples were thermally aged in an oven at 70℃ and 120℃ in 48h and 96h. Then, the uniaxial tensile tests were performed at room temperature. It shows that with the aging temperature and time increase, the fatigue life of natural rubber decreases. The fracture areas also have different macro morphology.

Keywords-natural rubber; thermal aging; fatigue lifetime; uniaxial loading

I. INTRODUCTION

Due to their excellent ability of elasticity and large deformation capacity, rubbers are widely used in transportation industry, which makes it ideal for many applications, such as vibration isolators, gaskets, seals, tires and so on [1]. However, since these rubber products are often exposed to high temperature working environment for a long time, thermal aging has become an important factor affecting their fatigue life. Thermal aging refers to the irreversible changes in the composition, structure, and other mechanical properties of the material due to the exposure to the high temperature in the working environment [2]. It is necessary to evaluate the aging resistance of rubber products in transportation industry, however it may take very long time to observe the real aging process. Therefore, scientists have developed an accelerate test method [3] and explored the effect of thermal aging on the physical properties of rubber material in the past decade.

The elongation at break and fatigue life of natural rubber decreases when the aging temperature and aging time increase [4,5]. In addition, the occurrence of heat aging is often accompanied by oxidative aging, which makes the rubber surface hard. Therefore, under the cyclic loading condition, cracks are easily formed and lead to failure in a short time [5,6]. With the increase of heat aging temperature, the hardness of rubber will also increase, but the tensile strength and elongation will decrease [7]. Since Charrier et.al [8] focused on the application of rubber materials in automobile industry, they chose the relevant temperature range of 40℃ to 120℃ for the aging test. They observed the thermal-oxidation process showed on the failure surface.

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According to the selected natural rubber vibration isolator as the experimental sample, a suitable temperature range was also selected for the aging test. The aim of this study is to investigate the effect of thermal aging at 70°C and 120°C on the fatigue life of natural rubber under uniaxial tension loading condition.

II. EXPERIMENT SETUP

In this paper, all samples purchased from Elesa USA Corporation. The material used was a natural rubber with a typical vibration isolators rubber formulation and the hardness of 55 shore A. The configuration of samples shows in Fig.1.

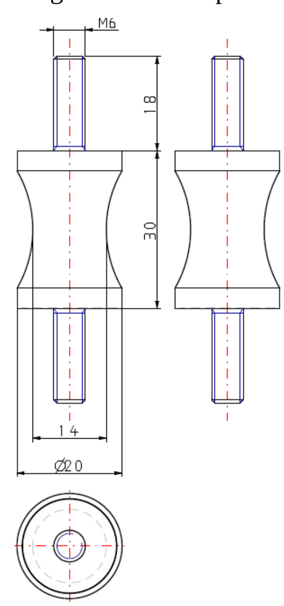

Figure 1. Configurations of the specimen.

According to the ASTM D572-04, all samples were exposed to temperatures of 70℃ and 120℃ for 48 hours and

96 hours, respectively. After the heat aging treatment, the samples need to be cooled to room temperature on the flat surface and rest not less than 16 h nor more than 96 h before doing the uniaxial tensile test.

Uniaxial tensile testing was carried out using the ElectroPuls E3000 All-Electric Dynamic Test Instrument (Fig.2) from Instron company. The uniaxial tensile test is strain controlled with the maximum strain of 50% at a frequency of 10Hz. All tests were performed at room temperature (23°C). In this study, the criterion of fatigue failure is the rubber samples fracture completely.

Figure 2. the ElectroPuls E3000 All-Electric Dynamic Test Instrument

III. RESULTS AND DISCUSSION

A. *Thermal aging effect of fatigue lifetime*

The figure 3 shows the relationship between the number of cycles and thermal aging condition. Under the heat aging condition of 70°C, with the increase of aging time, the fatigue life of natural rubber samples decreased slightly in proportion to the unaged samples. However, under the aging condition of 120°C, as the aging time increases, the fatigue life is dramatically reduced compared with the unaged sample. The fatigue life of the unaged sample can reach to 100,000 cycles. However, after 48 hours of aging at 120°C, the fatigue life decreases by about 30% which is almost 70,000 cycles. When the sample is aged at 120°C for 96 hours, the fatigue life of the sample is only about 14,000 cycles. This result is in consistence with findings of Tee et. al [5].

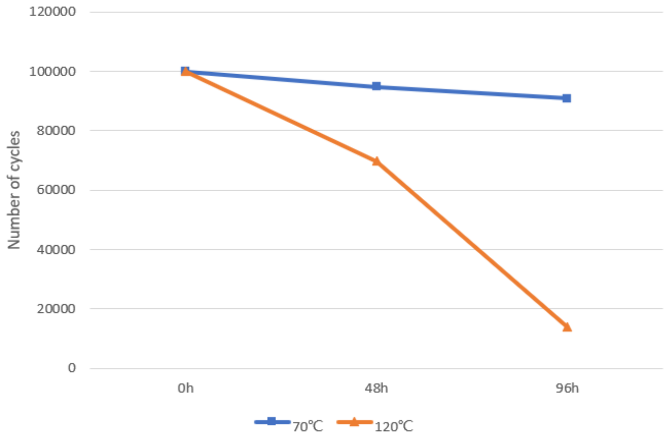

Figure 3. Fatigue life cycles in different aging condition

The figure 4 shows the relationship between loading and the number of fatigue life under different aging temperature and time. According to the figure 4, Before the rubber sample was obviously cracked, only the rubber sample aged at 120℃ for 96 hours had a significant decrease in tensile strength and broke quickly. The samples under the other three conditions and the unaged samples did not change significantly in tensile strength. However, although the samples aged at 120°C for 48 hours have no significant change in tensile strength, there is a significant decrease in fatigue life.

This shows that the aging environment of 70°C has little effect on natural rubber materials, while the aging temperature of 120°C causes more internal molecular chain breaks in natural rubber materials, resulting in rapid failure of rubber materials.

According to observations during the experiment, when the curve shows a downward trend, small cracks about 2 mm can be seen on the sample, and according to the curve in Fig. 4, it is known that the crack propagation speed is very fast. When small cracks appear, the sample will be completely broken within about 2000 cycles.

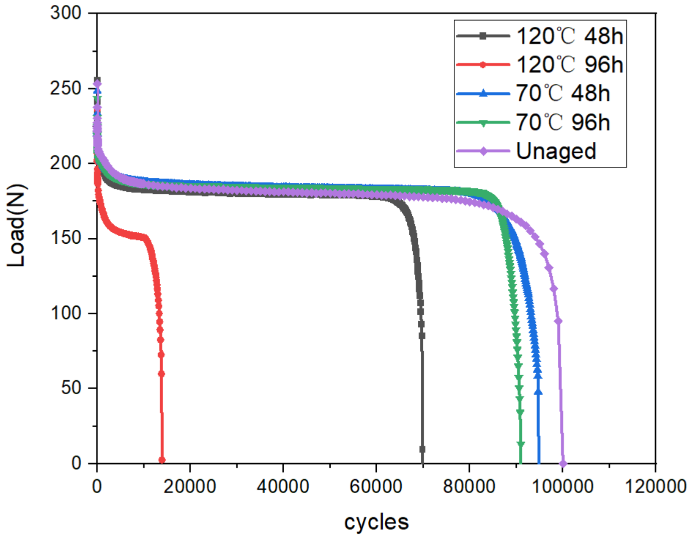

Figure 4. Relationship between load and fatigue life cycles in different aging condition

B. *Fracture surface in macroscopic scale*

Figure 5 shows the fracture surface of all aging conditions. For the samples aged at 70°C for 48 hours and 96 hours, the fracture surface is divided into two zones. After the microcracks appear on the surface, they gradually expand from the left to the right. The surface on the left is rough, and the right is smooth. This is because the final brittle fracture occurred in the sample, so the final fracture surface was smooth.

The fracture surface of the sample aged at 120°C for 48 hours looks like the sample aged at 70°C, but there are slight differences. Based on two zones, the sample aged at 120°C for 48 hours has a smooth and narrow ring near the surface. This feature looks clearer on the fracture surface of samples aged at 120°C for 96 hours. In other words, the crack propagation of this sample is divided into 3 zones and the direction is from the edge of the sample to the center. According to Charrier et.al [8], this phenomenon is due to the DOL (Diffusion Limited Oxidation) effect resulting in a sharp aging profile.

Figure 5. Fracture surfaces of fatigue test (from left to right are 70℃48h, 70℃96 h, 120℃48h, 120℃96h)

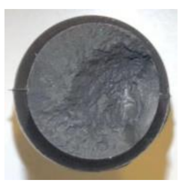

Figure 6. Fracture surface of unaged rubber sample of fatigue test

IV. CONCLUSION

This article aims to explore the influence of natural rubber vibration isolator on fatigue life under thermal aging conditions of 70°C and 120°C.

Under 70℃ aging conditions, the fatigue life is slightly reduced. As the aging temperature increases to 120℃, the fatigue life of natural rubber decreases significantly as the aging time increases.

The tensile strength is not affected under 70℃ aging conditions. However, after 96 hours of aging at 120℃, the tensile strength of the sample decreased by 25% and the fatigue life of the sample was greatly reduced, leading to rapid failure.

Different aging conditions lead to different fracture sections. With the increase of aging temperature and time, the DLO (Diffusion Limited Oxidation) effect is reflected on the fracture section.

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