Service Life Prediction of the Special Rubber Based on Nonlinear Regression Analysis

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Abstract. The accelerated aging tests of the special rubber were carried in laboratory. The tearing strength of the rubber in aging time was investigated. The rule of tearing strength and aging time was studied. The service life prediction function of the rubber was established and service life at 25℃ was estimated based on the index of tearing strength. The result shows that tearing strength of the rubber decreases in exponential form with aging time, and the service life of the rubber used in air at 25℃ is 35.79 years.

Introduction

Rubber represents a large family of polymers with many applications. Rubber widely used in many fields, such as aeronautics, astronautics, semiconductor, conveyor belts, biomaterials, ships, planes, cars and national defence, for their excellent elasticity and electrical resistivity [1-3]. And it has been widely reported that polymeric materials suffer severe degradation when they are used in outdoor, and that may endanger the safety of equipments and people [4-6]. So researches on the aging behavior and service life of the special are meaningful.

The mechanical properties of rubber, to some extent, determine the safety of the built-up member such as vehicles and spacecraft. Rubber aging failure is the main failure mode. Study on the service life prediction method of rubber can help predict rubber structure service life and failure position in advance, and then to replace the rubber structure or change the structure design to improve its service life [7-11]. However, the operational environment of rubber structure is complex, including the effects of temperature, external loads and so on.

In this work, the mechanical property change laws of special rubber were described and the accelerated aging tests of the rubber were carried in laboratory. The service life prediction model considering temperature effect is established. The life expectancy of the rubber was forecasted through detecting the physical properties of the rubber accelerated aging test in the hot air.

Experimental

Samples Preparation

The sheeted rubbers were cut into specimens according to GB528-82[12]. The samples were conditioned at temperature of 80℃, 100℃, 130℃ in air when the windage of aging temperature maintained at ±1℃. The interval between two samples should be no less than 5 mm. The samples were taken out when the aging time reach the set time, and they were conditioned at a temperature of 25±2℃ for no less than 4 hours before mechanical tests.

Mechanical Measurements

Mechanical tests were performed according to GB530-81[13] test method and were carried out using an Instron universal testing machine model TH-5000N at 25℃ and a crosshead speed of 500 mm/min.
Results and Discussion

Effect of Aging Time on Tearing Strength of the Rubber

Effect of aging time on tearing strength of the rubber aged in air was evaluated. The tearing strength of the samples aged in air at temperature of 80°C, 100°C, 130°C are shown in Figure 1, 2, 3 respectively. It can be observed that tearing strength of the rubber decreases with aging time.

Figure 1. Tear strength versus aging time for samples aging in air at 80°C.

Figure 2. Tear strength versus aging time for samples aging in air at 100°C.

Figure 3. Tear strength versus aging time for samples aging in air at 130°C.
The Relationships between Tearing Strength of the Rubber and Aging Time

Table 1. Tearing strength of samples aged in air at temperature of 80°C, 100°C, 130°C.

| Aging time(day) | Tearing strength(MPa) | Aging time(day) | Tearing strength(MPa) |
|----------------|-----------------------|----------------|-----------------------|
|                | 80°C                  | 100°C          | 130°C                 |
| 0              | 49.27                 | 49.27          | 49.27                 |
| 3              | 45.46                 | 44.83          | 33.02                 |
| 6              | 42.55                 | 37.52          | 29.04                 |
| 9              | 40.58                 | 37.29          | 21.89                 |
| 12             | 40.51                 | 33.14          | 19.93                 |
| 15             | 39.09                 | 31.76          | 15.58                 |
| 20             | 36.06                 | 27.31          | 14.67                 |
| 25             | 34.11                 | 24.74          | 13.29                 |
| 30             | 31.49                 | 22.42          |                       |
| 35             | 31.89                 | 21.87          |                       |
| 40             | 28.52                 | 20.25          |                       |
| 45             | 29.67                 | 19.99          |                       |
| 50             | 28.57                 | 17.87          |                       |
| 55             | 26.82                 | 15.91          |                       |
| 60             | 26.84                 | 15.93          |                       |

The average values of tearing strength in Figure 1, 2, 3 were shown in table 1. The variation of tearing strength of the special with aging time was accordant with as follow:

\[ S = b \exp(-kt^\alpha) \]  

where \( S \) is the tearing strength (MPa), \( k \) is the reaction rate, \( t \) is the aging time(day), \( b \) and \( \alpha \) is constant.

The data in table 1 were dealt with by means of Origin 6.1, the results shows that Eq. (2) to Eq. (4) are the rules of tearing strength of the rubber aged in air at temperature of 80°C, 100°C, 13°C respectively.

\[ S = 51\exp(-0.05761t^{0.58}) \]  \hspace{1cm} (2)  
\[ S = 51\exp(-0.105891t^{0.58}) \]  \hspace{1cm} (3)  
\[ S = 51\exp(-0.40245t^{0.58}) \]  \hspace{1cm} (4)

Service Life Prediction

The most important methodology for such extrapolations that is applied in polymer aging studies and has been used for decades is based on the Arrhenius relationship in Eq. (5) [14]. Lifetime prediction studies on polymeric materials rely heavily on the use of accelerated thermal aging exposures. It is determined at elevated temperatures and these data are used to extrapolate material performance.

\[ k = Ae^{-\frac{E_a}{RT}} \quad \text{or} \quad \ln k = \ln A + \frac{E_a}{RT} \]  \hspace{1cm} (5)

Where \( k \) is a reaction rate, \( E_a \) is the Arrhenius activation energy, \( R \) is the gas constant(8.314J/(mol \cdot K)), \( T \) is the absolute temperature and \( A \) is the pre-exponential factor.
Generally, the rubber cannot be used when the value of mechanical property decreased to half of the initial value\[14\]. Thus, in this work, 50% of the initial value was chose as critical value and it was used to predict service life of the rubber.

The data in table 1 were dealt with by means of Origin 6.1, the results shows that corresponding reaction rate k and b, α in Eq. (1) are shown in table 2.

| temperature /℃ | k     | b     | a     |
|----------------|-------|-------|-------|
| 80             | 0.05761 | 51    | 0.58  |
| 100            | 0.10589 | 51    | 0.58  |
| 130            | 0.40245 | 51    | 0.58  |

\[
\ln k = 12.9 - 5592 / T \quad \quad (6)
\]

The reaction rate k at any temperature and Ea can be extrapolated according to Eq. (5) and Eq. (1) respectively. The results show that

Ea=46.49KJ/mol, \( k_{25}\degree C = 2.86 \times 10^{-3} \)

Thus, the aging rule of the rubber aged in air at temperature of 25\degree C is followed Eq. (7).

\[
S = 49.5 \exp(-2.86 \times 10^{-3} t^{0.58})
\]  

(7)

It is 35.79 years according to Eq. (7) that the value of tearing strength approach the critical value (50% of the initial value), thus, the service life of the rubber used in seawater at temperature of 25\degree C is 35.79 years.

Conclusions

The heat air method was designed and the accelerated aging tests of the rubber were carried in laboratory. The tearing strength of the rubber in aging time was investigated. The rule of tearing strength and aging time was studied. The service life prediction function of the rubber was established and service life at 25\degree C was estimated based on the index of tearing strength. The result shows that tearing strength of the rubber decreased in exponential form with aging time, and the service life of the rubber used in air at 25\degree C is 35.79 years.

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