

Storage Lifetime Prediction of HTPB Coating in Solid Rocket Motor

Ke Li*, Jian Zheng^a and Jianzhuang Zhi^b

Shijiazhuang Campus, Army Engineering University, Shijiazhuang, China

*Corresponding author e-mail: 18599997647@163.com, ^a2172684627@qq.com, ^b15383819371@163.com

Abstract. To accurately predict the storage lifetime of hydroxyl-terminated polybutadiene (HTPB) coating in solid rocket motor, the accelerated aging test was conducted under 323.15K, 333.15K, 343.15K and 353.15K. The Arrhenius method was chosen as the aging model, which was aimed to predict the lifetime of the samples in normal temperature. The results show that the power function model with $\alpha = 0.4$ can describe the variation law of maximum elongation with time. Regarding the maximum elongation decline of 50% as the failure criterion, the predicted storage lifetime of HTPB coating is 16.70 years at 298.15K, which is able to satisfy the aging properties requirements of the coating.

1. Introduction

HTPB coating is a kind of hydroxyl-terminated polybutadiene rubber composite filled with some functional materials [1], and it is an important structural part of solid rocket motor, which is able to buffer the pressure from solid propellant and adiabatic layer, so the coating must keep in a state of good mechanical state [2]. However, the properties of the material will fall on the effect of thermal oxidation and stress in the storage aging process, leading to the destruction of the solid rocket motor's structural integrity ultimately [3]. Therefore, it is of great military significance to study the aging properties of HTPB coating and furtherly predict the life of the material [4].

At home and abroad, it is a common method to combine the accelerated aging test and Arrhenius equation to build an aging model, so as to predict the lifetime of rubber materials [5]. Researches have been done to study the aging properties and calculate the storage time of solid propellant [6-10], prospecting a valuable engineering importance. However, the aging of HTPB coating is a complex process, and hardly did any related studies have been reported.

In this work, the accelerated aging test and uniaxial tensile test were carried out, and the aging model was solved by the test data. Besides, associating with the Arrhenius equation, the storage lifetime at normal temperature of HTPB coating was predicted.

2. Experimental sections

2.1. Accelerated aging test of HTPB coating

According to the experimental standard GB/ 3512-2001, the accelerated aging test of HTPB coating was carried out at 323.15K, 333.15K, 343.15K and 353.15K. The test period was 50 days, and the



equipment was the DU288-electric heating oil bath incubator (Fig. 1). In the aging process, the change of temperature was kept in 1K, and the humidity was maintained under 30% by desiccant. 5 samples were taken out of the incubator every 5 days, which were used to test the elongation of HTPB coating.



Figure 1. DU288-electric heating oil bath incubator.

2.2. Uniaxial tensile test

The uniaxial tensile test was conducted on an INSTRON5982 material testing machine at $293.15 \pm 2K$, aiming to obtain the maximum elongation of aging HTPB coating.

Based on the tensile standard QJ 916-1985, the aging materials that had already naturally cooled for 24 hours were stretched symmetrically on fixtures with a tensile rate of 100mm/min. Moreover, the samples were torn until breakage, with the data recorded.

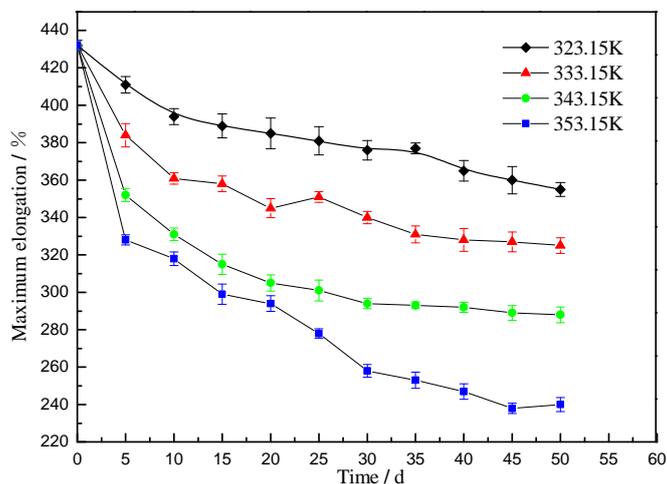


Figure 2. Variation curves of the maximum elongation with time for aging HTPB coating.

The variation curve of the aging properties of HTPB coating with time is shown in Fig. 2. It can be seen that the decrease trends of maximum elongation are similar at the four aging temperatures, implying that the coating in the four cases follows the same aging mechanism. In addition, the increase in temperature significantly accelerate the aging reaction rate, because high temperature condition enhances the aging process. From the perspective of the overall trend, the decrease in maximum elongation is fast at first and then slower, mainly due to the effect of oxidation crosslinking and

degradation of the chain. In the pre-aging period, post-curing and oxidative crosslinking results in a rapid decrease in maximum elongation. In the middle and later stages of aging, the main aging reactions are oxidation and chain scission, and the oxidation reaction is slightly stronger than the effect of degrading the chain, showing a slow decrease in maximum elongation.

3. Storage lifetime prediction

In the field, the three mathematic models below are able to describe the variation of the maximum elongation:

$$\text{Logarithmic model: } \varepsilon_m = \varepsilon_{m0} - k \lg t \quad (1)$$

$$\text{Power function model: } \varepsilon_m = \varepsilon_{m0} - kt^\alpha \quad (2)$$

$$\text{Exponential model: } \varepsilon_m = \varepsilon_{m0} \exp(-kt) \quad (3)$$

Where ε_m is the maximum elongation, ε_{m0} is the initial maximum elongation, k is the aging reaction rate, t is the time, α is a constant term ranged from 0 to 1.

The three models are fitted by the test data, suggesting that the power function model with $\alpha = 0.4$ has the best fitting effect, and the results are shown in Table 1.

Table 1. The fitting results of power function model with $\alpha = 0.4$.

Temperature/K	$\varepsilon_{m0}/\%$	$k/\% \cdot d^{-1}$	r^2
323.15	437.6	16.22	0.9784
333.15	428.3	22.86	0.9701
343.15	416.9	30.19	0.9280
353.15	424.2	40.87	0.9755

Arrhenius method is the most widespread way to study the aging characteristic of the rubber materials [11], and the Arrhenius equation is expressed as eq. (3),

$$k = Ae^{-E_a/RT} \quad (4)$$

Where k is the aging reaction rate, A is the pre-exponential factor, E_a is the apparent activation energy, T is the absolute temperature, R is the molar gas constant, $8.314 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$.

Fit the eq. (3) by the data in Table 1, the parameters are shown in Table 2.

Table 2. The fitting results of Arrhenius equation.

Parameters	$\ln A$	E_a	r^2
Values	13.58	2.898×10^4	0.9989

When T is 298.15K, the aging reaction rate solved by Arrhenius equation is $k_{25} = 6.6124$. In general, the failure criterion of rubber is the decrease of the maximum elongation [11]. In this work, bring $\varepsilon_{m0} = 432\%$ and $\varepsilon_m = 216\%$ into eq. (2), the storage lifetime of the samples is obtained as 6098 days, i.e. 16.70years.

When evaluating the integrity of the solid rocket motor, the storage lifetime of the coating is required to be ranged during 15~20 years [12], and the result in this paper can satisfy the performance demand.

4. Conclusion

In this work, the accelerated aging test and the Arrhenius method are combined to predict the lifetime of HTPB coating. The fitting results indicate that the power function with $\alpha = 0.4$ can describe the variation of maximum elongation well. Taking the maximum elongation decrease of 50% as the failure criterion, the estimated storage lifetime is 16.70 years, which is suitable for the properties requirement of the coating.

References

- [1] L. F. Hou, Composite solid propellant, China Aerospace Publishing House, Beijing, 1994.
- [2] K. Li, J. Zheng, W. Peng, et al. The visco-hyperelastic constitutive model of HTPB inhibitor, *Acta. Mater. Compos. Sin.*, 2018, DOI: org/10.13801/j.cnki.fhclxb.2018. 0211.002.
- [3] F. Q. CAO, Z. C. Liu and X. H. Li, Forced aging test of HTPB inhibitor, *Aero. Weapon*, 4 (2014) 58-61.
- [4] R. X. Chen. Design and research of solid rocket engine, China Aerospace Publishing House, Beijing.
- [5] Y. Q. Du, J Zheng, W Peng, et al. Review of the research of aging modeling and life prediction for HTPB propellant, *Chem. Ind. Eng. Prog.*, 35 (2016) 219-224.
- [6] W. Huang, L Duane. An alternative degradation reliability modeling approach using maximum likelihood estimation. *IEEE Trans. Relia.*, 54 (2) (2005) 310-317.
- [7] M. Celina, K. T. Gillen, R. A. Assink. Accelerated aging and lifetime prediction: review of non-Arrhenius behavior due to two competing processes, *Polym. Degrad. Stab.*, 90 (2005) 395.
- [8] Y. Q. Du, J Zheng, W Peng, et al. Storage life of HTPB propellant based on segmented aging model, *Chin. J. Energ. Mtaer*, 24 (10) (2016) 936-940.
- [9] J. Zhou, J. Yao, Y Song, Storage life evaluation method based on segmented nonlinear Arrhenius model, *J. B .Univ. Aeronaut. Astronaut*, 41 (4) (2015) 744-750.
- [10] X. G. Zhang. Study on the aging properties and storage life prediction of HTPB propellant, National University of Defense Technology, Changsha, 2009.
- [11] J. Zhang, H. G. Wang. Study on aging and life prediction of chloroprene rubber, *Chin. Rub. /Plast. Tech. Equip.(Plast.)*, 43 (16) (2017) 24-26.
- [12] Z. M. Qiu. Solid rocket engine materials and technology, China Aerospace Publishing House, Beijing, 1995.