Study on creep perform of epoxy resin for launch canister

Fu-Quan Wei¹, Wen-chao Yang², Zhe-xian Zhan ², Cun-gui Yu¹*

¹School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, Jiangsu 210094, China.
²Jiangxi Changjiang Chemical Co., LTD., Jiujiang 332006, China
*Corresponding author: yu-cungui@njust.edu.cn

Abstract. In order to study the creep perform of the launch canister, creep perform of the epoxy resin (matrix material) were studied. The creep model of epoxy resin was established based on Bailey-Norton model. Constant stress tensile creep tests at room temperature were carried out on epoxy resin specimens under different stress levels, and the model parameters were obtained by fitting the test data. The finite element model of the specimen was established in the ABAQUS software and the tensile simulation was carried out. The simulation results are consistent with the test results. Results show that time-hardening model can describe the short-term creep perform of epoxy resin with error less than 20%.

1. Introduction
The problems of mechanical properties degradation and creep deformation are found in the long-term storage process of rocket weapon launch canister [1]. Su [2] proposed a corresponding creep estimation scheme for the aging performance and creep behavior of GFRP launch canister. Qin [3] used a three-parameter solid model to characterize the viscoelasticity of FRP and conducted a simulation analysis on the long-term storage of FRP launch canister. Sun [4] conducted creep-recovery experiments on two main directions of materials (transverse and in-plane shear directions) dominated by matrix performance. A new Schapery nonlinear viscoelastic parameter identification method is proposed based on the residual viscoplastic strain observed in experiments, which can easily and accurately obtain the nonlinear viscoelastic parameters at different stress levels.

The research object of the above article is unidirectional board or laminated board, but the creep performance of resin matrix has not been studied in detail. Experimental studies have shown that the polymer matrix has greater viscoelasticity. Since the polymer matrix plays the role of bonding fibers and transferring stress in the resin matrix composite material, the change in the durable performance of the composite material caused by the resin matrix creep is dominant [5]. The creep properties of resin matrix are related to environmental factors such as stress state, molecular structure and temperature [6]. He [7] believe that the creep strain of many polymers is in a straight line with the double logarithm of time, which indicates that the time response of strain can generally be expressed as a power exponent. Xu [8] found that the improved time hardening model can describe the creep behavior of PTFE materials well. Zhang [9] found that the three-parameter time hardening model was more consistent with the experimental results than the Kelvin model. ABAQUS software was used to simulate the creep behavior of epoxy resin adhesives in different states, and the simulation results were consistent with the experimental results. Zeng [10] used time-hardening creep model to simulate multi-axis creep test of plate with round hole, and the simulation results are in good agreement with the test results.
This paper establishes the creep model of epoxy resin based on the Bailey-Norton model. Tensile creep tests were carried out at room temperature on standard specimens at different stress levels, and creep model parameters were obtained by fitting test data. ABAQUS software is used to simulate the tensile creep of the specimen, and the simulation results are in good agreement with the test results.

2. Creep constitutive model
The with H-type main steel beams and steel channels, lightweight precast panels set upon the steel skeleton, shear keys connected to the main steel beams and post-pouring concrete layer.

Under uniaxial stress, the creep strain is related to flow stress($\sigma$), time($t$)and temperature($T$). A typical uniaxial creep constitutive equation can be expressed as

$$\dot{\varepsilon}_\alpha = f_1(\sigma) f_2(t) f_3(T)$$  \hspace{1cm} (1)

Where, relationship between creep strain, time and stress can be obtained by bailey-Norton model [11].

$$f_1(s)f_2(t)=A_\sigma\sigma^p t^q$$  \hspace{1cm} (2)

In addition, creep can be considered as a thermally activated process. The relation between creep strain and temperature can be expressed as [12]

$$f_3(T)=A_e e^{Q/RT}$$  \hspace{1cm} (3)

Then, the isotropic nonlinear creep constitutive model is

$$\dot{\varepsilon}_\alpha = B_\sigma\sigma^p t^q e^{Q/RT}$$  \hspace{1cm} (4)

Where, $R$ is gas constant, $T$ is absolute temperature, $Q$ is thermal activation energy; $B$, $p$, $q$ are constants, generally $p > 1$, $0 < q < 1$, and can usually be determined by a creep test. The creep strain rate can be expressed as

$$\dot{\varepsilon}_\alpha = B_q\sigma^p t^{q-1} e^{Q/RT}$$  \hspace{1cm} (5)

Where, $A=B_q$, $n = p$, $m = q - 1$. All parameters in the model are related to the material and should be obtained by the corresponding creep test. This formula is the time-hardening model built in ABAQUS software.

The creep constitutive model of materials under uniaxial stress must be extended to multiaxial stress state. The creep strain rate under multiaxial stress was determined by Mises equivalent stress and associated flow rule.

$$\dot{\varepsilon}_ij = \frac{\partial F(\sigma_{\text{eq}})}{\partial \sigma_{\text{eq}}}$$  \hspace{1cm} (6)

Where, $F(\sigma_{\text{eq}}) = \sigma_{\alpha} - \sigma_{eq}$ is the equivalent stress, $\sigma_i$ is the yield stress, $\dot{\varepsilon}_ij^\alpha$ is the equivalent component of creep strain rate under multi-axial stress state. The total strain of the model includes elastic strain and creep strain: $\varepsilon_{ij} = \varepsilon_{ij}^e + \varepsilon_{ij}^\alpha$.

The constitutive model under multi-axial stress state [13] is

$$\dot{\varepsilon}_ij = D_{ijkl}\varepsilon_{kl} = D_{ijkl}\left(\dot{\varepsilon}_kl - \varepsilon_{ij}^\alpha\right)$$  \hspace{1cm} (7)

Where, $\dot{\varepsilon}_ij$, $\dot{\varepsilon}_ij^e$, $\dot{\varepsilon}_ij^\alpha$ and represent the total strain rate, elastic strain rate and equivalent creep strain rate respectively. This formula is the basis of derivation of finite element equation and elastic stiffness matrix $D_{ijkl}$.

3. Model verification
3.1. Test equipment and materials
The test equipment is shown in Figure 1. The loading equipment is SUNS UTM5105-G universal material testing machine (load range ±100KN, accuracy 0.5N), small range force sensor (load range
±5kN, accuracy: 0.05%). Strain measurement equipment is high-speed dynamic and static strain gauge (YE3818C), bridge box (YE29003A), resistance strain gauge (BF120-3AA/BA102-2BC model, resistance value of 120Ω), data acquisition instrument. According to the mold size specified in "GB/T2567-2008 Resin Casting Performance Test Method", use WSR epoxy resin and other auxiliary materials (coupling agent, plasticizer, flame retardant) for pouring, curing, stripping and polishing and after eliminating the residual stress, the specimen is obtained.

3.2. Test method
Test 1: Elastic modulus and tensile strength test of resin specimens.
According to GB/T 2567-2008 resin casting performance Test method, the tensile property test is carried out, mainly testing the elastic modulus $E$, Poisson's ratio $\nu$ and tensile strength $\sigma$. The loading speed of elastic modulus and poisson's ratio test was 2mm/min, and the loading speed of strength test was 10mm/min. Five parallel specimens were selected from each group and their average value was taken as the final test result.

Test 2: creep test of resin specimens.
According to "GB/T 11546.1-2008 determination of creep perform of plastics--Part 1: Tensile creep", tensile creep tests are carried out on specimens at room temperature. The testing system for creep test is the same as that for static mechanical properties. The creep test time is long, so the temperature compensation plate should be connected in the test system. The specimen was loaded within 5s, which was approximately considered as instantaneous loading. Strain values were recorded continuously during the whole test, and the sampling frequency was 10Hz. Each group was repeated for 3 times, and the data obtained were averaged as the final test result.

3.3. Analysis of test results
The stress-strain curve of the specimen obtained in test 1 is shown in Figure 2, the Poisson's ratio-time curve is shown in Figure 3, and the load-displacement curve is shown in Figure 4. The average value of
The elastic modulus is 3.7 GPa; the average value of Poisson's ratio is 0.37; the average value of tensile strength is 41.0 MPa. The stress level of creep is generally selected between 20% and 70% of the tensile strength. Due to the large dispersion of tensile strength, in order to avoid crack propagation or fracture of the specimen, a lower stress level is selected for the creep test. The selected stress levels are 9 MPa, 13 MPa and 17 MPa.

The strain-time curves under various stress levels obtained in test 2 are shown in Figure 6, and the creep-time curves are shown in Figure 7. The creep curve consists of two stages: transient creep and steady creep. The creep strain rate is higher in the transient creep stage, and gradually decreases with the increase of test time. In steady-state creep stage, the creep strain rate is low and basically unchanged. The creep strain is related to the level of stress applied to the specimen, and the greater the stress, the greater the creep strain.

Creep model parameters under various stress levels were obtained by fitting creep data according to literature [11-13], as shown in Table 1.

| Stress MPa | B       | p       | q       | A       | n       | m       |
|------------|---------|---------|---------|---------|---------|---------|
| 9          | 2.43E-06| 1.03298 | 0.26241 | 6.39E-07| 1.03298 | -0.73759|
| 13         | 3.02E-06| 1.06763 | 0.2006  | 6.06E-07| 1.06763 | -0.7994 |
| 17         | 3.32E-06| 1.07281 | 0.21939 | 7.28E-07| 1.07281 | -0.78061|
| average    | 6.65E-07| 1.05781 | -0.77253|         |         |         |

The finite element model of the specimen was established in ABAQUS with density of 1.3 g/cm³, elastic modulus of 3700 MPa and Poisson's ratio of 0.37. A, n and m are assigned to the values at the corresponding stress levels in the table respectively. The element type is C3D8R. The specimen is fixed at one end and subjected to a concentrated load through the coupling. Constant force tensile creep
simulation was performed in the 3600s using visco analysis step. The finite element model is shown in Figure 5. When the stress level is 9MPa, the cloud diagram of tensile creep stress is shown in Figure 5. The total strain and creep strain of the integral point at the geometric center of the specimen were extracted and the creep curve was obtained. The comparison between simulated total strain curves and test curves under different stress levels is shown in Figure 6. The comparison between the creep strain curve and the test curve is shown in Figure 7. The maximum creep strain error is 10.7% at 9MPa, 16.4% at 13MPa, and 13.19% at 17MPa.

![Fig. 6 Comparison of strain curve](image)
![Fig. 7 Comparison of creep strain curves](image)

The average values of creep model parameters $A=6.65E-7$, $n=1.05781$, $m=-0.77253$ were used to simulate the tensile creep at the stress level of 11MPa and 15MPa. According to test 2, tensile creep tests at stress levels of 11MPa and 15MPa were carried out. Each group of tests was repeated three times, and the data obtained were averaged as the final test result. The comparison between the simulated total strain curve and the test curve is shown in Figure 8. The comparison between creep strain curve and test curve is shown in Figure 9. The maximum simulation error is 19.43% at 11MPa. The maximum simulation error is 11.43% at 15MPa. The main reasons for the error are as follows: the fluctuation and poor regularity of creep test data lead to large error of fitting parameters of time hardening model; even if the creep model parameters are averaged, there is still a large error.

![Fig. 8 Strain curve comparison](image)
![Fig. 9 Comparison of creep strain curves](image)

5. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:

(1) The elastic modulus, poisson's ratio, tensile strength and other mechanical properties of epoxy resin for launch canister were measured.
(2) The time-hardening model was established to describe the creep perform of epoxy resin, and tensile creep tests under different stress levels were carried out.

(3) Parameters of the time hardening model were obtained according to the test curve, and tensile creep simulation was carried out with ABAQUS software.

(4) The study shows that the time-hardening model can describe the short-term creep perform of epoxy resin within error less than 20%.

References
[1] Tong-sheng Sun, Jun-yao Zhu, Cun-gui Yu, Wen-chao Yang, Qiang Xu. Prediction of Moisture Absorption-creep Coupling Behavior of Box-type Composite Directors for Multiple Launch System under Long-term Stacking Storage Rocket[J].Journal of China Ordnance, 2021, 42(03):487-498.
[2] Teng-teng Su, Cun-gui Yu, Tao Song. Research on Aging Properties and Creep Behavior About Glass-Steel Launching Tube[J].Journal of sichuan ordnance engineering,2015,36(10):139-141+146.
[3] Yu-zheng Qin, Zhi-gang Li, Tong-sheng Sun. Creep analysis of GFRP based on H-K solid model [J]. Ordnance industry automation,2019,38(10):83-87.
[4] Teng-teng Su, Cun-gui Yu, Wen-chao Yang,Jian-lin Zhong. Nonlinear viscoelastic response of glass fiber/epoxy resin composites[J].Journal of Harbin Institute of Technology, 2020,52 (07):133-138.
[5] T.MIYAKE,et al. Evaluation of time-dependent change in fiber stress profiles during long-term pull-out tests at constant loads using Raman spectroscopy[J]. Journal of Materials Science, 2001,36:5169-5175.
[6] Peng-fei Liu, Qi-lin ZHAO, Jing-quan Wang. Research progress on Creep perform of Resin Matrix Composites[J].Fiber Reinforced Plastics/Composites,2013(03):109-117+12.
[7] Ping-sheng He. Mechanical properties of polymer[M].Hefei:University of Science and Technology of China Press, 2008:66 ~ 70.
[8] Wang Xu. Study on Creep and Weather Resistance of PTFE Building Membrane[D].[Master's Thesis].Harbin: Harbin Institute of Technology, 2011.
[9] Yong-xiang Zhang. Experimental and Theoretical Study on Bonding Structure and Properties of Epoxy Resin Adhesives[D].Zhengzhou University,2014.
[10] Cheng Zeng. Research on Multi-axial Creep Behavior of Materials and Components Based on Time-hardening Model[D].Southwest Jiaotong University,2019.
[11] Kraus, H. 1980. Creep analysis. 1st ed. John Wiley & Sons,New York, NY, USA. pp. 20–21.
[12] Xia-ying Mu. Creep mechanics[M]. Xi’an: Xi’an Jiaotong University Press, 1990.
[13] Cun-Gui Yu,Tong-Sheng Sun, Guang-Yuan Xiao. Study on creep performance of launch canister under long-term storage[J].Transactions of the Canadian Society for Mechanical Engineer-in g,2018,43(2):