

Comparative Analyses of Creep Models of a Solid Propellant

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Abstract. The creep experiments of a solid propellant samples under five different stresses are carried out at 293.15 K and 323.15 K. In order to express the creep properties of this solid propellant, the viscoelastic model i.e. three Parameters solid, three Parameters fluid, four Parameters solid, four Parameters fluid and exponential model are involved. On the basis of the principle of least squares fitting, and different stress of all the parameters for the models, the nonlinear fitting procedure can be used to analyze the creep properties. The study shows that the four Parameters solid model can best express the behavior of creep properties of the propellant samples. However, the three Parameters solid and exponential model cannot very well reflect the initial value of the creep process, while the modified four Parameters models are found to agree well with the acceleration characteristics of the creep process.

1.Introduction

Most solid propellant is generally considered to be a typical viscoelastic material [1-5]. Because this materials exist obvious viscoelastic characteristics (the phenomenon such as creep, replies and stress relaxation), that strongly depend on the loads, environment temperature and time process [6]. Most solid propellant material belongs to high-molecular polymer, is also a typical viscoelastic material. Creep is one of the main mechanical properties indexes of solid propellant materials. However, there are relatively few researches on the creep characteristics of solid propellant. No creep model can be widely used in propellant materials. Choosing different creep model to describe the creep properties of the propellant materials, this can help to analyse its viscoelastic behaviour. With the help of creep test data can obtain the material Parameters of the models.

The common basic viscoelastic models are usually composed of the springs and the dampers, such as Kelvin and Maxwell model. A variety of complex fluid and solid models is widely applied to express the rheological characteristics of materials, such as bituminous sand [7-8], rocks [9] and asphalt mixtures [10], However, there are relatively few researches on the creep characteristics of solid propellant. To choose can be applied to the creep model of propellant material. The five models are used to express the propellant material creep properties under different stress level in this research, and compared with the experimental result analysis obtained a better creep model.

2.Experimental



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The solid propellant materials mainly include: nitration cotton (55%), nitroglycerin (29.3%), the second nitro toluene (10%), other (5.7%). The test sample are derived from the solid propellant grain. The standard samples are obtained through the standard QJ924-85 of the aerospace sectors. The schematic diagram of the standard dumbbell drawing sample is shown in figure 1. In order to remove the residual stresses generated during machining, all test samples must be kept at 50 degrees for more than 48 hours. Before creep experiment, the sample and fixture will be installed in the attemperator of the QJ211B material universal testing equipment. Five kinds of constant stress were 4MPa, 4.5MPa, 5MPa, 5.5MPa and 6MPa, respectively; under the environment temperature 293.15 K. Five kinds of constant stress were 1MPa, 1.5MPa, 2MPa, 2.5MPa and 3MPa, respectively, under the environment temperature 323.15 K.

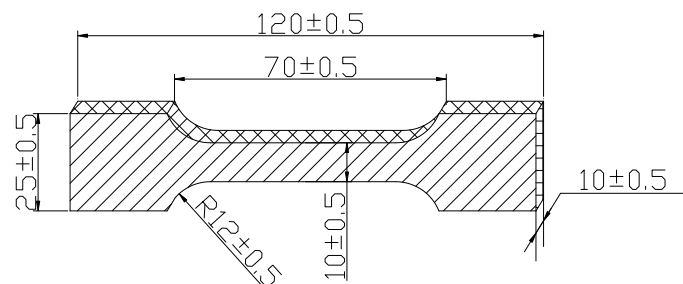


Figure 1. Solid propellant samples

Before creep experiment, the sample and fixture will be put in the attemperator for 10 hours. In order to eliminate the influence of the experimental system of mechanical clearance, the test equipment system will be offered preloading load of 2N. The specimen and fixtures were by thermal insulation in the temperature controller after 1 hour. The computer program was restarted, which the creep test data were recorded real-time by. The test results averaged from the repeated five times in each case.

3.Results and discussions

The creep curve of solid propellant material under ambient temperature 293.15 K and 323.15 K is shown in figure 2. The creep curves of each stress level in figure 2 show the creep curve under different stress levels contains only deceleration creep and constant creep at 293.15K; the creep curves under low stress level contains deceleration creep and constant creep, while under high stress will be accelerated creep stage, and the creep rate increased rapidly until the test sample was destroyed at 323.15k.

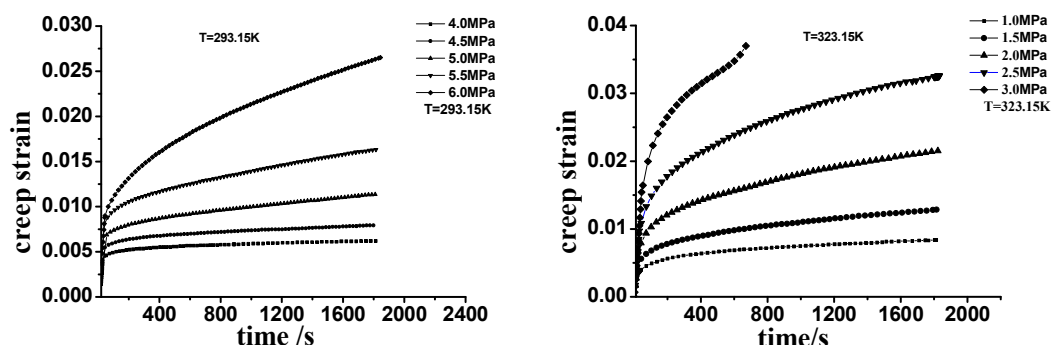


Figure 2. The creep curve of propellant material at different ambient temperature

The superposition of each curve using the time-temperature-stress equivalent principle in figure 2, it is concluded that solid propellant creep can be divided into three stages. The first stage is the

deceleration creep process. The deformation is increasing rapidly and creep strain rate is decreasing. The time of this stage is about 5% of the creep life, and the main performance is transient elastic deformation. The next stage is the constant velocity creep process. The creep deformation nearly linear increase, the strain rate nearly remains the same. The time period of this stage is about 80% of the creep life, mainly manifested as viscous flow deformation. The third stage is the accelerated creep process, also known as the creep damage process. The creep deformation increases rapidly, the strain rate rise sharply, causing the failure of the sample in a short time. The time period of this stage is about 15% of the creep life, mainly the visco-plastic deformation.

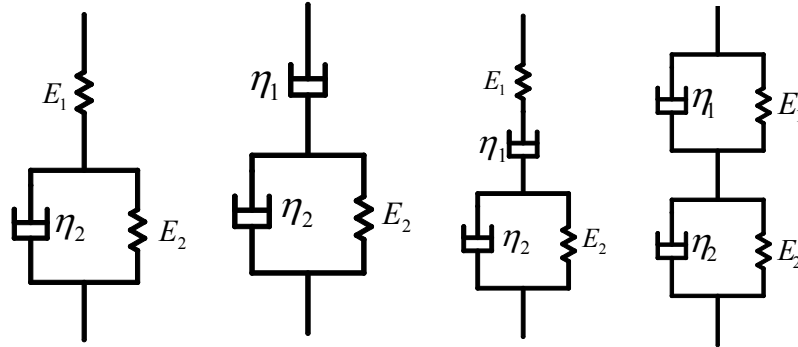


Figure 3. Four kinds of viscoelastic models. (a) Three Parameters Solid. (b) Three Parameters Fluid. (c) Four Parameters Fluid (d) Four Parameters Solid.

Table 1. All sorts of the differential and creep equations of models

models	differential equations	creep equations
three parameters solid	$\sigma + \frac{\eta_2}{E_1 + E_2} \dot{\sigma} = \frac{E_1 E_2}{E_1 + E_2} \varepsilon + \frac{E_1 \eta_2}{E_1 + E_2} \dot{\varepsilon}$	$\varepsilon(t) = \left[\frac{1}{E_1} + \frac{(1 - e^{-E_2 t / \eta_2})}{E_2} \right] \sigma_0$
three parameters fluid	$\sigma + \frac{\eta_1 + \eta_2}{E_2} \dot{\sigma} = \eta_1 \dot{\varepsilon} + \frac{\eta_1 \eta_2}{E_2} \ddot{\varepsilon}$	$\varepsilon(t) = \left[\frac{t}{\eta_1} + \frac{(1 - e^{-E_2 t / \eta_2})}{E_2} \right] \sigma_0$
four parameters fluid	$\sigma + \left(\frac{\eta_1}{E_1} + \frac{\eta_1 + \eta_2}{E_2} \right) \dot{\sigma} + \frac{\eta_1 \eta_2}{E_1 E_2} \ddot{\sigma} = \eta_1 \varepsilon + \frac{\eta_1 \eta_2}{E_2} \dot{\varepsilon}$	$\varepsilon(t) = \left[\frac{1}{E_1} + \frac{t}{\eta_1} + \frac{(1 - e^{-E_2 t / \eta_2})}{E_2} \right] \sigma_0$
four parameters solid	$\sigma + \frac{\eta_1 + \eta_2}{E_1 + E_2} \dot{\sigma} = \frac{E_1 E_2}{E_1 + E_2} \varepsilon + \frac{E_1 \eta_2 + E_2 \eta_1}{E_1 + E_2} \dot{\varepsilon} + \frac{\eta_1 \eta_2}{E_1 + E_2} \ddot{\varepsilon}$	$\varepsilon(t) = \left[\frac{(1 - e^{-E_1 t / \eta_1})}{E_1} + \frac{(1 - e^{-E_2 t / \eta_2})}{E_2} \right] \sigma_0$
exponential		$\varepsilon(t) = (A + Bt^n) \sigma_0$

The four viscoelastic models are shown in figure 3. The differential equations and creep equations of five models are shown in table 1. The fitting accuracy of different models is judged by correlation coefficient. According to the principle of least square method, the different creep models parameters and the correlation coefficients are obtained, as shown in table 2. As is known to all, the four Parameters solid model can best express creep properties curve of the propellant samples, followed by the four

parameters fluid model, again is three parameters fluid and exponential model, and the fitting of three parameters solid model is the worst.

Table 2. Correlation coefficients of different creep models

model	293.15K					323.15K					mean value
	σ_0 (MPa)					σ_0 (MPa)					
	4.0	4.5	5.0	5.5	6.0	1.0	1.5	2.0	2.5	3.0	
three parameters solid	0.967	0.794	0.791	0.863	0.967	0.924	0.923	0.932	0.965	0.980	0.910
three parameters fluid	0.967	0.989	0.993	0.993	0.991	0.981	0.985	0.991	0.992	0.997	0.988
four parameters fluid	0.967	0.999	0.993	0.992	0.991	0.984	0.985	0.990	0.992	0.997	0.989
four parameters solid	0.967	0.997	0.998	0.998	0.998	0.995	0.997	0.998	0.999	0.997	0.995
exponential	0.962	0.998	0.990	0.989	0.995	0.979	0.985	0.986	0.991	0.967	0.984

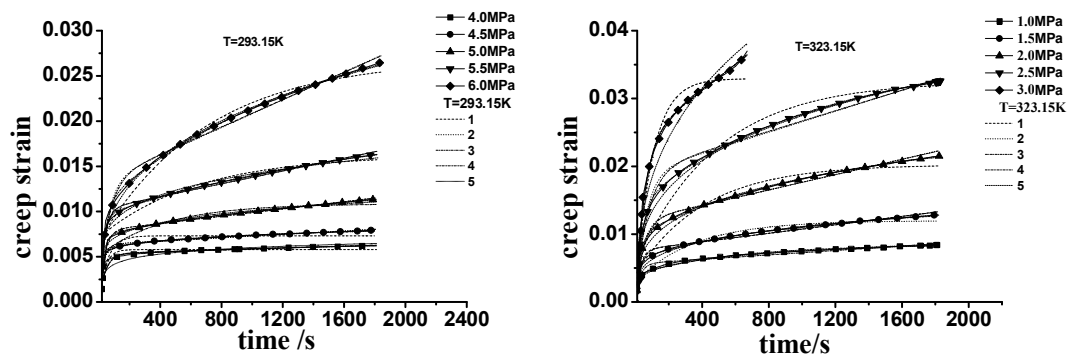


Figure 4. The fitting contrast of models (1-three Parameters solid; 2-three Parameters fluid; 3-four Parameters fluid; 4-four Parameters solid; 5- exponential).

The fitting results of creep curves of different models under different stress levels at 293.15K and 323.15K are shown in figure 4. By figure 4, particularly in the decelerating creep stages, four parameters fluid and four parameters solid model fitting precision is well which is consistent with the test curve under low stress, can better reflect the decelerating creep process, Followed by the three parameters fluid model. And the three parameters solid and exponential model fitting precision is the worst, which don't reflect the initial process of test curve. In constant creep phase, these five models fitting precision have little difference. But four parameters solid model fitting precision is well which is consistent with the test curve under high stress. Secondly is the four parameters fluid model. While the three parameters fluid model and the exponential model fitting precision is bad, which can't really describe the creep process of test curve. When the high temperature and high stress, four parameters solid model fitting precision is well that is consistent with the decelerating creep and the constant creep stage of the test curve, which has some deviation with the test curve in the accelerated creep stage, followed by the three parameters fluid and four parameters fluid model. While fitting precision of exponential model is the worst, which can't really describe the creep process of test curve.

4. Conclusions

Described above five creep models can reflect the second stage characteristics of the creep process under the same temperature and different stress level. Four parameters solid model not only can well fit the constant creep phase of creep curve under the different temperatures and different stress level, also can well reflect the first stage characteristics of the creep process, followed by three parameters fluid and four parameters fluid model. While the three parameters solid and exponential model can't reflect the initial value of the creep process of the solid propellant material. the modified four parameters models can better describe the acceleration characteristics of creep process.

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