Acquisition of the Variable Temperature Relaxation Modulus of Modified Double Base Propellant

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Abstract: The relaxation modulus curve of modified double-base propellant under constant temperature was obtained by stress relaxation tests at different temperatures. According to the time-temperature equivalent principle, the relaxation modulus main curve and time-temperature equivalent model were established by regression analysis method. The relaxation modulus curve of variable temperature is based on the relaxation modulus obtained under different constant temperature levels. By establishing the relaxation modulus main curve and the time-temperature equivalent model, the variation of mechanical properties of materials with temperature is obtained. The results show that the main relaxation modulus curve based on Prony series data fitting has high accuracy and convenient data processing, so it is suitable for obtaining the relaxation modulus of modified double-base propellant with variable temperature.

1. Introduction

The modified double-base propellant is a material with double-base propellant as the matrix and containing a large number of solid particles. At the same time, temperature has a great influence on the mechanical properties of materials. Therefore, in order to accurately study the viscoelastic mechanical model of composite solid propellant materials, it is necessary to accurately obtain the relaxation modulus of materials under different temperatures, and obtain the variable temperature relaxation modulus of materials by establishing an accurate time-temperature equivalent model. Usually, the relaxation modulus of materials can be obtained through static relaxation experiments. Due to the simplicity and convenience of data processing, the relaxation modulus has been deeply studied by scholars at home and abroad, and the acquisition accuracy of the relaxation modulus has been greatly improved after the improvement of data processing methods [1,2].

The relaxation modulus of viscoelastic material obtained at constant temperature is called the curve of constant temperature relaxation modulus, which can only describe the mechanical properties of the material at the temperature level, while the relaxation modulus of variable temperature can describe the change of the elastic modulus of the same material at different temperatures. In order to describe the mechanical properties of viscoelastic materials in the process of changing temperature, it is necessary to establish an accurate relaxation modulus curve. Generally, the establishment of the relaxation modulus curve of variable temperature is based on the constant temperature relaxation modulus obtained at different constant temperature levels. By establishing the main relaxation modulus curve and the time-temperature equivalent model, the change of the mechanical properties of materials with temperature can be obtained [3-5].

2. Experiment And Variable Temperature Relaxation Modulus Model

2.1. Experiment

The test specimen for relaxation test is dumbbell strip. In the test, an incubator was used to keep the propellant warm to ensure the internal and external temperature balance of the specimen, and then the relaxation characteristics of the propellant were tested on the QJ211B electronic universal test machine. The specific test procedure is as follows: (1) The specimen holds heat for 3h to ensure that the temperature inside and outside reaches the same; (2) Clamp the specimen to the testing machine fixture; (3) Pretighten the test piece by using low-speed tensile test machine, and the pretension force is 3N; (4)The tensile speed of 100mm/min was used to stretch the specimen until the strain was 6%.;(5)Keep the displacement unchanged, record the mechanical response of specimens, relaxation time as the 1800s.

The test adopts the microcomputer controlled electronic universal material testing machine QJ211B. The test system includes the testing machine host, temperature control box, force sensor, displacement sensor, fixture and fittings, and data transmission equipment. Test temperature: -50℃, -25℃, 0℃, 20℃, 40℃, 60℃. Curves of relaxation modulus obtained at different temperatures are shown in Figure 1.

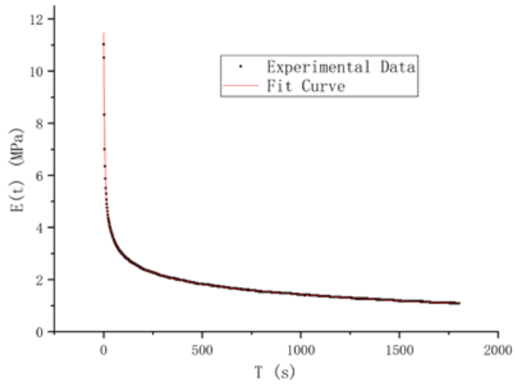

Figure 1 Curves of relaxation modulus at 20℃.

2.2. Time-temperature Equivalence Principle

The experimental results show that a certain relaxation time is required for viscoelastic materials to exhibit mechanical relaxation, and the relaxation time of the same material varies with the ambient temperature conditions. The relaxation time is shorter in the high temperature environment and longer in the low temperature environment. This is because the thermal motion energy of molecules in the material is low and the relaxation time is longer in the low temperature environment, while in the high temperature environment, the thermal motion energy of molecules increases and the relaxation time is shortened. It can be seen that the effect of extended loading time and elevated temperature on molecular thermal motion is equivalent, that is, the change of temperature scale and the change of time scale are equivalent to the mechanical properties of viscoelastic materials, which is called time-temperature equivalence principle.

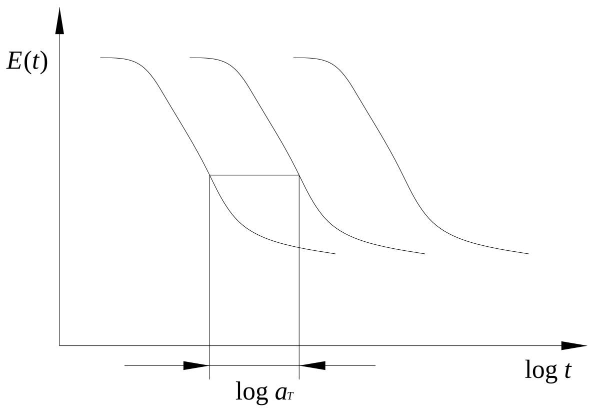

Figure 2 Time-temperature shift diagram.

There are many ways to study the correlation between the mechanical properties of viscoelastic materials and temperature, such as deformation-temperature curve, relaxation modulus-temperature curve, and temperature spectrum of dynamic mechanical properties. However, the temperature spectrum of dynamic mechanical properties has high requirements on experimental conditions. Although the deformation-temperature curve method is simple, because the amount of deformation cannot be used as the characteristic parameter of the material, the most commonly used method in the study is the relaxation modulus-temperature curve method. Use the same logarithmic coordinate to describe the relationship between relaxation modulus and time at different temperatures, select T0 as the reference temperature, and translate the modulus curve corresponding to temperature T with the logarithmic time axis to coincide with the curve at the reference temperature T0, The amount that needs to be moved is recorded as $\log a_T$. As shown in Figure 2, the following relationship can be obtained:

$$E\left(\log(t),T\right)=E\left(\log(t)-\log a_T,T_0\right) \tag{1}$$

$$E\left(t,T\right)=E\left(t/a_T,T_0\right) \tag{2}$$

The above formula shows that the relaxation modulus at time t at temperature T is equal to the value at time T_0, which is called the time-temperature equivalent factor, T is the current temperature, and T_0 is the reference temperature. Strictly speaking, the change in temperature will also cause the relaxation modulus itself and the density of the material to change, and the modulus will change with the number of substances contained in the unit volume. Considering these influencing factors, the time-temperature conversion relationship needs Considering the correction of $\rho T/\rho_0 T_0$, ρ and ρ_0 represent the material density at the experimental temperature T and the reference temperature T_0, respectively. After correction, formula (2) is expressed as:

$$E\left(t,T\right)=\frac{\rho T}{\rho_0 T_0}E\left(t/a_T,T_0\right) \tag{3}$$

For CMDB material, the density variation caused by temperature change is small, which can be basically ignored in the actual research process. Therefore, formula (3) can be further amended as:

$$E\left(t,T\right)=\frac{T}{T_0}E\left(t/a_T,T_0\right) \tag{4}$$

2.3. Acquisition of the Variable Temperature Relaxation Modulus

According to the time-temperature equivalence principle, the mechanical properties of materials under different temperature conditions are studied, and a set of relaxation modulus curves at temperature are obtained, which are expressed by logarithmic coordinates. Then in the same logarithmic coordinate system, the temperature correction is carried out for the modulus curve at different temperatures. A certain temperature is selected as the reference temperature, and the modulus curve corresponding to different temperatures is translated to overlap with that corresponding to the reference temperature, that is, the relaxation modulus main curve is obtained. The value $\log a_T$ of translation required by different modulus curves, that is, the log value of time-temperature equivalent factor, was recorded respectively, as shown in Figure 3.

In the curve group as shown in the figure, T_0 is selected as the reference temperature first, and the logarithm value of temperature impact factor $\log a_T$ is calculated by drawing method. The average translation distance between curves at all adjacent temperatures is obtained, as shown in Figure 3, $\overline{AB}$、$\overline{CD}$、$\overline{EF}$ 、$\overline{GH}$. The translation distance of the curve at all temperatures when it overlaps with the curve at the reference temperature can be calculated, and the corresponding translation distance is the logarithm of the temperature influence factor.

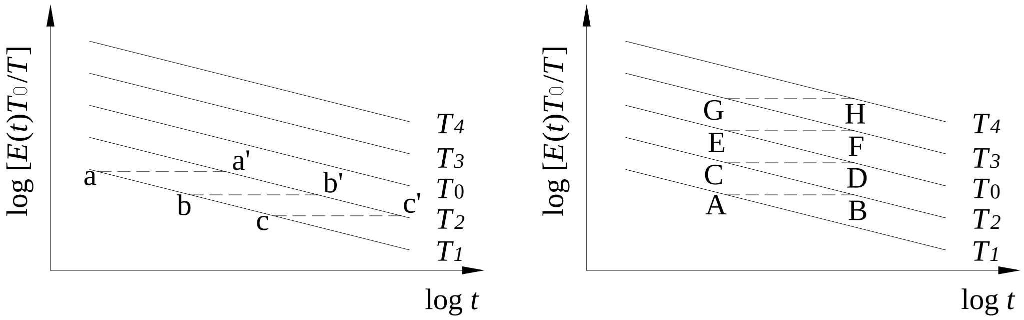

Figure 3 Thermostatic relaxation modulus curve at different temperatures.

According to the above steps, the logarithms of time-temperature equivalent factors at different temperatures are obtained, and corresponding time-temperature equivalent models are fitted. According to the corresponding log values, all the characteristic curves at different temperatures were translated to overlap with the characteristic curves at the reference temperature, and the logarithmic coordinates were converted to constant coordinates. The resulting final curve was the main relaxation modulus curve at the reference temperature T_0.

Based on the linear viscoelastic theory, the specific form of this study [6] :

$$\sigma(t)=\int_0^t E(t-\xi)\dot{\varepsilon}(\xi)\mathrm{d}\xi=\varepsilon_0 E(t)+\int_{0^+}^t E(t-\xi)\dot{\varepsilon}(\xi)\mathrm{d}\xi \tag{5}$$

Where, the relaxation modulus $E(t)$ is expressed in the form of Prony series of order 8, as shown in Equation (6) :

$$E(t)=E_\infty+\sum_{i=1}^{8}E_i\exp\left(-\frac{t}{\tau_i}\right) \tag{6}$$

3. Conclusion

The logarithmic relation curve of constant temperature relaxation modulus at different temperature levels is shown in Figure 5. It can be seen from Figure 4 that the strength of the material varies greatly with the temperature, and the strength value increases with the decrease of the temperature. The stress relaxation phenomena at different temperature levels are basically the same. The stress relaxation is more obvious at the initial stage of the relaxation process, and the phenomenon decreases with the passage of time.

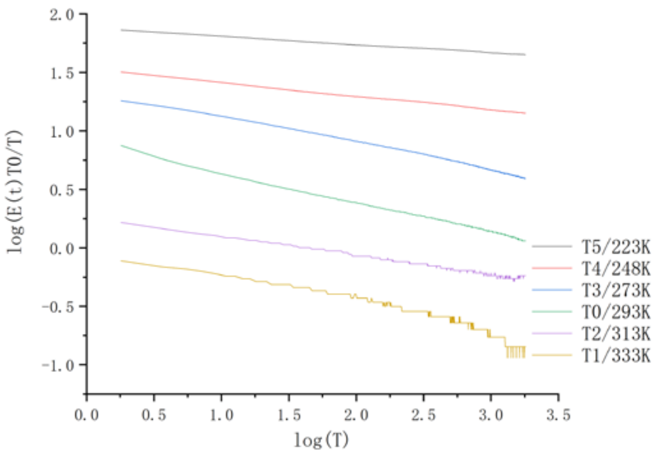

Figure 4 Logarithmic relation curve of constant temperature relaxation modulus at different temperature.

According to the acquisition method of the time-temperature equivalent factor introduced above, 293K was selected as the reference temperature to obtain the time-temperature equivalent factor at different temperatures, and the time-temperature equivalent model was prepared. According to the time-temperature equivalent factors at different temperatures, the relaxation curves at different temperature levels were translated to coincide with those at the reference temperature, so as to obtain the main relaxation modulus curve, which was fitted into the form of Prony series of order 8. The fitting results were shown in Figure 5. The fitting result of the main curve of the relaxation modulus of the eighth order Prony series is:

$$\begin{aligned} E(t) = {} & 0.41707 + 29.68582\ \exp(-\frac{t}{0.001}) - 0.16053\ \exp(-\frac{t}{0.01}) \\ & + 7.63908\ \exp(-\frac{t}{0.1}) + 4.41618\ \exp(-\frac{t}{1}) + 3.3968\ \exp(-\frac{t}{10}) \\ & + 1.16517\ \exp(-\frac{t}{100}) + 0.92694\ \exp(-\frac{t}{1000}) + 0.7108\ \exp(-\frac{t}{10000}) \end{aligned} \tag{7}$$

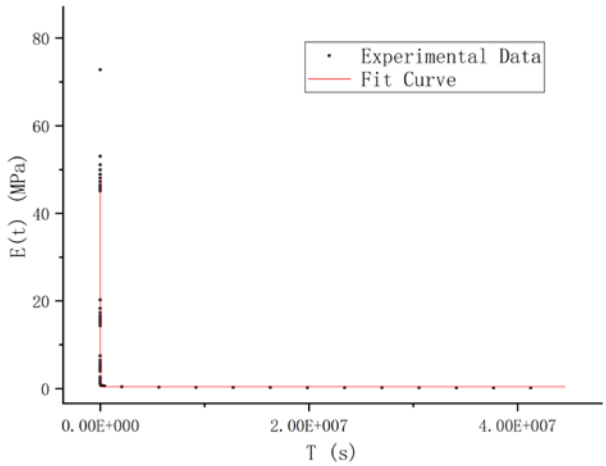

Figure 5 Relaxation modulus main curve.

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