Dynamic mechanical properties of ZN-35 silicone rubber materials based on H-N model

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Keywords: Viscoelastic damping material, temperature, frequency, energy storage modulus, loss factor, H-N model.

Abstract. ZN-35 silicone rubber is a kind of effective vibration damping material in aerospace, which can be made into a vibration damping pad for preventing vibration and damage to important components in the rocket. In this paper, the energy storage modulus and loss factor of ZN-35 silicone rubber materials at 11 different temperatures were tested by DMTA . The dynamic mechanical properties of the materials were analyzed at different temperatures. Finally, through the selection and fitting of data, the four parameters(α, β, E_0, E_∞) of H-N model is determined. Meantime the H-N model curve is drawn. The dynamic mechanical properties of the materials are provided by using the H-N model, which provides the basic data for the use of vibration damping materials and the design of shock absorber.

1. Introduction

Damping material is a kind of vibration attenuation material, which can consume kinetic energy in the process of mechanical vibration, so that the resonance frequency of the structure can be reduced or transferred. Because of the damping of the material, the amplitude of the vibration is attenuated in the free vibration, and the amplitude of the response is suppressed or deformed in the forced vibration.

ZN-35 silicone rubber, which belongs to the viscoelastic damping material, has the following characteristics: (1) high temperature performance. in high temperature environment, silicone rubber can still maintain a certain degree of flexibility, resilience and surface hardness, and no significant changes in mechanical properties. (2) low temperature performance. The glass transition temperature of silicone rubber is generally -70-50℃, the special formula can reach -100℃, which indicates that the low temperature performance is excellent. it is significant for the aviation and aerospace industry. (3) electrical performance. Silicone rubber has excellent insulation performance, resistance to corona resistance and strong arc resistance. So it is very important to apply ZN-35 silicone rubber materials in aviation field [1].

Pertinent literature about the dynamic mechanical properties of ZN-35 silicone rubber were not found. In this paper, the energy storage modulus and loss factor of ZN-35 silicone rubber were studied . Because of the limitation of the present test instrument, it is very difficult to obtain the dynamic mechanical properties of the materials in a wide frequency domain. [2] for practical application and theoretical research, as early as 1970s, the U.S. air force used the master curve method to expand the dynamic mechanical properties of a wider frequency range. This method has now become the national standard and ISO standard. However, this method can produce all kinds of errors in the process of data translation. Moreover, the parameters of the main curve obtained by this method have no physical meaning. H-N model overcomes the disadvantages of the

method ,which connect the complex modulus and low frequency modulus and high frequency glass plateau modulus. By introducing four temperature independent parameters and a direct correlation with temperature parameters can accurately describe the dynamic mechanical properties of viscoelastic damping material in a wide frequency range. [3] In this paper, the H-N model is used to study the dynamic mechanical properties of ZN-35 silicone rubber, and the dynamic mechanical properties of the data are obtained from a higher frequency.

2.test and results

2.1 materials

In the experiment, the ZN-35 silicone rubber samples are shown in Figure 1, ZN-35 silicone rubber samples are 2mm thick slices, and cut into 15mm x 6mm strip.

Fig.1 ZN-35 material sample

2.2 test condition

The test conditions are as follows: choosing the constant temperature sweep frequency test method, the choice of the mode of action is tension. Initial static force is 0.5N. The minimum static force is 0.0001N. The temperature measuring point was -55, -40, -25, -10, 0, 25, 30, 40, 55, 70, 85℃. Force frequency range is 0.1 to 25hz.

2.3 test results and analysis

Set the temperature of the test piece, then get the energy storage modulus and loss factor. Fig.2 and Fig.3 show the average storage modulus and loss factor at-55、-40、-25、-10、0、25、30、40、55、70、85℃ respectively.

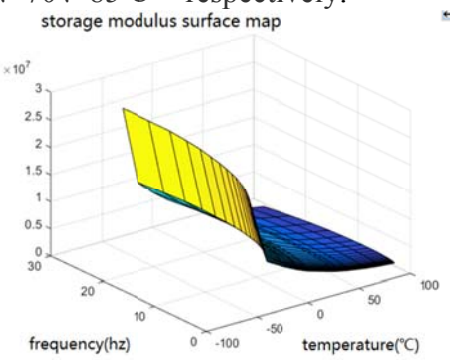

Fig.2 Storage modulus surface map

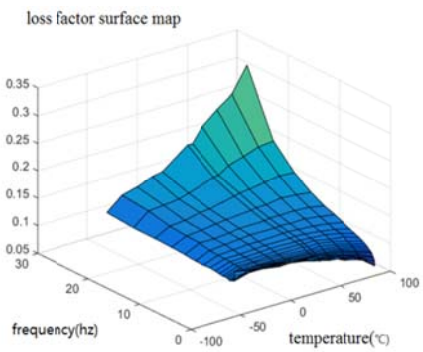

Fig.3 Loss factor surface map

From the change of the storage modulus(pa), the low temperature storage modulus is high, and the storage modulus is gradually lower with the rise of temperature. At the same time, the storage modulus increases with the rise of frequency, but when the frequency increases to a certain extent, about 10Hz, the storage modulus will gradually decrease. The change law of the loss factor increases with the rise of temperature, and increases with the rise of the frequency.

Temperature from low to high, the flow of molecules increased. Different molecular forms of movement are presented in the micro. On the whole, The polymer will experience three kinds of mechanical state of glass, rubber and viscous flow.

The lower temperature, the molecules are almost in the "frozen" state, and the storage modulus is the largest. With the rise of temperature, the molecular chain begins to "thaw". The molecular motion space begins to change, and the mechanical energy of the external force can be dissipate. The storage modulus will decrease. The loss factor increases with the increase of temperature.

The thermal movement of the polymer is related to the external force frequency. The effects of

frequency and temperature are just the opposite. At a certain temperature, with the increase of frequency, the polymer undergoes a sticky, rubber and glass. From the rubber to the glass, the storage modulus increases with the increase of frequency, the loss factor reach the maximum in transition area and then begin to fall until the glass state. [4]

3.H-N model

The Havriliak-Negami equation is[5]

$$E^*(w) = \frac{E_0 - E_\infty}{[1+(iw\tau)^\alpha]^\beta} + E_\infty \quad (1)$$

where $E^*(w)$ is the complex Young's modulus， E_0 is the low frequency modulus， E_∞ is the high frequency modulus， w is the angular frequency， α is a parameter governing the width of the relaxation， β is a parameter governing the asymmetry of the relaxation， τ is a relaxation time governing the position of the relaxation in the frequency domain,

$$E^*(w) = E' + iE'' \quad (2)$$

Solving for the real E' and imaginary E'', parts of Young's modulus respectively,

$$E' = E_\infty + \frac{(E_0 - E_\infty)\cos(\beta\theta)}{[1+2(w\tau)^\alpha \cos(\alpha\pi/2) + (w\tau)^{2\alpha}]^{\beta/2}} \quad (3)$$

$$E'' = E_\infty + \frac{(E_0 - E_\infty)\sin(\beta\theta)}{[1+2(w\tau)^\alpha \cos(\alpha\pi/2) + (w\tau)^{2\alpha}]^{\beta/2}} \quad (4)$$

where

$$\theta = \tan^{-1}[\frac{(w\tau)^\alpha \sin(\alpha\pi/2)}{1+(w\tau)^\alpha \cos(\alpha\pi/2)}] \quad (5)$$

Thus the loss factor is

$$\tan\delta = \frac{E''}{E'} = (E_\infty / E' - 1)\tan(\beta\theta) \quad (6)$$

In this model it is assumed that the only temperature dependent parameter is the relaxation time and that only one polymer relaxation is involved. If there are multiple relaxation processes then a more complicated analysis or the use of more than one H-N equation is required.

4.The Wicket plot

In order to reduce the errors caused by the improper operation of and the overload of the instrument, the test data should be selected to reduce the error The screening method is to draw the measured loss factor and the storage modulus data directly into the double logarithmic coordinates, that is, the Wicket plot. The Wicket plot is an extremely useful tool in analyzing dynamic viscoelastic data. The principle is that the storage modulus and loss factor are the only function of the conversion frequency for most amorphous polymers. Therefore, there must be a functional relationship between the energy storage modulus and the loss factor. It means that there is only one function relationship curve in the loss factor and the energy storage modulus. [6,7] No matter how the frequency and temperature of the test, all the valid data should be close to this curve, and those who are obviously deviate from the curve are questionable. The deviation data should be abandoned.

Fig.4 shows the original data Wicket plot for the ZN-35 silicone rubber material. Fig.5 shows the fitting data. It can be seen from figures, the original data dispersion is greater, there are obvious defect data. After screening, the data curve is smooth and continuous, which is convenient for the data fitting.

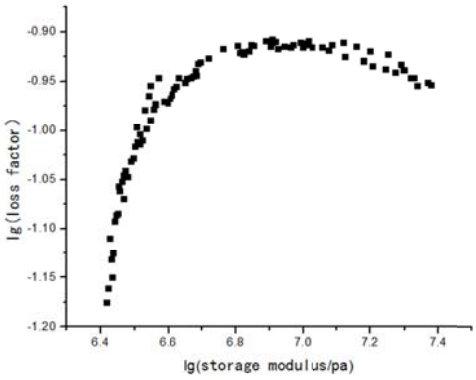

Fig.4 Experimental data

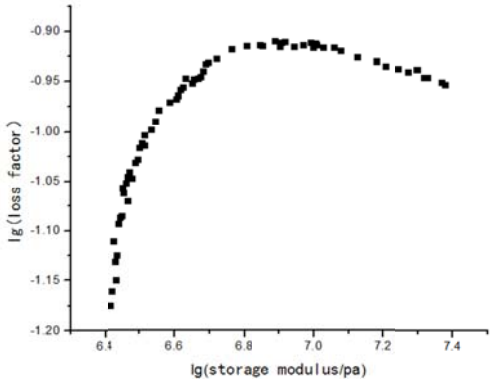

Fig.5 Processed data

5. data fitting

The purpose of data fitting is to optimize and determine the four parameters of the H-N model, α, β, E_0, E_∞. In Wicket plot, Parameters related to the shape of the complex modulus curve are α, β, E_0, E_∞. However, The relaxation time does not affect the shape of the curve in the Wicket plot. Therefore under the condition of τ is unchanged, α, β, E_0, E_∞ can be first determined. Then, According to the H-N model, the experimental data were fitted to the different temperatures to expand the frequency. [8]

In order to determine α, β, E_0, E_∞, we can follow the below method. Set relaxation time $\tau=1$. α, β, E_0, E_∞ can be optimized by using the Matlab optimization toolbox. The fitting error is related to the sum of the squares of the differences between the experimental and calculated loss factor.

Wicket error function

$$T=\sum_{E'}\left|\tan\delta_{\exp}-\tan\delta_{calc}\right|^2 \qquad (7)$$

where, T is fitting error, $\tan\delta_{\exp}$ is experimental loss factor, $\tan\delta_{calc}$ is calculated loss factor. Table1 shows that Optimized ZN-35 silicone rubber material H-N model fitting curve parameters.

Table 1 H-N fitting curve parameters

material	α	β	E_0	E_∞
ZN-35	0.61	0.24	2600000 pa	27000000 pa

It can be seen from Fig.6 that the error between the H-N model curve and experimental data is small.

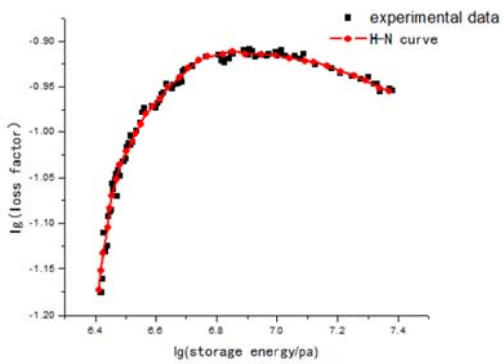

Fig.6 ZN-35 H-N curve of silicone rubber test data

6.Prediction of dynamic mechanical properties

In condition of DMTA test, the test frequency of viscoelastic damping materials is low. It is hard to get the mechanical dynamic properties at high frequency. Therefore, the H-N model can be used to expand the frequency to high frequency, to obtain high frequency dynamic mechanical properties.

By adjusting the angular frequency, the data can be extended to the high frequency, and the H-N model with a wider frequency range can be obtained. As is shown in Fig.7 and Fig.8, at different temperatures, the H-N model curve agrees quite well with the test data. So, H-N model can accurately predict the variation trend of storage modulus and loss factor at different temperatures, and thus obtain high frequency dynamic mechanical data.

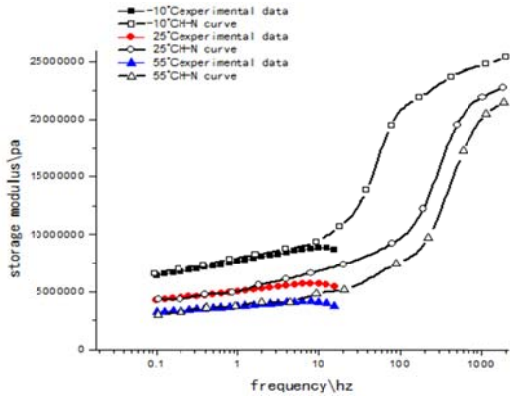

Fig.7 Storage modulus H-N curve

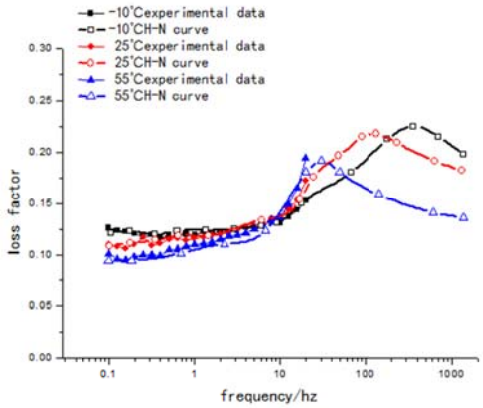

Fig.8 Loss factor H-N curve

7.conclusion

(1) The dynamic mechanical properties of ZN-35 silicone rubber were tested by DMTA. The spectrum of different temperatures was obtained and the variation of its storage modulus and loss factor was analyzed. At the same frequency, with the rise of temperature, the storage modulus of ZN-35 silicone rubber was decreased, and the loss factor was increased. When the temperature is constant, the storage modulus increases with the increase of the frequency until it becomes stable.

(2)The H-N model maintains the physical relationship between the storage modulus and loss factor, and the model parameters have a clear physical meaning. H-N model can accurately simulate the dynamic mechanical properties of viscoelastic materials; Based on the test data of different temperature points, it can effectively expand the frequency range, and accurately predict the mechanical properties of high frequency.

Acknowledgments

This work was financially supported by “the National Science and Technology Major Project of the Ministry of Science and Technology of China (2014ZX04001-171)”

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