Improved Design and Performance Test of Viscoelastic Assembled Shock Absorber

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Abstract: In order to reduce the overall vulcanization cost of the viscoelastic shock absorber and prevent the premature cracking of its adhesive layer, the viscoelastic shock absorber was improved and designed. A new type of viscoelastic assembled shock absorber suitable for cold adhesive bonding was made by adding grooves to the steel plate and increasing the lateral pressure with bolts. Then, the mechanical properties of the new assembled shock absorber were tested under different working conditions to study its energy dissipation characteristics and failure mode. The storage modulus and loss factor of the viscoelastic damping material were calculated through the force- displacement hysteresis curve, and the influence of the device structure, lateral pressure, loading frequency and displacement amplitude on the mechanical properties of the shock absorber were obtained. The test results show that adding grooves to the steel plate and increasing the lateral pressure of the shock absorber can improve the ability of the shock absorber to dissipate vibration energy. Moreover, the greater the displacement amplitude and loading frequency, the more energy dissipated. Therefore, by adopting appropriate external conditions and reasonable internal structure, the energy dissipation performance of the damping material can be fully utilized and the shock absorption effect of the shock absorber can be greatly improved.
***Keywords*:** viscoelastic material; viscoelastic assembled shock absorber; performance test; lateral pressure; bonding failure

1. Introduction

As a typical passive energy dissipation device, viscoelastic shock absorbers can effectively reduce wind vibration and seismic response of structures. Viscoelastic shock absorbers are made of steel plates and viscoelastic damping materials bonded together. Through the reciprocating shear motion of the damping material, the effect of seismic isolation and energy dissipation is achieved [1] . The shock absorber reduces the dynamic response and damage of the structure under seismic loads through the hysteretic deformation of the damping material [2] .

A typical viscoelastic shock absorber consists of three steel plates and two viscoelastic damping materials, as shown in Figure 1. Under repeated loads such as earthquakes, the steel plates move relative to each other [3] , causing the damping material to undergo reciprocating shear deformation to dissipate energy. To achieve the purpose of energy dissipation and shock reduction [4] .

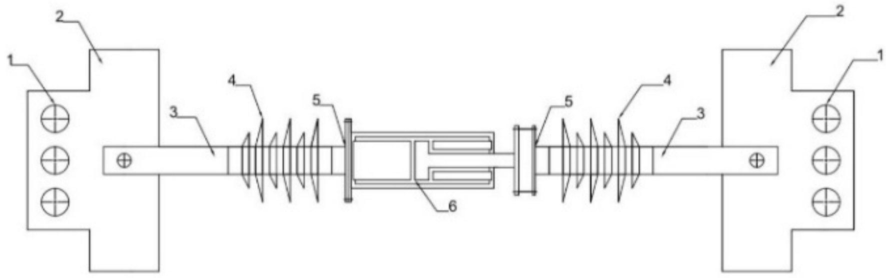

Figure 1. Typical viscoelastic assembled shock absorber structure

Displacement hysteresis curve of the viscoelastic shock absorber is approximately elliptical. When the structure deforms slightly, the shock absorber can exert an energy dissipation effect. It can be used for wind vibration and earthquake control of the structure and has a wide range of engineering applications. Applicability [5] . Viscoelastic shock absorbers have reliable performance, simple structure, convenient production, and low cost. They can significantly reduce the dynamic response and damage of structures under earthquake action.

However, the existing viscoelastic shock absorbers have a high overall high temperature and high pressure vulcanization cost and limited adhesiveness during fatigue tests and actual use. The damping material and the steel plate often crack and fall off before the damping material is subjected to shear failure strength [6] , resulting in device failure and inability to fully exert the performance of the damping material. To this end, inspired by the bridge shock-absorbing bearing, this paper improves the design of the existing viscoelastic shock absorber and produces a new viscoelastic assembled shock absorber suitable for cold glue bonding, which tries to avoid the damage of the connection between the damping material and the steel plate before the damage of the damping material itself, so as to maximize the effect of the damping material and improve the working performance of the viscoelastic assembled shock absorber.

2. Improved design of viscoelastic assembled shock absorber

Improved design of the existing viscoelastic shock absorber in this paper (see Figure 2) includes: using cold glue bonding process to avoid overall high temperature and high pressure vulcanization; adding grooves at the bonding position between the steel plate and the viscoelastic damping material so that the damping material is completely embedded therein; and adding lateral pressure to the shock absorber through bolts and ear plates (steel plates).

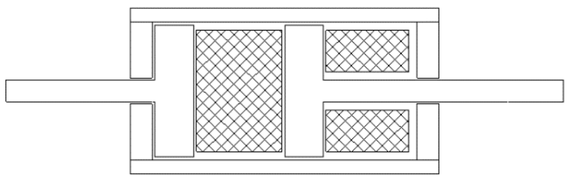

Figure 2. Improved structure of viscoelastic assembled shock absorber

The specific design parameters of the improved viscoelastic assembled shock absorber are shown in Table 1, and the physical structure of the steel plate is shown in Figure 3. The ratio of the groove depth to the thickness of the viscoelastic damping material is 5%. The damping material uses nitrile rubber JSR200S as the matrix, and carbon black, accelerator, vulcanizer, plasticizer, antioxidant and other modified ingredients are added. The hardness of the damping material measured by the physical property test is 70 to 80 HA, elongation at break is 440%, and permanent deformation is 30%.

Figure 3. Physical structure of steel plate

3. Mechanical properties test of viscoelastic assembled shock absorber

The mechanical properties of the assembled shock absorber manufactured according to the design parameters in Table 1 were tested under different working conditions to study its energy consumption characteristics and failure mode. The storage modulus and loss factor of the viscoelastic damping material were calculated through the force- displacement hysteresis curve, and the influence of steel plate structure, lateral pressure, loading frequency and amplitude on the mechanical properties of the shock absorber were obtained.

Table 1. Improved design parameters of front and rear viscoelastic assembled shock absorbers

Shock absorber type	Steel plate geometric dimensions / mm	Damping material geometric dimensions / mm	Groove area / mm^2	Groove depth / mm	Number of damping material layers
Before improvement	150 × 50 × 8	60 × 40 × 10	0	0	2
After Improvement	150 × 50 × 8	60 × 40 × 10	2 400	0.5	2

Note: The groove area of 0 means there is no groove on the steel plate of specimen 2.

During the test, 100 kN fatigue testing machine for reciprocating cyclic loading. The shock absorber is subjected to lateral pressure through bolts, and the applied lateral pressure is controlled and monitored by force sensors and data acquisition systems. The specific loading arrangement is shown in Figure 4. The test set up a variety of working conditions, with lateral pressures of 0, 1000 and 2000 respectively. N, The loading frequencies are 0.1, 0.2, 0.5 and 1.0 respectively. Hz, displacement amplitudes are 1, 3, 5 and 7 mm, 10 cycles were performed under each working condition, and more than 200 working condition tests were conducted in total. The loading conditions were in sequence from low frequency to high frequency, small displacement amplitude to large displacement amplitude, and small lateral pressure to large lateral pressure. After each working condition was completed, it was necessary to check whether the bolt connection and the connection between the damping material and the steel plate were firm.

4. Analysis of mechanical properties test results

4.1 Mechanical principles

Viscoelastic assembled shock absorber can be measured by the work done when it is displaced under the action of a force [7] , that is, by the area enclosed by the force - displacement hysteresis curve. The larger the enveloping area, the greater the energy dissipation capacity of the shock absorber [8] .

The hysteresis curve of the viscoelastic assembled shock absorber is elliptical. It has good energy dissipation performance [9-14] . The tilt angle of the ellipse is related to the storage modulus. The area enclosed by the hysteresis curve is the energy consumed by the unit volume of viscoelastic damping material in each vibration cycle., its expression is:

$$E_d = \int_0^{\frac{2x}{\omega}} \tau(t)\dot{\gamma}(t)\,dt = \pi\gamma_0^2 G_2(\omega) \tag{1}$$

Where: $\tau(t)$ is the shear stress of the damping material; γ_0 is the maximum shear strain of the $\dot{\gamma}(t) = \gamma_0\omega\cos\omega t$ viscoelastic material; ω is the frequency of excitation; $G_2(\omega)$ represents the loss modulus of the viscoelastic material, which measures the energy consumed per cycle .

The equivalent damping ratio can be used to measure the damping performance of viscoelastic materials. The equivalent damping ratio ξ is the ratio of the energy dissipated in one cycle to 4π times the stored strain energy when the system produces the maximum deformation, that is,

$$\xi = \frac{\pi G_2\gamma_0^2}{4\pi(G_1\gamma_0^2/2)} = \frac{G_2}{2G_1} \tag{2}$$

Where: G_1 is storage modulus of viscoelastic materials, a measure of the energy stored and recovered per cycle, and, a measure of the energy consumed per cycle .

Loss factor expression is

$$\eta = \frac{G_2(\omega)}{G_1(\omega)} = \tan\alpha \tag{3}$$

Where: η is the loss factor, which measures the energy dissipation capacity of viscoelastic materials; α represents the difference in phase angle.

4.2 Test results of shock absorber performance parameters

Viscoelastic assembled shock absorber can be obtained by the formula in 3.1. Since there are too many cycles under each working condition, the most stable part of the 10 cycles is selected to draw the hysteresis curve and analyze and calculate, and the storage modulus and loss factor of the shock absorber under various working conditions are obtained. The results are shown in Table 2.

Table 2. Performance parameters of shock absorber

Shock Absorber Type	Frequency (Hz)	Displacement (mm)	Force (N)	Storage Modulus G1 (MPa)	Ita
d4mmf0.2Hz	0.2	2.113	0.113	2.973	0.991
d10mmf0.2Hz	0.2	0.485	0.563	1.812	1.007
d4mmf0.5 Hz	0.5	0.654	0.257	2.721	1.129
d8mmf0.1Hz	0.1	7.090	0.165	3.402	1.033
d8mmf0.2Hz	0.2	0.738	0.458	3.066	1.022
d10mmf0.1Hz	0.1	9.726	1.332	2.389	1.009
d2mmf0.5Hz	0.5	0.265	0.136	2.549	0.987
d6mmf0.2Hz	0.2	5.805	0.511	3.107	1.054
d10mmf0.2Hz	0.2	7.330	0.705	1.812	0.999
d10mmf0.5Hz	0.5	5.670	0.572	2.152	1.007

4.3 Analysis of hysteresis characteristics of viscoelastic assembled shock absorber

In order to study the variation law of the performance parameters of the viscoelastic assembled shock absorber under different working conditions, the test data were processed and the force- displacement hysteresis curves of the shock absorber before and after improvement under different working conditions were drawn. Both shock absorbers showed the same variation law. Two relatively stable working conditions were selected for analysis, as shown in Figures 4.

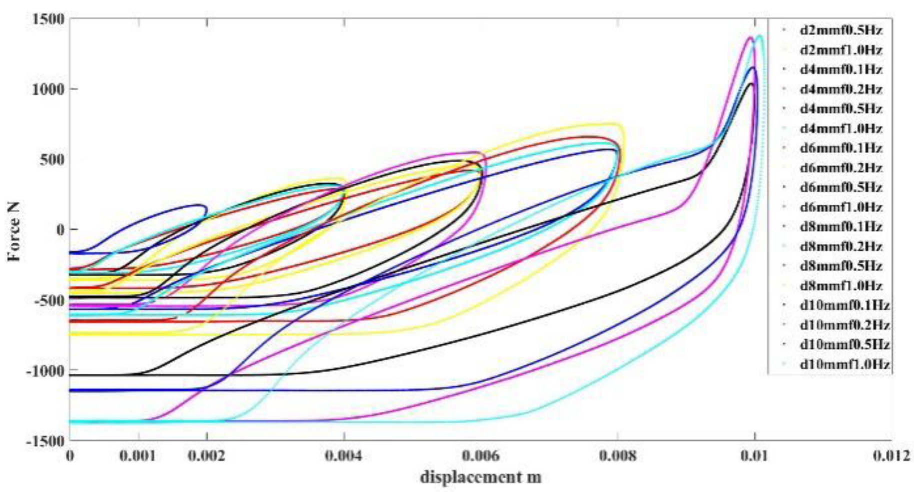

Figure 4. The hysteresis curve changes with the displacement amplitude (F = 1 000 N, f = 0.5 Hz)

It can be seen that when the displacement amplitudes are 1, 3, 5, and 7 mm, the envelope areas of the hysteresis curves are 0.3097, 2.3914, 6.1146, 10.7477. The displacement amplitude is 1 ~ 3 mm, the envelope area increased by 672%; in the 3 ~ 5 mm, the envelope area increased by 156%; in the 5 ~ 7 mm interval, the envelope area increases by 76%. Therefore, when the lateral pressure and loading frequency are the same, as the displacement amplitude increases, the envelope area of the hysteresis curve increases, the inclination angle decreases, and the single-turn energy consumption of the shock absorber continues to increase.

It can be seen from Figure 6 that, when the lateral pressure, loading frequency and displacement amplitude are the same, the envelope area of the hysteresis curve of the grooved shock absorber is larger than that of the non-grooved shock absorber. The larger the displacement amplitude, the more obvious this change trend is. Therefore, the single-turn energy consumption of the grooved shock absorber is greater than that of the non-grooved shock absorber. When the shock absorber has grooves, the damping material is embedded in the grooves, and the thickness of the damping material layer sandwiched between the steel plates is slightly reduced, which increases the stiffness of the shock absorber. Therefore, the inclination angle of the hysteresis curve of the grooved shock absorber is larger than that of the non-grooved shock absorber.

5. Design suggestions

From the above analysis, it can be seen that the existence of grooves and lateral pressure can improve the shock absorption performance of viscoelastic assembled shock absorbers. According to Figure 7, as the lateral pressure continues to increase, the trend of the shock absorber's performance parameters continuing to increase decreases. It is recommended that the lateral pressure value be controlled between 0.5 and 1.5. MPa. When the lateral pressure increases to a sufficient level, the damping material sandwiched between the steel plates will be squeezed and deformed and bulge out. Therefore, when the lateral pressure is too large, it will affect the shock absorption performance of the shock absorber. The presence of grooves can improve the shock absorption performance of viscoelastic assembled shock absorbers, but the ratio of the thickness of the damping material to the depth of the grooves should be controlled within the range of 0.05 to 0.10. The reason is that if the groove depth is too small, the grooves do not have enough embedding effect on the damping material and thus cannot play the role of the grooves; when the groove depth is large, the damping material is embedded deeper, and the edge of the steel plate has a shearing effect on the damping material, thereby tearing the damping material, causing the damping material to be damaged and unable to fully exert its energy dissipation characteristics.

6. Conclusion

Damping material and the steel plate of the viscoelastic assembled shock absorber, the existing viscoelastic assembled shock absorber was improved and designed, and the corresponding shock absorber model was made. The mechanical properties tests under different working conditions were carried out, focusing on the influence of steel plate structure, lateral pressure, loading frequency and displacement amplitude on the working performance of the shock absorber, and the following conclusions were obtained:

(1) The presence of grooves has a great influence on the shock absorption performance of viscoelastic assembled shock absorbers. Compared with specimens without grooves, 5% deep grooves increase the storage modulus of the shock absorber by 12.2% to 27.4% and the loss factor by 8.2% to 9.5%.

(2) The size of the lateral pressure has a great influence on the damping performance of the viscoelastic assembled shock absorber. MPa increased by 0.83 MPa, the storage modulus increases by 16.0% and the loss factor increases by 15.2%.

(3) The displacement amplitude and loading frequency have a certain impact on the shock absorption performance of the viscoelastic assembled shock absorber. When the displacement amplitude increases by 1 times, the storage modulus decreases by 5% and the loss factor decreases by 10% to 15%; loading When the frequency is doubled, the storage modulus increases by 5% to 10% and the loss factor increases by 10% to 20%. Therefore, the loading frequency has a more significant impact on the damping performance of the shock absorber.

(4) The existence of grooves and lateral pressure can improve the shock absorption performance of viscoelastic assembled shock absorbers. In the future design and practical application of viscoelastic assembled shock absorbers, the effects of grooves and lateral pressure should be considered, the lateral pressure size and groove depth should be controlled, and the performance of the shock absorber should be maximized.

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