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Experimental Study on Vibration Performance of Partial Constrained Layer Damping Structure

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Abstract. In this paper, the dynamic mechanical properties of Qtech-T501 damping material were studied using dynamic thermal mechanical analysis (DMA). The single-point hammering tests were conducted on simply supported samples to study the factors that affect the vibration of partial constrained damping structure, including the fraction of coverage of constrained layer and damping layer and the thickness of constrained layer. The maximum amplitude on the time-domain waveform and the transfer function were presented. Results shows when the thickness of constrained layer is fixed and the fraction of coverage increases from 40% to 100%, the maximum amplitude on the time-domain waveform and transfer function both decreased and the best damping ability were achieved with 80% fraction of coverage. With fixed fraction of coverage of constrained layer and damping layer, the samples have 6cm or 8cm thick constrained layer has the maximum amplitude on the time domain waveform, while the value of transfer function is smaller than that of other samples. Take the weight of structure, the energy dissipation capacity, the economic factors and the results of this experiment research into account, it is concluded that the best fraction of coverage is 80% and the optimized thickness of constrained layer is 6 cm.

Key words: Partial Constrained Layer Damping Structure; Dynamic Mechanical Property; Fraction of Coverage; The Thickness of Constrained Layer.

INTRODUCTION

The constrained layer damping (CLD) structure is a kind of simple damping structure that receives abroad attention and research [1-3]. The structure of CLD yet has not been widely used because of the limitations in various fields. At present, the widely used damping structure in fields is partial constrained layer damping (PCLD) structure. In 1987, Lall [4] firstly proposed the PCLD structure, however, after that the research of PCLD was mainly focused on the topology optimization of the coverage [5-8]. There has been few article published on the experimental study of model of PCLD structure.

This study is based on the experiences of the construction of Qingdao Mero® light rail. The base and constrained layer researched here is the mortar board which has good grading of aggregates. To study the PCLD structure in specific area, the Dasp software and the vibration tests was used. The single-point hammering test was conducted on PCLD structure with simply support. The effects of fraction of coverage of constraint and damping layer and the thickness of constrained layer on the vibration of PCLD structure were studied.

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EXPERIMENT

Materials and Equipment

The PCLD samples were manufacture using 42.5 ordinary Portland cement, standard sand, distilled water and the Viscoelastic Damping Material Series Qtech Qtech-T501[9] (hereinafter referred to as the T501, Qingdao Shamu Advanced Material Co., Ltd.). The equipment used were the Dynamic Mechanical Thermal Analyzer (DMA242C, NETZSCH®, Germany), the Vibration Data Collector (INV3062T0, china orient institute of noise&vibration) and the Vibration Signal Processing software (Dasp-v11,china orient institute of noise&vibration).

Preparation

The samples have 3 layers: base layer, constrained layer and damping layer. The base layer is 40cm×20cm×2cm sized M15 mortar board. The constrained layer is 40cm long M15 mortar board with different width of 8cm, 12cm, 16cm and 20cm respectively (40%, 60%, 80% and 100% of base area respectively) and their thickness is 2cm, 4cm, 6cm and 8cm respectively. The damping layer is the 2mm thick T-501 and the applied area is the same as the area of the constrained layer. The series number are showing in Table 1, in which A, B, C and D stands for the thickness of 2 cm, 4 cm, 6 cm and 8 cm constrained layer respectively. The figure 40, 60, 80 and 100, represents 40%, 60%, 80% and 100% coverage of constraint and damping layer. The diagram of sample C80 is showing in Fig. 1.

TABLE 1. Serial number of samples

the thickness of constrained layer(cm)	Fraction of coverage			
	40%	60%	80%	100%
2	A40	A60	A80	A100
4	B40	B60	B80	B100
6	C40	C60	C80	C100
8	D40	D60	D80	D100

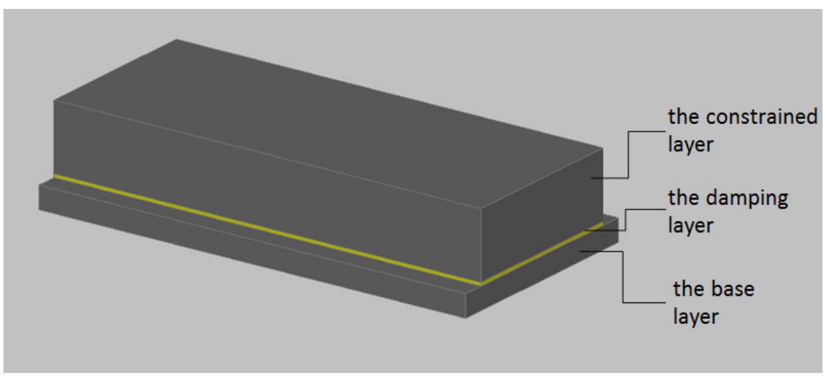


FIGURE 1. Sketch for sample C80.

Procedure

The base layer is mortar board (water cement ratio was 0.5), that was cured under standard condition for 28 days. After curing, the T501 was sprayed on the surface of one mortar plate by spray machine under 23°C and 50%RH, and then another mortar plate was covered on the sample as the constrained layer. The prepared samples were cured under standard condition.

The data of single-point hammer test of two sides simply supported constraints was collected by INV3062T0 vibration data collector with V11 vibration signal processing software with excited force 200 N, sampling frequency 2560Hz and overlap coefficient was 15/16.

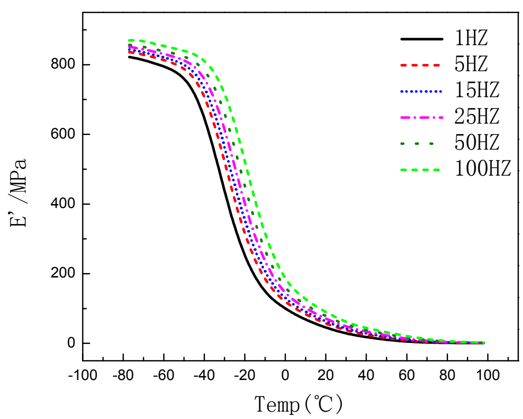
RESULTS AND DISCUSSION

The Results of DMA

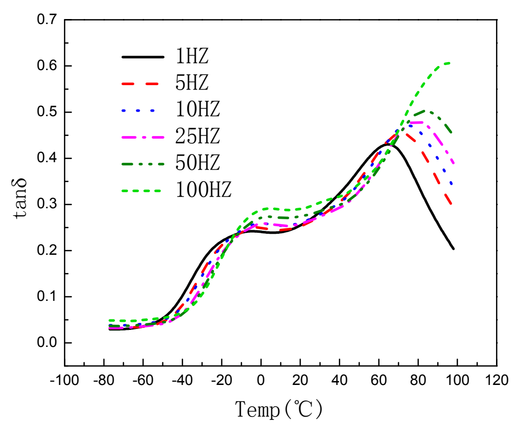
The DMA result of T501 is shown in Fig. 2. From Fig. 2 (a) which shows the E '~ T curve (energy storage modulus vs temperature). It can be seen that for the same frequency, the value of the high E' and low E ' are both low. This is due to the good viscoelastic of molecular chain of this material. Meanwhile, there is a glass transition zone of this material which occurred on the temperature between -40°C and 20°C. The value of E ' increases with the rising of frequency, and this increase is specially fast when the temperature of materials within the glass transition region.

From Fig.2(b)which shows the tanδ~ T curve (composed loss factor vs temperature), it can be seen that, T501 shows 2 mechanical loss waves (Tgs and Tgh) which reflects the two phases structure of this material. When the frequency were raised from 1Hz to 100Hz, the loss factor of tanδ increased from 0.430 to 0.607, showing good energy consumption capability. The greatest reduction of mechanical properties showed in the high temperature region from 65°C ~100°C, which reflects the glass change temperature (Tgh). The loss shows in the temperature between -20°C ~5°C reflects the glass transfer in soft region. It seems that T501 has a wide glass transfer region as its transfer procedure moving towards to the high temperature region.

According to the DMA curve of T501, this material has good damping capability and wide glass transfer region to be the damping layer for vibration control.



(a)



(b)

FIGURE 2. the DMA curve of T501(a)the E '~ T curve(b)the tanδ~ T curve

Maximum Amplitude in Time-Domain Waveform

The maximum amplitude in time-domain waveform recorded in tests was listed by Table 2.

When the thickness of the constrained layer is 2cm, and the fraction of coverage increased from 40% to 100%, the maximum amplitude of vibration reduced from 126.77m /s2 to 88.33m /s2. It can be seen that the larger the laying area of the constrained layer and the damping layer, the smaller the maximum amplitude. When the fraction of coverage increased from 40% to 60%, 80% and 100% respectively, the maximum amplitude of vibration decreased by 24.94m /s2, 37.59m /s2 and 38.44m /s2, respectively. Although increasing the fraction of coverage from 40% to 80% could reduce the maximum amplitude of significantly, when continue to increase the fraction of coverage from 80% to 100%, the maximum amplitude of vibration basically remained stable, only decreased by 0.85 m/s2. Other analysis of the maximum amplitude for samples with thickness of constrained layer 4cm, 6cm and 8cm, obtained the same rule.

It can be seen that, with the increase of fraction of coverage, the maximum value of vibration is effectively reduced while the damping performance is obviously improved. When the fraction of coverage of the constraint and damping layer increased from 40% to 80%, the vibration amplitude has been reduced mostly, while, if continue to increase the fraction, the amplitude remain steady. It seems that the sample would have the best damping efficiency when the fraction of partial constraint is around 80%, This conclusion is in consistent with literature [10] which says the optimal fraction of coverage ratio for constraint and damping layer in the first two-class-mode is about 75%.

TABLE 2. The maximum amplitude of samples with different constrained layer, damping layer and the thickness of constrained layer (m/s2)

the thickness of constrained layer(cm)	Fraction of coverage			
	40%	60%	80%	100%
2	126.77	101.83	89.18	88.33
4	103.98	94.15	58.08	72.72
6	65.77	59.85	39.83	38.06
8	37.28	34.59	28.29	21.48

When the fraction of coverage of constraint and damping layer was 60% and the thickness of constrained layer is increased from 2 cm to 8 cm, the maximum amplitude of vibration went down from 101.83 m/s2 to 34.59 m/s2. It follows that, the thickness of constrained layer has more important effects on the maximum amplitude than the fraction of coverage; nevertheless the maximum amplitude is sensitive to the increase of the thickness of the constrained layer. When the thickness of the constrained layer increased from 2 cm to 4 cm, from 4 cm to 6 cm, and from 6 cm to 8 cm respectively, the maximum amplitude fell by 7.68 m/s2, 34.3 m/s2 and 25.26 m/s2 respectively. It seems that, when the thickness of the constrained layer increased from 4 cm to 6 cm, the maximum amplitude of vibration experienced the most severe drop, which is a phenomenon that has also been showed by other samples with different fraction of coverage.

In conclusion, the experimental results illustrate that the increase of thickness of the constrained layer can effectively reduce the vibrating acceleration. The reduction is especially obvious when the thickness of the constrained layer increased from 4 cm to 6 cm, in terms of the maximum amplitude decrease. This is because the increase of thickness could exacerbate the shear deformation of damping layer, so as to make the maximum amplitude of vibration decreases. However, if the constrained layer thickness was too large, their weight would cause excessive compression on damping layer, which would reduce the shear energy and result in a decline in the decrease of the maximum amplitude of the structure vibration.

Transfer Function

Firstly, the effects of the fraction of coverage of the constrained and the damping layer on the level of vibration acceleration under the unit excitation force were studied. The experimental results are shown in Fig. 3.

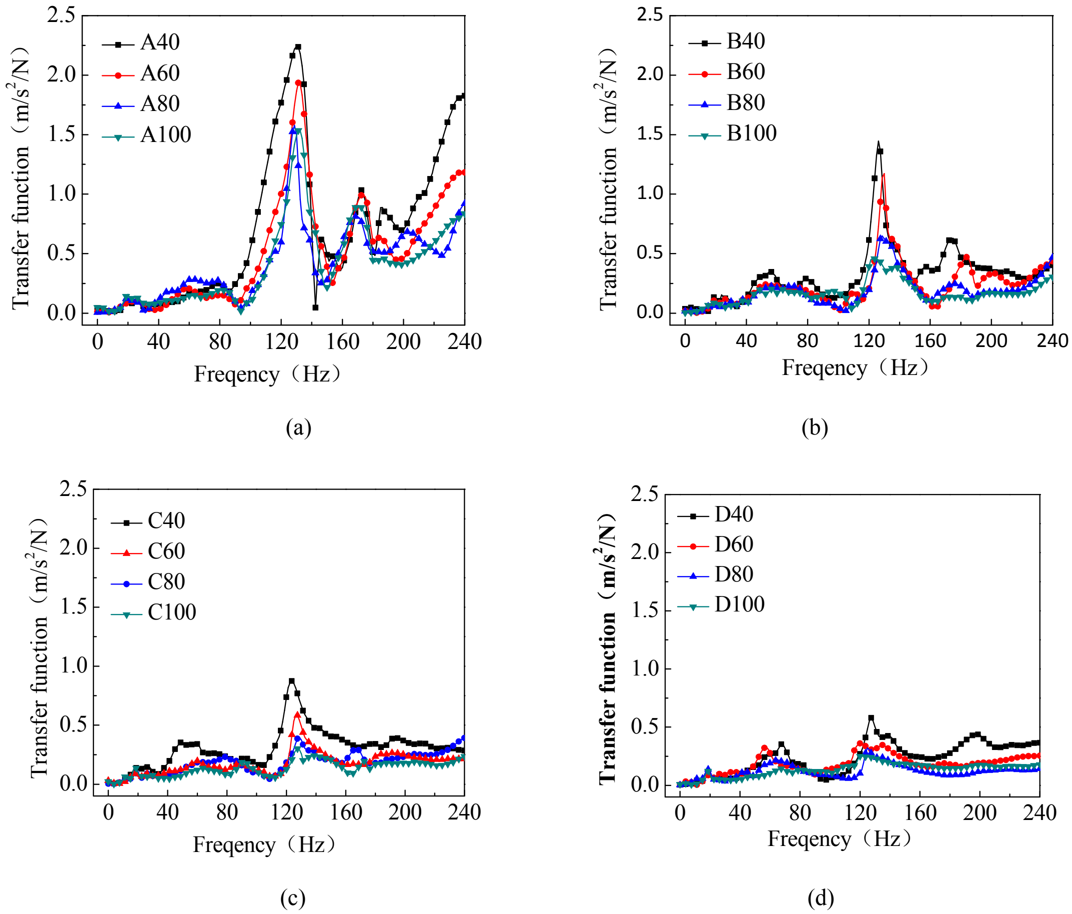


FIGURE 3. Effects of fraction of coverage of constraint and damping layer on the transfer function(a)2cm constrained layer(b)4cm constrained layer(c)6cm constrained layer(d)8cm constrained layer

The Fig. 3 (a) shows that when the thickness of the constrained layer is 2 cm and the constraint and damping layer covers 40%, 60%, 80% and 100% of the sample area (i.e. A40, A60, A80 and A100), under unit vibration force the maximum value of acceleration is 2.24 m/s2 / N, 1.94 m/s2 / N, 1.58 m/s2 / N and 1.54 m/s2 / N respectively. It is clear that the big the faction of coverage of constraint and damping layer, the great the inhibitory effect on vibration acceleration. Nonetheless the decreasing trends among different samples have big differences. Compared with A40, the decrease of sample A60, A80 and A100 is 13.39%, 29.46% and 13.39% less respectively. It has been shown that when the fraction of coverage of constraint and damping layer increased from 40% to 80%, the vibration acceleration peak value dropped significantly. However, if it was kept increasing to 100%, the trend of decline turned gradual. The sample with 4 cm, 6 cm and 8 cm constrained layer also showed similar rules.

Comparing the results showing in Fig. 3 (a) ~ (d), it is clear that, in addition to special frequencies, generally the maximum value of the transfer function would occur on the fraction of coverage 40% or 60%. Meanwhile, when the fraction of coverage of constraint and damping layer is 80% and 100%, the minimum value of transfer function occurs. This result is in consistent with the analysis of the maximum amplitude in the time-domain waveform. The reason for this behaviour may be that the damping layer is quite effective in terms of energy consumption, so as to make the vibration acceleration increase with the fraction of coverage; also, during vibration, the shear deformation will reach the largest value in the center position, so as to make sample A80 more efficient than sample A100 despite similar vibration acceleration. Considering the increase of weight of sample will reduce the vibration acceleration, the samples with 80% fraction of is believed to have the best damping effect.

Fig.4 illustrates the changes of transfer function between samples with different thickness of constrained layer and fixed fraction of coverage.

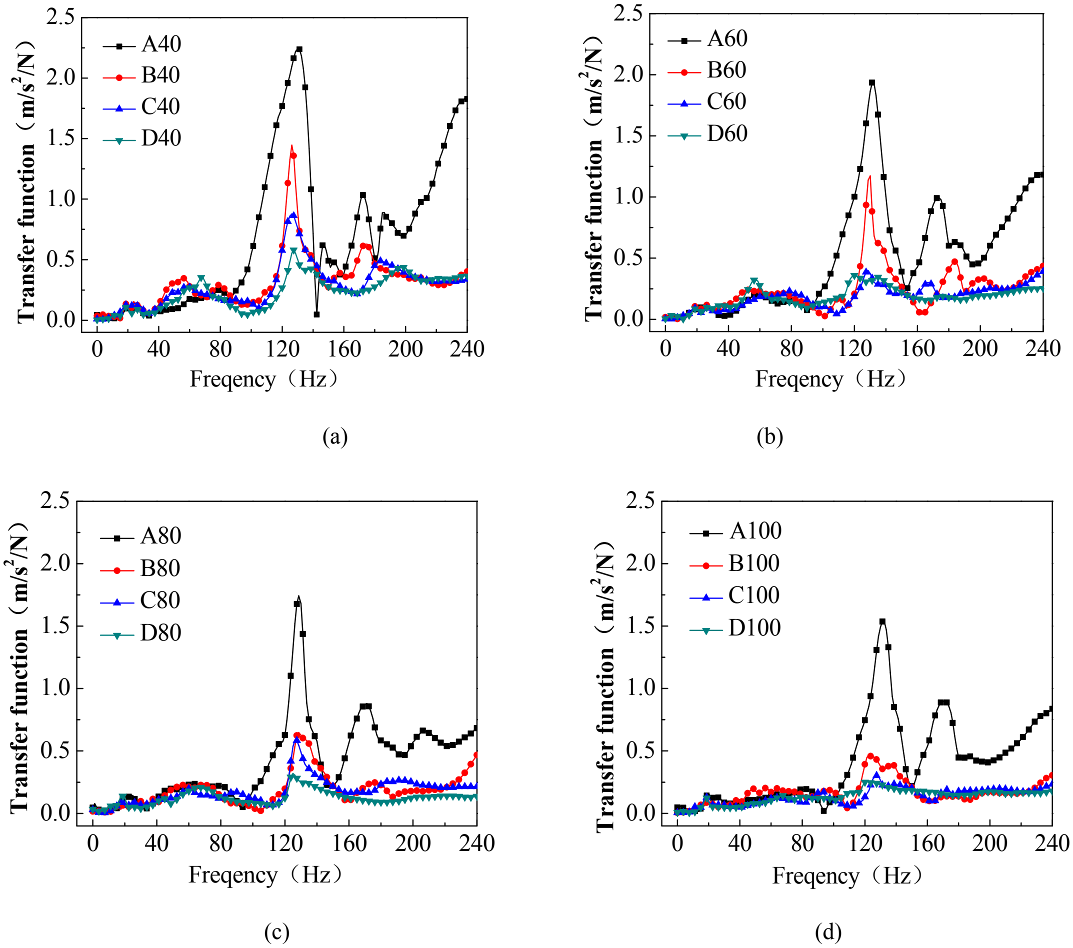


FIGURE 4. Effects of different thickness of constrained layer on the transfer function (a) 40% fraction of coverage (b) 60% fraction of coverage (c) 80% fraction of coverage (d) 100% fraction of coverage

When the fraction of coverage of constraint and damping layer is 40% and the thickness of constrained layer is 2 cm, the transfer function reached the maximum value. Increasing the thickness of constrained layer to 4cm or 6cm have decreased the value of transfer function. While if keep increasing the thickness of the constrained layer to 8cm, the value of transfer function keeps steady. From the curves showed in Fig. 4(a)~(d), it is clear that the values of transfer function of samples have different fraction of coverage shared similar changing trends, which is especially obvious when the fraction of coverage is 60% and 80%.

The above result obtained by this research shows that, the amplitude of the transfer function of each group is basically decreasing with the increase of the thickness of the constrained layer. Meanwhile, when the thickness of the constrained layer increased from 6cm to 8cm, there is no obvious change in the magnitude of amplitude. The reason is that, increasing the thickness of the constrained layer contributes to the stiffness of this layer, which increased its constraint to the damping layer, the magnitude of shear deformation and the energy consumption. Nonetheless, after the thickness of constrained layer exceeded to 6cm, its constraint to the damping layer stop increasing. The increase of the thickness of constrained layer also increases the pressure to the damping layer and hereby reduces the shear energy dissipation. Consequently, the authors suggest 6cm as the optimized thickness of constrained layer.

CONCLUSIONS

(1) T-501 damping materials presented a typical viscoelastic material characteristic in terms of energy storage modulus. The energy storage modulus of this material increased with the increase of frequency; When the frequency increased from 1 Hz to 100 Hz, the tanδ (peak of loss factor) increased from 0.430 to 0.430, which is a prove of good energy consumption ability.

(2) When the thickness of the constrained layer locates between 2 and 8 cm and the fraction of coverage is in the range of 40% ~ 100%, the maximum amplitude on the time-domain waveform decreased with the increase of the fraction of coverage of constraint and damping layer and the thickness of the constrained layer. With the thickness of thee constrained layer increased from 4 cm to 6 cm, the maximum amplitude dropped dramatically. It has been showed that the highest efficiency of damping could be achieved when the fraction of coverage is 80%.

(3) When the thickness of constraint and damping layer increased from 40% to 80%, the amplitude of the transfer function was significantly reduced. When it increased from 80% to 100%, the downward trend of the transfer function was not obvious. If the thickness of the constrained layer increased from 2cm to 6 cm, the transfer function would drop considerably. When the thickness of the constrained layer increased from 6cm to 8 cm, the changes showed the transfer function was inconspicuous.

(4) Consequently, according to the rules showed in the time-domain waveform and the transfer function and considering the cost and weight of structure, it is concluded that the best fraction of coverage is 80% and the optimized thickness of the constrained layer is 6 cm.

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