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Effect of Thickness of Damping Material on Vibration Control of Structural Vibration in Constrained Layer Damping Treatment

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Abstract

The reduction of noise and vibration is a major requirement for performance of any vibratory system. Passive damping technology using viscoelastic materials is classically used to control vibrations. Viscoelastic material among the damping materials is widely used to dissipate the structural vibration energy. Three-layer sandwich beams, made of two elastic outer layers and a viscoelastic layer sandwiched between them, are considered as damping structural elements.

This paper presents the effect of thickness of constrained damping material on modal loss factor of vibrating structures. Measurements are performed on sandwich beam structure. In order to understand the effectiveness of the sandwich structures, the dynamics of beam with constrained viscoelastic layers are investigated. Comparisons of the experimental and the Numerical results confirm that the damping levels and the natural frequencies of damped structures are well corroborated.

1. Introduction:

The attenuation of the structural vibration and noise has been a great challenging subject in various engineering fields during several decades, because a dynamic system or its components with insufficient damping may produce significantly high vibration which results in undesirable noise.

The damping materials are used in many fields including aerospace, aeronautics, automotive and domestic appliances in order to minimise undesirable structure borne vibrations and radiated noise while eliminating high cycle fatigue and failure of critical components [1–5]. To meet today's high-performance requirements; smart structures composed of passive viscoelastic materials are become practical.

Constrained-layer damping treatment provides an effective way to suppress vibration and noise in structures. The structural vibration of a CLD sandwich beam is characterized by a combination of two distinct deformation modes, the oscillating flexural bending deformation of two metallic faces and the alternating distortional shear deformation of a core viscoelastic layer. These layered structures can be used into automotive components such as sound system enclosures, brake shims, dash panels, gear box covers, various brackets and engine oil pans [6].

A special type of damping material involves polymer-based coatings that exhibit both elastic flow and viscous flow, depending on their temperature, and are commonly referred to as viscoelastic materials [7]. Damping refers to the extraction of mechanical energy from a vibrating system usually by conversion of this energy into heat. Damping serves to control the steady-state resonant response and to attenuate traveling waves in the structure.

The efficiency of damping present in a system is evaluated by determining the loss factor of the system. This paper will discuss the effect of thickness of damping material on modal loss factor of vibrating structures.

2. Sandwich CLD beam

Viscoelastic sandwich composites are structures in which a viscoelastic layer is sandwiched between elastic layers, and are widely used in engineering applications in order to reduce vibration amplitude and noise.

The pioneering work related to sandwich beam was done by Kerwin. He derived an expression for an effective complex flexural stiffness of the three-layer beam with a damping core layer [8]. Johnson gave a brief review of recent developments in passive damping treatments [9]. Frequency and loss factors of sandwich beams were calculated by Rao for various boundary conditions [10].

When the damping material to be evaluated is soft or if the complex modulus properties in shear are required, the symmetric sandwich beam configuration is often used. The sandwich beam under study (shown in Fig.1) consists of the upper constraining layer(CL) and lower face layer of thicknesses h_1 and h_3 respectively .These layers are purely linear elastic with Young's moduli of E_1 and E_3, while a constrained core layer of thickness h_2 is linearly viscoelastic with a complex shear modulus.

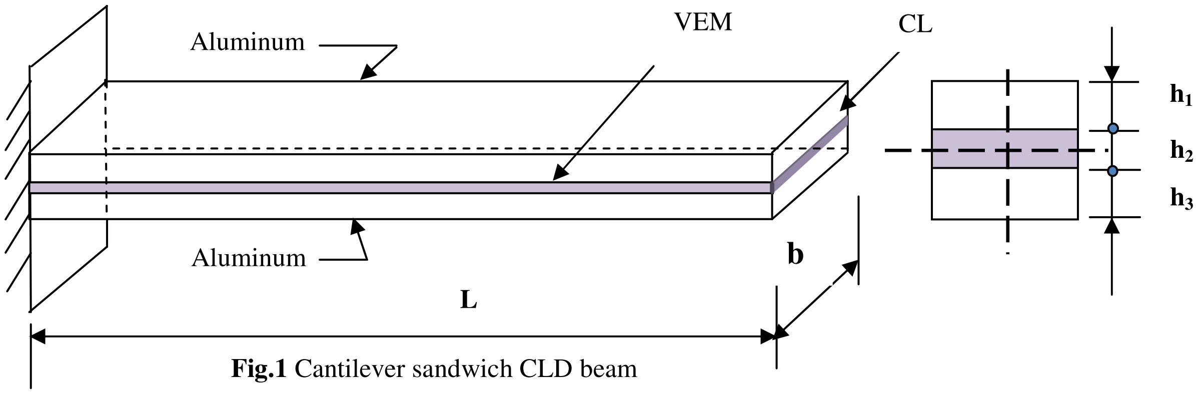


Fig.1 Cantilever sandwich CLD beam

The properties of sandwich beam under study are shown in Table 1.

Table 1 Beam properties

Material properties			Geometric properties		
E_1	Young's modulus of upper CL layer	69 GPa	L	Length of beam	400 mm
E_3	Young's modulus of lower layer	69 GPa	b	Width of beam	50 mm
ϱ_1	Density of upper CL layer	2700 kg/m^3	h_1	Thickness of upper CL layer	2 mm
ϱ_3	Density of lower layer	2700 kg/m^3	h_3	Thickness of lower layer	2 mm
ϱ_2	Density of constrained VEM layer	1330 kg/m^3	h_2	Thickness of VEM core layer	
μ_1	Poisson's ratio of Aluminum	0.33		Beam - 1	0.5 mm
μ_2	Poisson's ratio of VEM	0.42		Beam - 2	1.0 mm
				Beam - 3	2.0 mm

3. Scope and objective

There is an ever-growing need to produce efficient and lightweight structures (e.g. automobiles, pumps, ships, trucks, automobile engines, manufacturing machinery etc.). This need has created lightweight structures that move and/or vibrate at higher frequencies, producing higher temperatures and thus creating higher undesirable noise and vibration levels. This, in turn, has necessitated the search for better vibration-damping materials [11]. The objective of the optimal design of sandwich beam structures is to maximize its structural damping, which is given by the modal loss factors of the vibration modes of interest [12]. Here the damping maximization is reported to the third mode of free vibration, related with imposed initial amplitude given by an external impact force. The damping maximization of sandwich beam has been conducted as an optimization of the thicknesses of viscoelastic layer.

3.1 Thickness of damping material

As the damping material thickness increases, the composite damping of the beam or panel increases. However, it only increases significantly near the glass transition temperature of the damping material due to the large change in the damping material loss factor [13].

If the damping layer is too thin or too thick, its damping effect is low. An optimum thickness and/or material stiffness maximize the damping [14]. If the damping layer is too thick, the cost effect is always considered, so the thickness of CLD (representing the cost) is treated as a penalty as well. By considering above references, following 3 types of beams are considered for analysis:

a] Sandwich CLD beam-1 with VEM 0.5 mm thick.
b] Sandwich CLD beam-2 with VEM 1.0 mm thick.
c] Sandwich CLD beam-3 with VEM 2.0 mm thick.

4. Numerical analysis

In this paper three models of sandwich CLD beam are considered for finite element analysis using commercial software MSC.NASTRAN [15]. All the models used in numerical analysis share a common representation of the viscoelastic layer using solid CHEXA element. The lower layer and constraining layer are both modeled by solid element. First by using modal analysis of individual CLD beam, the frequency of bending modes are obtained and then the harmonic analysis corresponding to frequency of bending modes is performed .Numerical results in terms of the modal strain energy (MSE) are illustrated and the damping effects are emphasized.

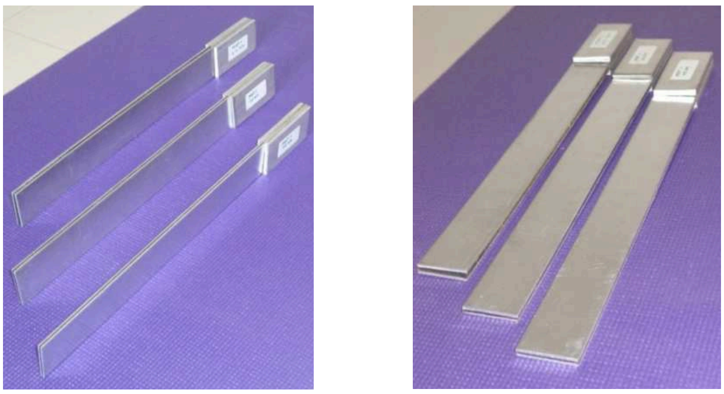
In the method of MSE, the system loss factor (system damping), η^r is directly proportional to the ratio of the energy dissipated in the viscoelastic elements to the energy stored in the entire system through one cycle of vibration [16].This ratio is then multiplied by the Loss factor of the viscoelastic material as explained in equation (1)

$$\eta^r = \eta_v \frac{U_v^r}{U_{Tot}^r} \quad (1)$$

By using above equation(1), the modal loss factor corresponding to mode 3 of three sandwich CLD beams are found and shown in Table 3.

5. Experimental investigation

The damping performance of CLD beams is often quantified in terms of system loss factor and it is determined by ASTM beam test method [17]. The symmetrical sandwich beam as shown in Fig.2 is composed as per ASTM standard E-756(05). It consists of two layers of aluminum and the viscoelastic material in the core composed of a 3M 300 LSE High-Strength Acrylic double-face Adhesive [18].



(a) (b)

Fig. 2 Sandwich CLD beams

The dynamic responses of the beams were measured by using accelerometer during a free vibration test performed by employing instantaneous hammer impact as excitation. The main features of the used equipment and the data acquisition are: accelerometer model uniaxial type 4515 (B&K) make, Impact Hammer 8206-002 (B&K) make and FFT Analyzer: 4 channel (B&K Photon +All in one).The result of beam FRF response are shown in RT Pro software [19]. The typical experiment setup is shown in Fig.3

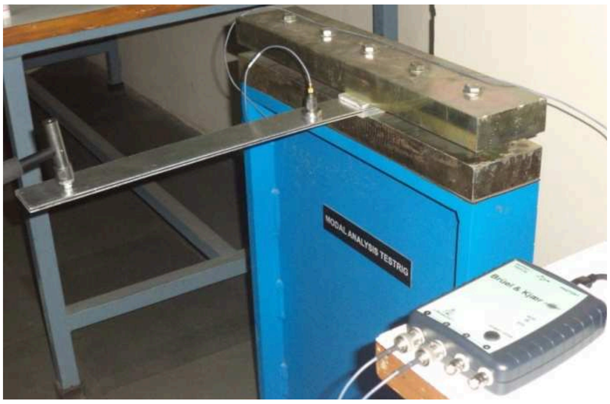


Fig.3 Experimental test setup

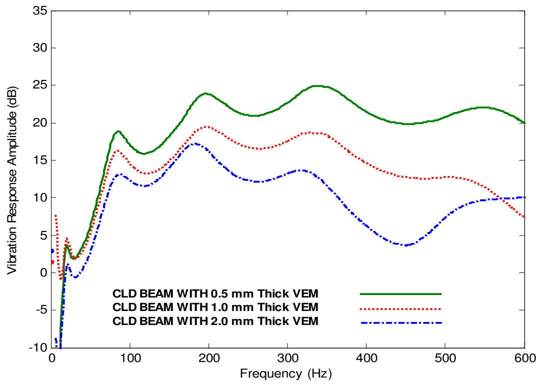


Fig.4 Comparison of frequency response curves

By analyzing the resonant peaks for a particular mode, the loss factor, a measure of damping, is obtained from the real part of the response spectrum as shown in Fig. 4. These curves are presented using Matlab software [20].

6. Results and discussion

Half-power bandwidth method is used for calculating the loss factor at one of the natural modes of vibration for the system [21]. By using half- power bandwidth method the modal loss factor corresponding to 3rd mode of all CLD beams are found. The comparison of result obtained by numerical analysis and experimental analysis are shown in Table 3.

Table No.3
Comparison of Numerical and Experimental Analysis results

Sr. No.	Beam type	Natural frequency (Hz)		Modal loss factor (η^r)	
		Numerical Analysis	Experimental Analysis	Numerical Analysis	Experimental Analysis
1	CLD beam-1	208	197	0.412	0.340
2	CLD beam-2	205	195	0.502	0.476
3	CLD beam-3	196	182	0.456	0.368

7. Conclusions

This paper has presented the effect of appropriate thickness of damping VEM of CLD beam, on modal loss factor. The numerical results are well corroborated with experimental results. From comparison of results obtained by numerical analysis using MSE method and experimental investigation, it is observed that the modal loss factor of the sandwich CLD beam-2 is found to be more as compared to CLD beam-1 and CLD beam-3. As modal loss factor is more, the vibrational energy in the beam-2 decreases more. The damping of vibrations at high frequencies by the method of constrained layers is done best when the thickness of viscoelastic layer is half the thickness of constraining layer (CL).Hence to achieve maximum damping in the vibrating structure, the thickness ratio of constrained layer (damping material) to constraining layer (CL) should be equal to one half.

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