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Estimation of Loss Factor of Viscoelastic Material by Using Cantilever Sandwich Plate

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Abstract: Viscoelastic materials show good damping property. Damping is related with the energy dissipation capacity of the material. Viscoelastic materials are widely used to reduce the vibration of the vibrating structures. The damping property of the viscoelastic material is investigated through the loss factor. These materials have no self-supporting characteristic. So for evaluating their loss factor they are required to be applied on some base metal plate. In the present study the damping properties of the cantilever sandwich plate having silicon rubber viscoelastic core sandwiched between two aluminium plates is studied. The damping properties of sandwich plate are investigated through the loss factor. The loss factor of the structure is determined by using logarithmic decrement method. From the loss factor of the cantilever sandwich specimen the loss factor of the viscoelastic core material is estimated by using ASTM E-756 norms.

I INTRODUCTION

A viscoelastic material is characterized by possessing both viscous and elastic behaviour. A purely *elastic* material is one in which all the energy stored in the sample during loading is returned when the load is removed. As a result, the stress and strain curves for elastic materials move completely in phase. For elastic materials, Hooke's Law applies, where the stress is proportional to the strain. A complete opposite to an elastic material is a purely *viscous* material. This type of material does not return any of the energy stored during loading. All the energy is lost as "pure damping" once the load is removed. In this case, the stress is proportional to the rate of the strain, and the ratio of stress to strain rate is known as viscosity (μ). These materials have no stiffness component, only damping. For all others that do not fall into one of the above extreme classifications, we call *viscoelastic* materials. Some of the energy stored in a viscoelastic system is recovered upon removal of the load, and the remainder is dissipated in the form of heat. The cyclic stress at a loading frequency ω is out-of-phase with the strain by some angle δ (where $0 < \delta < \pi/2$). The angle δ is a measure of the materials damping level; the larger the angle the greater the damping.The loss factor is also given by the relation: $\eta = tan\delta$.

Viscoelastic materials are widely used in passive control of vibration by free layer damping and constrained layer damping. So it becomes necessary to obtain their dynamic characteristics. Oberst (1952) proposed to apply a thin layer of viscoelastic material to the surface of flexible structures for passive vibration control, called unconstrained (free layer) damping and the dissipation of energy occurs due to the alternate extension and compression of the VEM layer. Kerwin (1959) introduced the constrained viscoelastic damping, in which the viscoelastic layer is covered in turn by a high tensile stiffness constraining layer. The constraining layer induces shear strain in the viscoelastic layer, and thus greater damping is produced. These so-called sandwich structures are very effective in controlling and reducing the vibration response of flexible and light structures. After this work, Ungar and Kerwin gave a formulation for the loss factor in terms of energy, which has become the basis for the evaluation of the loss factor and the parametric design of damped composite structures. Loss factor can be determined by several different methods, which are divided in two categories: frequency domain and time domain tests. Examples of the frequency domain methods are the half-power point and the magnification-factor methods, and examples of the time domain methods are logarithmic decrement and hysteresis loop methods.

In the present paper the damping property of the viscoelastic material is evaluated. For this purpose first the sandwich structure having viscoelastic silicon rubber sandwiched between two aluminium metal plates is prepared. Then the loss factor of the cantilever sandwich structure is determined by using logarithmic decrement method. By using the loss factor of the cantilever sandwich specimen the loss factor of the viscoelastic core material is estimated by using ASTM E-756 norms.

II THEORY

2.1 Logarithmic decrement method: The loss factor of the sandwich specimen is determined by using logarithmic decrement method. Logarithmic decrement is defined as the ratio of any two successive amplitudes on the same side of the mean line. As per the definition logarithmic decrement δ for two successive amplitudes x_1 and x_2 is given as

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$$\delta = ln\frac{x_1}{x_2} \qquad 2.1$$

For under damped system the equation for amplitude is given as

$$x = c_4 e^{-\varepsilon\omega t}\cos\left(\sqrt{1-\varepsilon^2}\,\omega t + \phi_2\right) \qquad 2.2$$

Here c_4 and ϕ_2 are constants which are determined from the initial conditions, ε is the damping ratio.
Let t_1 and t_2 denote the times corresponding to two successive amplitudes. We can find the ratio of amplitudes x_1 and x_2 as

$$\frac{x_1}{x_2} = e^{-\varepsilon\omega(t_1-t_2)}\frac{\cos\left(\sqrt{1-\varepsilon^2}\omega t_1 + \phi_2\right)}{\cos\left(\sqrt{1-\varepsilon^2}\omega t_2 + \phi_2\right)} \qquad 2.3$$

Let us assume $t_2 = t_1 + t_d$

Where $t_d = \frac{2\pi}{\omega_d}$ is the period of damped vibration.

The term

$$\frac{\cos(\omega_d t_1 + \phi_2)}{\cos[\omega_d(t_1+t_d)+\phi_2]} \; as \; \sqrt{1-\varepsilon^2}\,\omega = \omega_d$$

$$\frac{\cos(\omega_d t_1 + \phi_2)}{\cos[\omega_d(t_1+\frac{2\pi}{\omega_d})+\phi_2]} = \frac{\cos(\omega_d t_1 + \phi_2)}{\cos[\omega_d t_1 + 2\pi) + \phi_2]} \qquad 2.5$$

Again considering equation 2.3 and using equation 2.5 in it, we have

$$\frac{x_1}{x_2} = e^{-\varepsilon\omega(t_1-t_1-t_d)} = e^{\varepsilon\omega t_d} = e^{\frac{\varepsilon\omega 2\pi}{\omega_d}}$$

$$\frac{x_1}{x_2} = e^{\frac{\varepsilon\omega 2\pi}{\sqrt{1-\varepsilon^2}\omega}} = e^{\frac{2\pi\varepsilon}{\sqrt{1-\varepsilon^2}}}$$

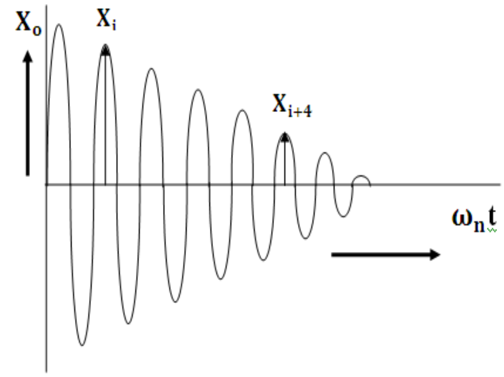
$$\delta = ln\frac{x_1}{x_2} = \frac{2\pi\varepsilon}{\sqrt{1-\varepsilon^2}} \qquad 2.6$$

When the value of the ε is very small the above equation can be written as

$$\delta = 2\pi\varepsilon \qquad 2.7$$

If the system executes n cycles, the logarithmic decrement δ can be written as

$$\delta = \frac{1}{n}ln\frac{x_1}{x_{n+1}} \qquad 2.8$$



Where x_1= amplitude at the starting position

X_{n+1}= amplitude after n cycles

2.2 ASTM E-756 norms for evaluating loss factor of damping material

From experiment the loss factor of the sandwich plate is determined by using the logarithmic decrement method. Then the loss factor of the viscoelastic core material from the cantilever sandwich plate is estimated by following the ASTM E-756 norms. The following expression is used to estimate the loss factor of the damping material:

$$\beta = \frac{A\eta_s}{[A-B-2(A-B)^2-2(A\eta_s)^2]} \qquad 2.9$$

Where
$A = (f_s/f_n)^2(2+DT)(B/2)$

$B = 1/[6(1+T)^2]$

$D_o = \rho_1/\rho$

$T = H_1/H$

Where D is the density ratio, f_n is the resonance frequency for mode n of base plate (Hz), f_s is the resonance frequency for mode s of sandwich plate (Hz), H is the thickness of base beam, H_1 is the thickness of damping material, T is the thickness ratio, β is the shear loss factor of damping material, η_s is the loss factor of sandwich plate, ρ_1 is the density of damping material, ρ is density of base material and s is index number: 1,2,3…..(s= n)

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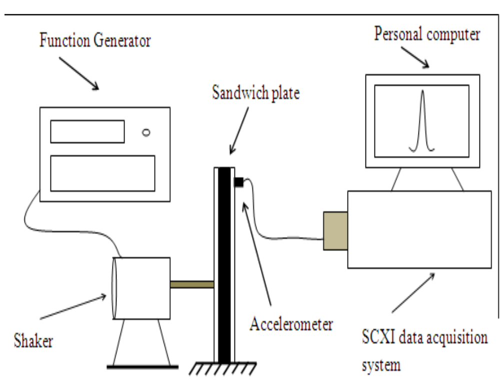
III EXPERIMENTAL PROCEDURE

In the present work sandwich plate having 3 mm thickness of viscoelastic core material is used. Aluminium plates of 1mm thickness are used as the face plate and silicon rubber is used as core material. The silicon rubber is bonded to the aluminium plates with the standard epoxy resin araldite having Young's modulus 2432 MPa and density is 1.17 g/cm^3. The plate dimensions are 90 mm in length and 90 mm in width. Then these test specimens are excited with the help of electro dynamic shaker under sweep sine and free vibration mode. Agilent Function generator 3322A was used to generate the required sine function to excite the shaker. The vibrational response of the specimens was recorded using one piezoelectric accelerometer with sensitivity 10mV/g. For data acquisition National Instruments SCXI 1000 chassis with SCXI 1530 Integrated Electronic Piezoelectric acceleration measurement module was used. The experimental set up is shown in figure 3.1. Sweep sine test is used to determine the natural frequencies of these specimens and free vibration test is used to determine the loss factor. The loss factor of the bare aluminium plate and the sandwich plates are determined by logarithmic decrement method. Then the loss factor of the viscoelastic core material is evaluated from the cantilever sandwich specimens by following the ASTM E-756 norms and using equation 2.9.

Name of material	Thickness	Density
Aluminium (base material)	1 mm	2700 kg/m^3
Silicon rubber (damping material)	3 mm, 6 mm, 9 mm	950 kg/m^3

Table 3.1: Summary of geometrical and physical properties of base material and damping material



VI RESULT AND DISCUSSION

The vibration response of the specimen obtained under sweep sine and free vibration test are shown in figure 4.1 From free vibration test at 3rd mode the damping ratio and loss factor of sandwich plate is obtained by logarithmic decrement method and then the loss factor of the damping material is obtained by ASTM E-756 norms as shown in table 4.1

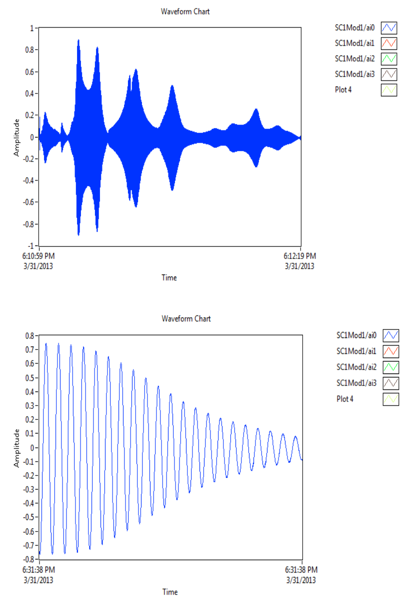


Figure 4.1 Vibration response of sandwich plate (a) response of forced vibration (b) response of free vibration

Table 4.1 Loss factor of the sandwich plate and damping material

Name of specimen	Thickness of rubber	Damping ratio of sandwich plate	Loss factor of sandwich plate	Loss factor of damping materialevaluated from sandwich plate
Cantilever sandwich plate	3 mm	0.01926	0.03853	0.1790

V CONCLUSION

Evaluation of the loss factor of the viscoelastic (damping) material by cantilever sandwich plate is a suitable method. For sandwich composite beams/plates, this approximation is acceptable only at higher modes and it has been the practice to ignore the first mode results. The sandwich beam technique usually is used for soft viscoelastic materials with shear moduli less than 100 MPa.

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