ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

CRITICAL COMPARISON OF VISCOELASTC DAMPING, ELECTRORHEOLOGICAL FLUID AND MAGNETORHEOLOGICAL FLUID CORE DAMPING IN CANTILEVER SKEW PLATES

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Abstract
The present article deals with the damping and frequency behavior of cantilever skew sandwich plates with different core materials. Viscoelastic layer (VEL), Electrorheological (ER) fluid and Magnetorheological Fluid core (MR) are studied as core materials using finite element method. Critical comparison of these core materials is made in terms of frequency and loss factor. The present study includes the effect of skew angle and core thickness on frequency and damping of the structure. In addition, the influence of electric field and magnetic field on frequency and loss factor were also examined.

INTRODUCTION

Sandwich structures have extensive applications due to their high strength and structural efficiency. Skew plates of these types are used as important structural components of aircrafts and ships. Often these structures are subjected to vibration due to mechanical loads and hence, substantial knowledge of their natural frequency is critical to avoid resonance. Damping plays an important role in limiting the structural response at resonance. Electrorheological (ER) fluid and Magnetorhelogical (MR) are smart fluids, which stiffen by themselves into a semi-solid when subjected to an electric and magnetic field respectively. When the sandwich structure is subjected to an electric field or magnetic field, the system's damping increases. At present, smart or intelligent materials have gained much importance in various control applications.

Kathua and Cheung [1] have studied the free vibration of multilayer sandwich plates and beams, using finite element method. Recently, Pradeep and Ganesan [2] have carried out studies on the behavior of viscoelastic sandwich plate in thermal environment. Yeh and Chen [3] have carried out studies on dynamic stability of isotropic rectangular sandwich plate with ER fluid core. They have investigated the electric field dependent frequency and loss factor. Rakesh Kumar *et al.* [4] have studied the free vibration of composite sandwich plates. They have determined the frequency for different types of lamina. Woo *et al*. [5] have studied the free vibration of skew plates with and without cut-outs. They have calculated the frequencies for different boundary conditions and also have made observations on the influence of skew angle on the frequency. Yalcintas [6] has compared the performance of magnetorheological fluid and electrorheological fluid in adaptive beam structures.

FINITE ELEMENT FORMULATION

Figure-1 shows a skew sandwich plate, of length a, skew (oblique) width b and skew angle β . The thickness of core is denoted by t_c and the thickness of each stiff layer by t_s . In the present study, the thickness of each stiff layer assumed to be same. The formulations presented by Khatua and Cheung [1] has been extended to characterize the vibration and damping behavior of the skew sandwich plate with VEL (or ER or MR fluid) core by converting the strain displacements of orthogonal coordinates into skew coordinates by the use of conventional chain rule.

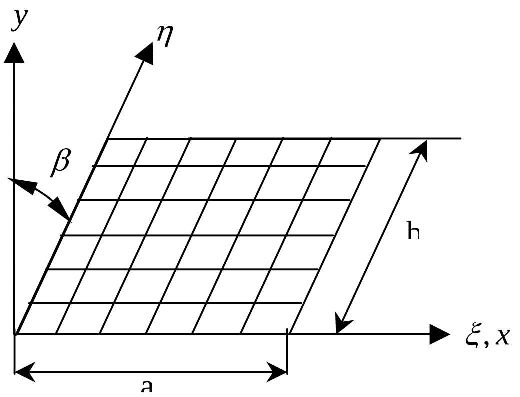

Figure-1 Finite element discretization of a skew plate.

The transformation between the orthogonal [1] and the oblique coordinates as follows.

$$\{\varepsilon_{bi}\} = \begin{Bmatrix} -\dfrac{\partial^2 w}{\partial x^2} \\ -\dfrac{\partial^2 w}{\partial y^2} \\ 2\dfrac{\partial^2 w}{\partial x \partial y} \end{Bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ -\cot^2\theta & -\cos ec^2\theta & 2\cot\theta\cos ec\theta \\ -2\cot\theta & 0 & 2\cos ec\theta \end{bmatrix} \begin{Bmatrix} \dfrac{\partial^2 w}{\partial \xi^2} \\ \dfrac{\partial^2 w}{\partial \eta^2} \\ \dfrac{\partial^2 w}{\partial \xi \partial \eta} \end{Bmatrix} \tag{1}$$

$$\{\varepsilon_{bi}\} = [G_{bi}] \{\varepsilon_{bsi}\} \tag{2}$$

Where, $i = 1, 2$

$\{\varepsilon_{bi}\}$ and $\{\varepsilon_{bsi}\}$ are the arrays of bending strain for i^{th} stiff layer in orthogonal and skew coordinates respectively. $[G_{bi}]$ is the bending transformation matrix between orthogonal and skew coordinates for i^{th} stiff layer

$$\{\varepsilon_c\} = \begin{Bmatrix} \gamma_{xz} \\ \gamma_{yz} \end{Bmatrix} = \frac{c}{h}\begin{bmatrix} 1 & 0 \\ -\cot\theta & \cos ec\theta \end{bmatrix} \begin{Bmatrix} \dfrac{\partial w}{\partial \xi} \\ \dfrac{\partial w}{\partial \eta} \end{Bmatrix} + \frac{c}{h}\begin{bmatrix} (u_2 - u_1)/c \\ (v_2 - v_1)/c \end{bmatrix} \tag{3}$$

$$\{\varepsilon_c\} = [G_c] \{\varepsilon_{cs}\} \tag{4}$$

$\{\varepsilon_c\}$ and $\{\varepsilon_{cs}\}$ are the array of strain for core in orthogonal and skew coordinates respectively. $[G_c]$ is the transformation matrix between orthogonal and skew coordinates for core.

$$\{\varepsilon_{Pi}\} = \begin{Bmatrix} \dfrac{\partial u_i}{\partial x} \\ \dfrac{\partial v_i}{\partial y} \\ \dfrac{\partial u_i}{\partial y} + \dfrac{\partial v_i}{\partial x} \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -\cot\theta & \cos ec\theta \\ -\cot\theta & \cos ec\theta & 1 & 0 \end{bmatrix} \begin{Bmatrix} \dfrac{\partial u_i}{\partial \xi} \\ \dfrac{\partial u_i}{\partial \eta} \\ \dfrac{\partial v_i}{\partial \xi} \\ \dfrac{\partial v_i}{\partial \eta} \end{Bmatrix} \tag{5}$$

$$\{\varepsilon_{Pi}\} = [G_{pi}] \{\varepsilon_{psi}\} \tag{6}$$

$\{\varepsilon_{pi}\}$ and $\{\varepsilon_{psi}\}$ are the arrays of inplane strain for i^{th} stiff layer in orthogonal and skew coordinates respectively. $[G_{pi}]$ is the inplane transformation matrix between orthogonal and skew coordinates for i^{th} stiff layer. Final form of the resultant array of strain, for a skew sandwich plate in skew coordinates is

$$\{\varepsilon_s\} = [\varepsilon_{bs1} \quad \varepsilon_{ps1} \quad \varepsilon_{cs} \quad \varepsilon_{bs2} \quad \varepsilon_{ps2}]^T \tag{7}$$

Where, $\{\varepsilon_s\}$ is the strain matrix for skew sandwich plate.
The strains can be related to the nodal degrees of freedom by the following relation

$$\{\varepsilon_s\} = [B_s]\{\delta\}^e \tag{8}$$

Where B_s is the strain displacement matrix for a skew sandwich plate.
The stiffness and mass matrices can be computed in skew coordinates as

$$[K]^e = \int_{-b}^{b}\int_{-a}^{a}[B_s]^T\left[D^*\right][B_s]\sin\theta d\xi d\eta \tag{9}$$

Where, $\left[D^*\right] = [G]^T[D][G]$

$$[G] = \begin{bmatrix} [G_{b1}] & & & & \\ & [G_{p1}] & & & \\ & & [G_c] & & \\ & & & [G_{b2}] & \\ & & & & [G_{p2}] \end{bmatrix} \tag{10}$$

[G] denotes the transformation matrix.

$$[M]^e = \int_{-b}^{b}\int_{-a}^{a}[N]^T[P][N]\sin\theta d\xi d\eta \tag{11}$$

VALIDATION

Due to the lack of availability of comparative solutions in the literature on skew sandwich plate with ER or MR fluid core, the present method $(\beta = 0^0)$ is validated using the literature available on rectangular sandwich plate with ER fluid core. From Figure-2, it is observed that the present method shows very good correlation with Yeh [3].

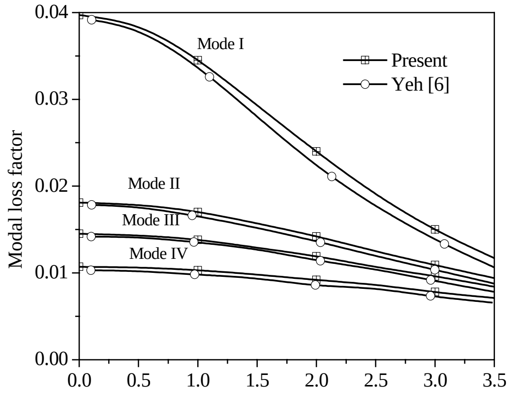

Figure-2 Variation of modal loss factor with different electric fields

RESULTS AND DISCUSSIONS

The complex shear modulus of VEL core made up of EC2216 material, ER fluid and MR fluid are given in Table 1. Class- I and class-II denote the two types of ER material given by Yeh [3] and for MR fluid the data is considered from literature [6].

Table 1 the complex shear modulus of VEL, ER and MR core

Shear modulus	VEL core (N/m^2)	ER fluid		MR fluid (N/m^2)
		Class- I	Class- II	
Real	≈ 5.75e8	$\approx 15000 E_*^2$	$\approx 50000 E_*^2$	1.25e3B
Imaginary	≈ 1.75e8	≈ 6900	$\approx 2600 E_*^2 + 1700$	1.375e1B

Where, E_* is the electric field in kV/mm and B is the magnetic induction in oersted.Tables 2 and 3 show the frequency of skew sandwich plate with VEL (ER or MR fluid) for $\beta = 30^0$, $\beta = 45^0$ respectively. It is evident from Tables that, skew sandwich plate with VEL core is stiffer and shows higher frequency than the sandwich plate with ER (or MR fluid) core. It is due to fact that the complex shear modulus of VEL core is much higher compared to ER and MR fluid core (see Table 1). It is further noticed from Tables 2 and 3 that as skew angle increases, frequency increases.

Table 2 Comparison of natural frequency of the skew sandwich plates ($\beta = 30^0$ *) with cores made of VEL, ER and MR fluid for* t_c/t_s*=1.0*

Mode No	VEL	ER Fluid		MR Fluid
		ER-I	ER-II	
1	25.29	6.82	7.01	13.43
2	59.80	16.24	16.49	25.50
3	165.16	44.00	44.23	56.27
4	168.07	44.44	44.71	59.02

Table 3 Comparison of natural frequency of the skew sandwich plates ($\beta = 45^0$ *) with cores made of VEL, ER and MR fluid for* t_c/t_s*=1.0*

Mode No	VEL	ER Fluid		MR Fluid
		ER-I	ER-II	
1	29.55	7.92	8.10	14.88
2	71.77	19.30	19.58	29.97
3	178.84	46.70	46.91	59.78
4	209.11	56.48	56.83	70.50

Table 4 shows the loss factors of skew sandwich plate with VEL (or ER or MR fluid) core for $\beta = 45^0$. From Table it is evident that sandwich plate with VEL core shows poor damping characteristics when compared to the ER and MR fluid core. Further it is noticed that plate with ER core is having higher damping than its MR core counterpart. It is due to fact that the influence of shear parameter on loss factor is high in the case of ER fluid, and it varies in the following ascending order: VEL, MR and ER core.

Table 4 Comparison of loss factor of the skew sandwich plates ($\beta = 45^0$ *) with cores made of VEL, ER and MR fluid for* t_c/t_s*=1.0*

Mode No	VEL	ER Fluid		MR Fluid
		ER-I	ER-II	
1	0.00749	0.03748	0.01528	0.00492
2	0.01492	0.02274	0.00931	0.00496
3	0.02149	0.00700	0.00300	0.00477
4	0.02665	0.00989	0.00413	0.00392

Figure-3 shows the variation of frequency and loss factor for a skew sandwich plate with MR fluid core. It is seen that as magnetic field increases, frequency increases. It is further observed from Figure-3 that, the 1st mode of loss factor decreases with magnetic field, but at higher harmonics loss factor increases with magnetic field.

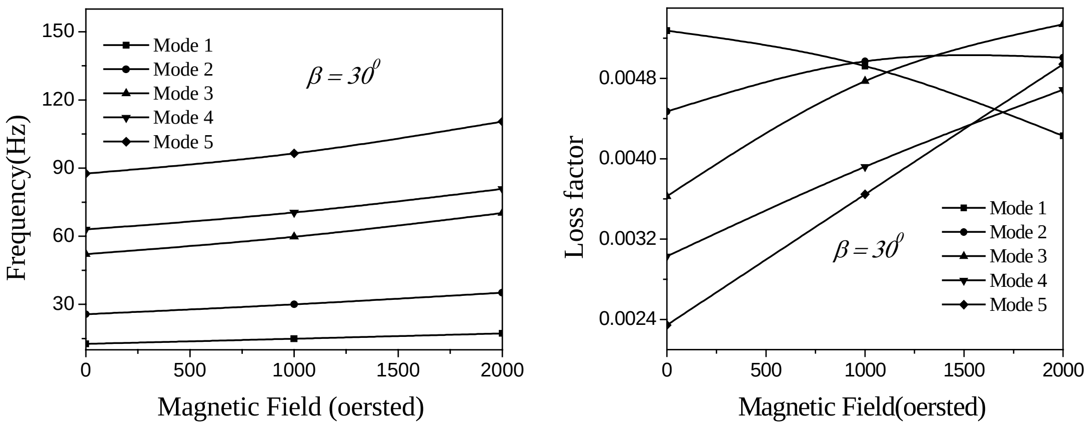

Figure-3 Variation of frequency and loss factor with magnetic field for skew sandwich plates with MR fluid.

Figure-4 shows the variation of frequency and loss factor for a skew sandwich plate with ER fluid core. It is observed that frequency increases with the electric field, since the real part of shear modulus increases with the electric field (see Table 1). It is further noticed that the loss factor decreases with the electric field.

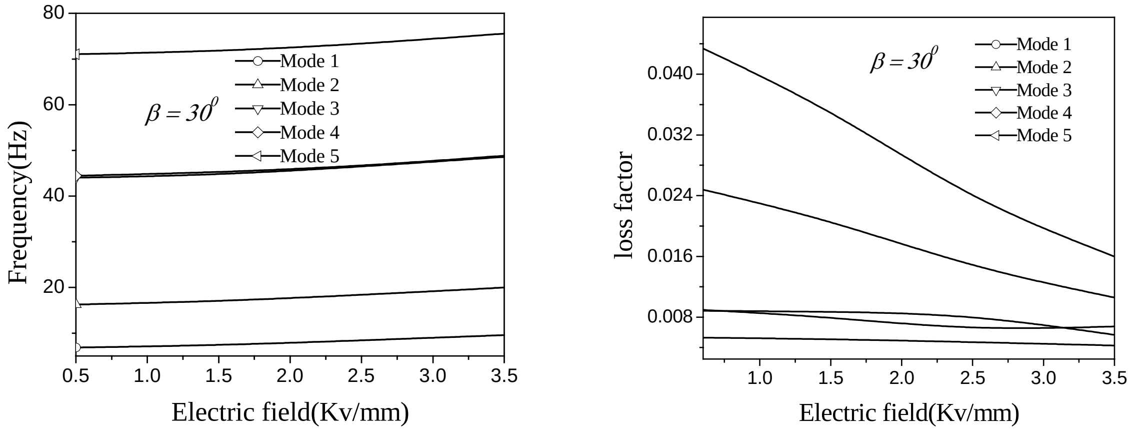

Figure-4 Variation of frequency and loss factor with electric field for skew sandwich plates with ER fluid.

CONCLUSIONS

The damping and frequency behavior of a skew sandwich plate with VEL (ER or MR fluid) core are determined, using finite element method.

1. The skew sandwich plate with VEL core is stiffer and shows a higher frequency when compared to the plate with ER (or MR fluid) core. In contrast, sandwich plate with VEL core shows a poor damping characteristics than its ER fluid counterpart.
2. It has been observed that, the system is sensitive to skew angle, as skew angle increases frequency increases.
3. The frequency of skew sandwich plate increases with electric and magnetic fields.

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