Sandwich patch with thermoviscous fluid core, for increasing damping of panels

Jean-Louis Guyader, Ha Dong Hwang, Kerem Ege

To cite this version:

Jean-Louis Guyader, Ha Dong Hwang, Kerem Ege. Sandwich patch with thermoviscous fluid core, for increasing damping of panels. 20th International Congress on Sound and Vibration, ICSV20, Jul 2013, Bangkok, Thailand. pp.#17. hal-00823973

HAL Id: hal-00823973
https://hal.science/hal-00823973

Submitted on 30 Jan 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

20th International Congress on Sound & Vibration

ICSV20
Bangkok,Thailand
7-11 July 2013

SANDWICH PATCH WITH THERMOVISCOUS FLUID CORE, FOR INCREASING DAMPING OF PANELS

Jean-Louis Guyader, Ha Dong Hwang and Kerem Ege
LVA, INSA-Lyon , 25 bis Avenue Jean Capelle, F-69621 Villeurbanne Cedex, France
e-mail: jean-louis.guyader@insa-lyon.fr

The introduction of a thermo-Viscous Fluid (TVF) between two skins, produces a sandwich with high dissipation. This was studied by Hussain and Guyader[1] leading to equivalent material properties depending on skins and fluid core properties. An important result is that contrary to standard sandwich panels with polymers cores, the damping loss factor of such TVF sandwich is constant with frequency. When applying damping treatment on structures, bonded patches are generally used. In this paper the use of TVF sandwich patches on a panel is described through a model of heterogeneous plate, the predicted vibration response of the structure shows an increase of damping due to the patch. Estimation of modal damping loss factors for the plate with TVF sandwich patches are given depending on the patch size and TVF thickness.

1. Introduction

A method has been developed by Hussain and Guyader[1] to predict the damping behavior of an equivalent plate formed out of sandwich panels with thermoviscous fluid core, which is based on an asymptotic approach. The technique works on the breakup of the basic physical quantities of the fluid core such pressure, temperature and particle velocities as constants and linear functions of the z coordinate which signifies the perpendicular direction from the plate mid surface. The asymptotic modeling is performed in a very thin and highly thermoviscous fluid layer on the full set of linearized Navier Stokes equations. The use of highly viscous fluid layers yields high damping coefficients in all the frequency range and not strongly variable with temperature. Experimental validation provides a good agreement.

2. Equivalent thin plate equation

In order to consider the plate and the thermo-viscous fluid layer as a single structure, Hussain and Guyader[1] developed an asymptotic analysis of a double plate system with internal thermo-viscous fluid. In the limit of thin fluid film, the transverse vibrations of both plates are identical and the fluid film motion can be expressed from that of the plate in order that a global plate equation can be derived:

$$L_P\{W(x,y)\}+L_F\{W(x,y)\}=0 \quad (1)$$

Where the plate displacement is $W(x,y)$ (identical for both skins of the sandwich), $L_P\{W(x,y)\}$ (resp. $L_F\{W(x,y)\}$) is the operator associated to the plates (to the thermo-viscous fluid film).

Considering harmonic motions of angular frequency ω, these operators are expressed as:

$$L_P\{W(x,y)\}=-\omega^2(\rho_1 h_1+\rho_2 h_2+\rho_0\delta)+(D_1+D_2)\Delta^2 \quad (2)$$

$$L_F\{W(x,y)\}=j\omega\left(\frac{h_1+h_2}{2}\chi+\delta\mu\right)\Delta \quad (3)$$

Where Δ is the Laplacian, the skin plates thicknesses are h_1 and h_2, and the fluid film thickness is δ. The mass per unit volume of the plates and the fluid are ρ_1, ρ_2 and ρ_0 , the bending rigidity of skin plates are D_1 and D_2. The thermo-viscous fluid has a coefficient of shear viscosity (resp. Bulk viscosity) μ (resp. μ_B) and $\chi=\mu_B+\frac{1}{3}\mu$.

The equation (1) corresponds to that of an equivalent thin damped plate which is expressed as:

$$\left(-\omega^2 M_{eq}+D_{eq}\Delta^2+j\omega\lambda_{eq}\Delta\right)\{W(x,y)\}=0 \quad (4)$$

Where $M_{eq}=(\rho_1 h_1+\rho_2 h_2+\rho_0\delta)$, $D_{eq}=(D_1+D_2)$ and $\lambda_{eq}=\frac{(h_1+h_2)}{2}\chi+\delta\mu$

The equivalent mass is the sum of that of plates $(\rho_1 h_1+\rho_2 h_2)$ and of the added fluid mass $\rho_0\delta$. The equivalent rigidity is the sum of the plates bending stiffnesses (D_1+D_2). The damping term is associated to a Laplacian operator that does not appear in the standard plate equation. So, the equation for the equivalent sandwich plates with thermo-viscous fluid core is different from the standard Love Kirchhoff bending plate equation. The equivalent plate damping effect is related to the skin plate thicknesses and viscosity of the visco-thermic fluid.

3. Equivalent structural damping

In order to find out the structural damping factor of the equivalent plate let us consider a one dimensional plate solution of progressive wave form in the x direction whose displacement function given as:

$$W(x,y)=Ae^{jkx} \quad (5)$$

Substituting this expression in the homogeneous equivalent plate equation yields:

$$-\omega^2 M_{eq}+D_{eq}k^4+j\omega\lambda_{eq}k^2=0 \quad (6)$$

Eq. (6) can be resolved for k giving the two values.

$$k_{a,b}^2 = \frac{-j\omega\lambda_{eq} \pm \sqrt{\Delta}}{2D_{eq}} \quad \text{and} \quad \Delta = -(\omega\lambda_{eq})^2 + 4\omega^2 M_{eq} D_{eq} \tag{7}$$

With these values, Eq. (6) can be rewritten as:

$$-\omega^2 M_{eq} + D_{eq}\left(\frac{\Delta - \omega^2\lambda_{eq}^2}{\Delta + \omega^2\lambda_{eq}^2} + j\frac{2\omega\lambda_{eq}\sqrt{\Delta}}{\Delta + \omega^2\lambda_{eq}^2}\right)k^4 = 0 \tag{8}$$

Eq. (8) supposes that Δ is real, this is true in the majority of cases however for very light materials with low rigidity, Δ becomes imaginary and the following calculations must be changed accordingly. Let η be the loss factor due to the viscous layer, then this factor is identified as the ratio of the imaginary and the real stiffness:

$$\eta = \frac{2\omega\lambda_{eq}\sqrt{\Delta}}{\Delta - \omega^2\lambda_{eq}^2} = \frac{2\lambda_{eq}\sqrt{\Gamma}}{\Gamma - \lambda_{eq}^2} \tag{9}$$

Where $\Gamma = -\lambda_{eq}^2 + 4M_{eq}D_{eq}$

In the case where $\lambda_{eq} << 2\sqrt{M_{eq}D_{eq}}$ a simpler expression of the damping loss factor can be derived:

$$\eta \approx \frac{\lambda_{eq}}{\sqrt{M_{eq}D_{eq}}} \tag{10}$$

One important tendency appears here; the damping loss factor is not frequency dependant contrary to sandwich plates with visco-elastic cores, in addition the coefficients of viscosity of thermo-viscous fluids are generally not temperature dependant in a wide range of temperature and the loss factor remains identical in a larger range of temperatures.

In the following numerical results are presented in order to show the efficiency of sandwich plates with thermo-viscous fluid core to get highly damped panels. Results are compared to standard sandwich panels with viscoelastic cores and the case of partial and total coverage of panels is discussed.

4. Modal Loss Factors of Sandwich Plates

Modal damping levels of a simply supported rectangular aluminum plate treated with a constrained layer damping (CLD) patch of a thermoviscous fluid core are computed, and the results are compared to the same plate structure of a viscoelastic polymer core. Dimensions of the base plate and the patch are 0.5*0.6*0.0005 (m^3) and 0.16*0.25 (m^2) respectively, and the location of the patch is arbitrarily selected. Aluminum and High-Density PolyEthylene (HDPE) are considered for the constraining layer materials, and their thicknesses are varied. The base plate thickness is kept constant (0.5 mm) for all cases. The modal damping loss factor of the composite layer is deduced from the equivalent single layer modeling developed by Guyader et al[2]. This methodology is implemented in MOVISAND software which computes the equivalent moduli of a single layer plate model for an infinite plate, and then obtained parameters are used to compute the modal damping loss factor of finite plate models. Nastran software is used to render the modal analysis of the finite plate models. Note that the complex moduli of viscoelastic polymer, which considers the Williams-Landel-Ferry model i.e. the temperature dependence of viscosity, are taken into the calculations.

Table 1. Mechanical properties of Aluminum and Polymer

	Aluminum	Polymer
E (Pa)	7.2E+10	E (f)
ρ (kg/m^3)	2790	1500
ν	0.33	0.45
η	0.002	η (f)

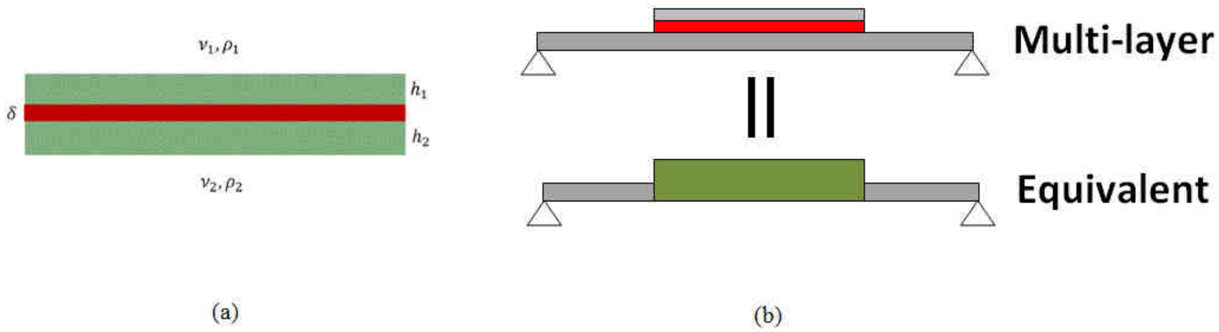

Figure 1. Schematic of CLD (Constrained Layer Damping). (a) Infinite sandwich panel with a core material (thermoviscous or viscoelastic). (b) Equivalent single layer modelling of a simply supported rectangular plate damped with a CLD patch.

4.1 High density rigid constraining layer

The CLD patch with an aluminum constraining layer of 0.5 mm applied on a base plate is considered for two plate models with a thermoviscous core and a polymer core. Both cores have the same thickness (δ) of 0.2 mm. For the thermoviscous core, Rhordsil™ 47 500,000 is considered, and its viscosity is 486 kg/s·m. Equivalent moduli (Young's modulus, density, Poisson's ratio and damping loss factor) of the sandwich plate models with both core materials are calculated.

Table 2. MOVISAND calculation: equivalent parameters for infinite plate models. Thicknesses of Aluminum (h_1 and h_2), Rhodorsil™ 47 (δ) and Polymer layers (δ) are 0.5 mm, 0.2 mm and 0.2 mm respectively.

	Sandwich plate	
Equivalent parameters	Aluminum Rhodorsil™ 47 500,000 Aluminum	Aluminum Polymer Aluminum
E (Pa)	1.04E+10	E(f)
ρ (kg/m^3)	2487.2	2575

ν	0.32	0.35
η	0.0795	η(f)

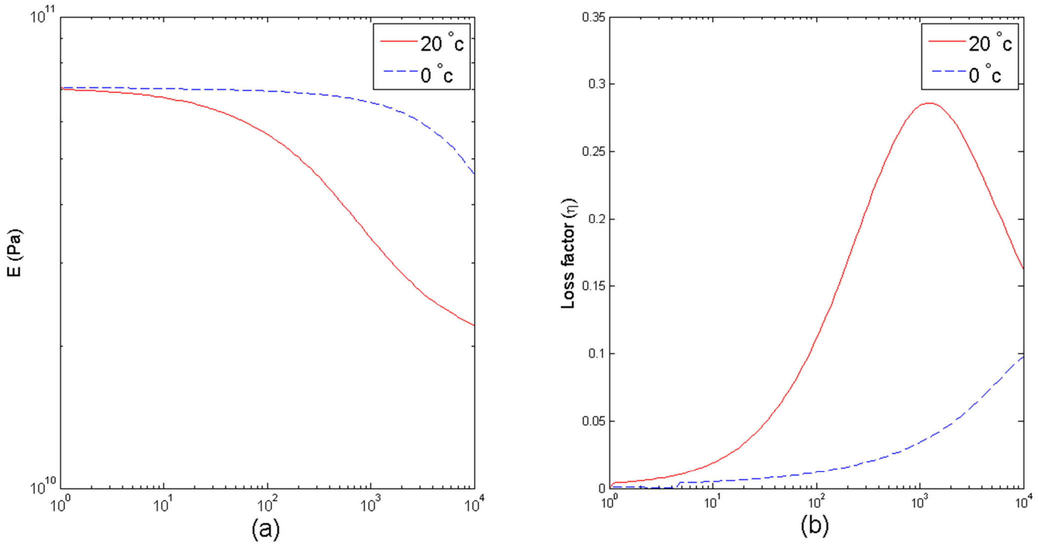

Figure 2. Equivalent moduli of the Aluminum-Polymer-Aluminum sandwich infinite plate model at different temperatures. (a) Young's modulus, (b) Loss factor.

The composite layer of a polymer core displays the frequency/temperature dependent characteristics. These parameters are taken for calculating finite plate models, and the results are shown in Fig. 3. At 20 ^{o}C, the CLD patch with a polymer core has higher damping levels throughout the frequency range. The polymer core gives almost twice higher damping than the thermoviscous core for the same thickness applied.

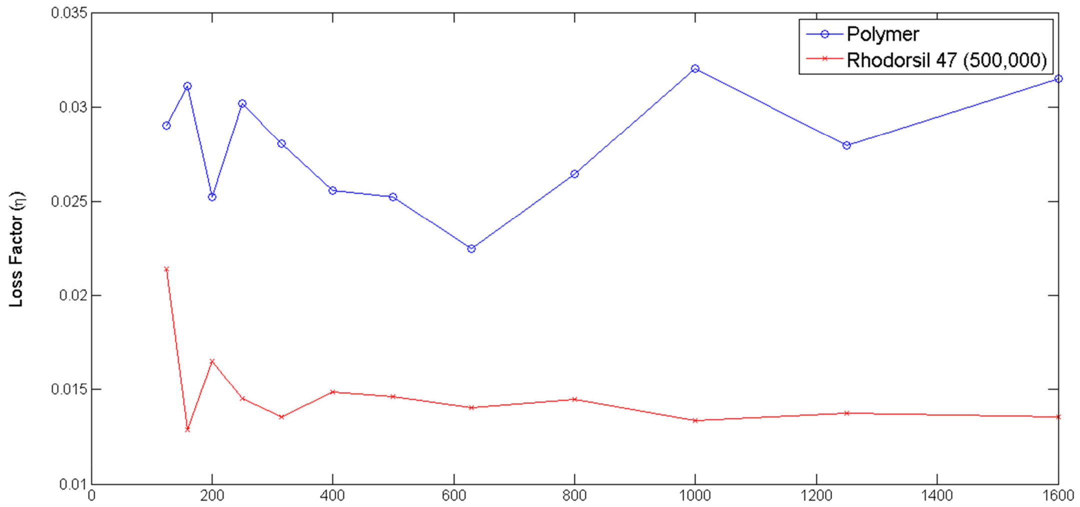

Figure 3. The 1/3 octave band averaged modal loss factor of finite plate models damped with a CLD patch at 20 ^{o}c: Aluminum-Rhodorshil™-Aluminum and Aluminuim-Polymer-Aluminuim.

4.2 Low density elastic constraining layer

The constraining layer of aluminum is replaced with a HDPE (High-Density PolyEthylene) layer of 0.5 mm. Thicknesses of the base plate (h_2) and the core (δ) for both plate models are kept 0.5 mm and 0.2 mm respectively. The mechanical properties of HDPE taken from Ege et al.[3] are E = 850 MPa, ρ = 945 kg/m^3 and η = 15%. The damping loss factor of the infinite thermoviscous composite plate is clearly seen higher than the polymer for computed range of frequency, and this is consistent for finite plate models.

Table 3. MOVISAND calculation: equivalent parameters for infinite plate models. Thicknesses of HDPE (h_1), Rhodorsil™ 47 (δ) and Polymer layers (δ) are 0.5 mm, 0.2 mm and 0.2 mm respectively.

	Sandwich plate	
Equivalent parameters	HDPE Rhodorsil™ 47 500,000 Aluminum	HDPE Polymer Aluminum
E (Pa)	5.34E+10	E(f)
ρ (kg/m^3)	1718.4	1806.25
ν	0.31	0.337
η	0.1345	η(f)

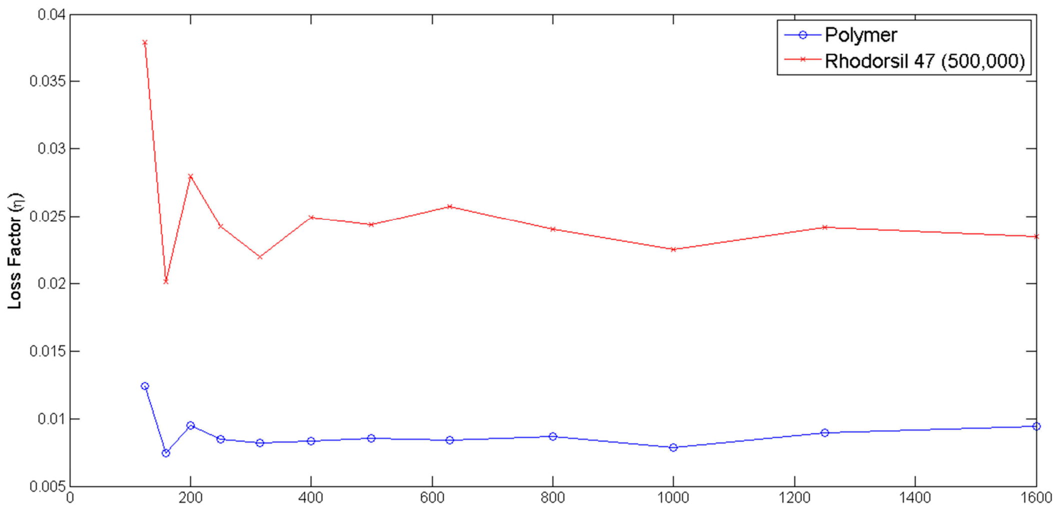

Figure 4. The 1/3 octave band averaged modal loss factor of finite plate models damped with a CLD patch at 20 ^{o}c: HDPE-Rhodorshil™-Aluminum and HDPE-Polymer-Aluminuim.

Since a density of polymer is higher than that of the thermoviscous fluid, a thickness (δ) of the thermoviscous core is increased to 0.31 mm in order to apply the same total mass of core materials to the composite plate models. Rhodorsil™ 47 1,000,000 oil is used for the computation, and its viscosity is 972 kg/s·m. A thickness (δ) of the polymer core is kept constant as 0.2 mm. As seen in figure 5, modal damping levels of the thermoviscous CLD patch are significantly higher for both infinite and finite plate models.

Table 4. MOVISAND calculation: equivalent parameters for infinite plate models. Thicknesses of HDPE (h_1) and Rhodorsil™ (δ) are 0.5 mm and 0.31 mm respectively.

	Sandwich plate
Equivalent parameters	HDPE Rhodorsil™ 47 1,000,000 Aluminum
E (Pa)	4.10E+09
ρ (kg/m^3)	1621.47
ν	0.31
η	0.3445

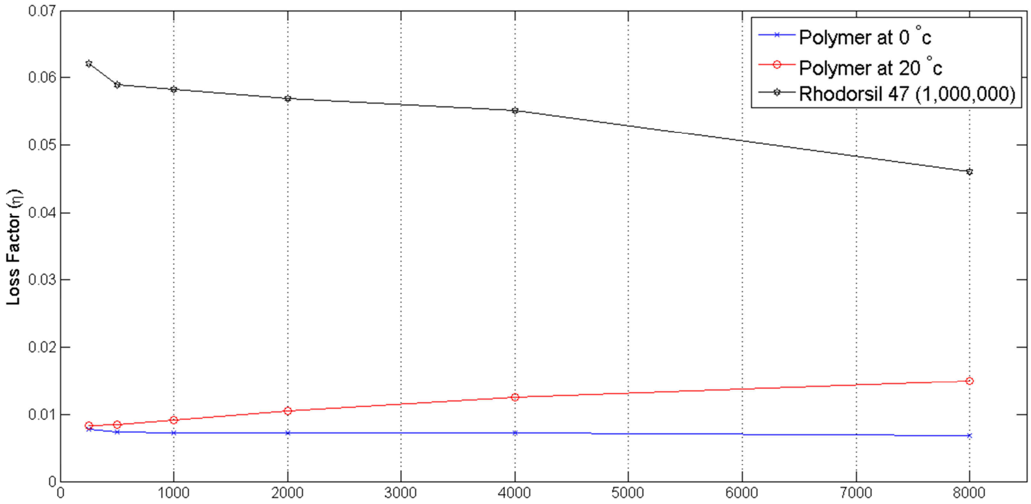

Figure 5. The octave band averaged modal loss factor of finite plate models damped with a CLD patch at different temperatures: HDPE-Rhodorshil™-Aluminum and HDPE-Polymer-Aluminuim. Rhodorshil™ 47 oil is temperature-independent.

5. Conclusion

Rectangular plates partially treated with a CLD patch have been investigated for two different core materials: thermoviscous and viscoelastic. Rhodorsil™ 47 oil and a polymer layer are considered for their damping loss factors. It is shown that the damping provided by the thermoviscous fluid is proportional to its viscositiy (Rhodorsil™ 47, 500,000 and 1,000,000). The thermoviscous fluid can yield higher damping than the polymer layer for the same core thickness applied if the constraining layer is a light-weight elastic material. With such a material, the thermoviscous fluid guarantees significantly higher damping loss factors than the polymer layer at different temperatures if the same total mass is applied. The main advantage of the thermoviscous fluid core compared to the viscoelstic one is that the high damping property of the sandwich is not frequency and temperature dependent.

6. Acknowledgements

This work was co-funded by the French government (FUI 12 - Fonds Unique Interministériel) and European Union (FEDER - Fonds européen de développement régional). It was carried out in the framework of the LabEx CeLyA ("Centre Lyonnais d'Acoustique", ANR-10-LABX-60) and the research project CLIC (“City Lightweight Innovative Cab”) labelled by LUTB cluster (Lyon Urban Truck and Bus), in partnership with Renault Trucks, Arcelor-Mittal, ACOEM, CITI Technologies, FEMTO-ST (Univ. de Franche-Comté) and LVA (INSA de Lyon).

REFERENCES

[1] H. I. Hussain and J.-L. Guyader, ‘An equivalent plate model for sandwich panels with thermo viscous fluid core’, *J. Vibration Acoustics, ASME trans.* ,031007, 7 pages, (2012).

[2] J.-L. Guyader, Ch. Cacciolati, E. Guyader, *‘MOVISAND’ software technical presentation and users guide,* (2010)

[3] K. Ege, T. Boncompagne, B. Laulagnet, J.-L. Guyader, Experimental estimations of viscoelastic properties of multilayer damped plates in broad-band frequency range, *Proceedings of InterNoise 2012*, New York, USA (2012)