Analysis of Constrained Layer Treatment For Damping in Skin Panels of Aircraft

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Abstract— Constrained layer damping is a mechanical engineering technique for suppression of vibration. Typically a viscoelastic or other damping material is sandwiched between two sheets of stiff materials that lack sufficient damping by themselves. A theoretical analysis of the constrained layer damping treatment for thin metallic panels is conducted. Analysis developed by Ross, Ungar and Kerwin is used to predict the response of damped three layer system, assuming that the properties of the damping material are known. Numerical simulation of the constrained damping treatment is done using ANSYS software. The results obtained from the numerical simulation are compared to that from theory to understand the range of applicability of the analytical solution.

Keywords—*VEM ; Constrained Layer Damping*

I. INTRODUCTION

Vibration is normally a destructive by product of the force that is transmitted through a structure, which, if not adequately controlled, provokes human discomfort and structure fatigue. If not properly addressed, high vibration levels can propagate throughout a composite structure, leading to significant noise levels and reductions in equipment longevity. Most problems concerning noise and vibration are generated by components that exhibit low levels of material damping treatments, which are now being used as design parameter rather than being applied only when faulty conditions occur. One of the most effective ways of controlling vibrations in structures is by means of constrained damping treatments.

Early studies were carried out by Boubaker Khalfi, Annie Ross [1], who dealt with analytical modeling based on Lagrange's equations of a plate with CLD, to obtain transient response due to an impact.The analytical modelling of a plate with partial constrained layer damping (PCLD) was exercised. The stiffness of the viscoelastic core was assumed to be complex and frequency dependent. Two validations were made; the first was done in harmonic motion by comparing the natural frequencies of the plate with PCLD with results available in the literature. The second validation was made in transient response by comparing displacements to the ones obtained by an experimental set-up. Excellent agreement was noted between results. Once the model was validated, graphs of the transient response were presented and discussed. Sher B.R., Moreira R.A.S. [2] explored effects of various parameters namely thickness/length ratio, constraining layer thickness, material modulus, natural mode and boundary conditions on efficiency. Their work presented a dimensionless analysis and provided useful general guidelines for the efficient design of constrained and integrated damping treatments based on single or multi-layer configurations.The effects of the thickness parameters on the stored strain energy of the VEM layer in a constrained configuration were explored, especially on the sets that produced a non-monotonic efficiency curve. The main aim of their work was, besides the verification and justification of this interesting feature to explore the effects of design parameters of the CDL treatments on the shape of the efficiency vs. VEM thickness curve. In addition, it was also an objective of the study to provide some useful and straight forward guidelines towards the efficient design of thin CLD damping treatments taking advantage of the efficiency curve peak position. K.S.K. Sasikumar [3] investigated effects of constrained layer materials analytically using ANSYS. The results obtained showed that there is a considerable increase in the loss factor due to the stiffer constraining layer material as compared with the base layer. The study presented a passive vibration control technique applied to a beam type structures. The smart beam consisting of a steel beam modelled in cantilevered configuration with surface bonded viscoelastic material and constrained layer was used. In the study, the effect of constrained layer material in vibration control was studied. It was found that in constrained layer damping, the constrained layer material modulus greatly influences the loss factor of the system. An attempt was made to find the loss factor variation due to the constrained layer material modulus with different coverage. So far the studies have considered sandwich materials alone and its analysis has been carried out. In this paper, an attempt has been made to study variation in amplitude of displacements of base material, composite material and the viscoelastic material under similar loading conditions. Skin panel of aircraft has been considered as a simply supported beam.

II. MODELLING

To carry out the analysis, a cantilever beam with simply supported end conditions is considered. A sinusoidal force (P= 1000Sin(50πt)) is applied on the beam. Initially a simple beam with aluminium as the only constituent is used. Its behaviour is studied under dynamic loading conditions. Then keeping the cross-sectional area and the dimensions constant, but using aluminium with steel, similar study is carried out. Composite section theory is fully utilised and results are obtained. Viscoelastic material is then introduced between the two layers of steel and aluminium in the composite section. The study of the beam with different material configuration and viscoelastic sandwich structure is carried out.

A. Analytical Solution

A pulsating force is applied on the middle of a simply supported beam, and the displacement function [4] is given by following Equation 1.

$$y = \frac{2Pl^3 \sin \omega t}{EI\pi^4}\left[\frac{\sin\frac{\pi x}{l}}{1-\alpha^2} - \frac{\sin\frac{3\pi x}{l}}{3^4-\alpha^2} + \frac{\sin\frac{5\pi x}{l}}{5^4-\alpha^2} - \dots\dots\dots\right] \quad \dots. (1)$$

a. Case 1: When only aluminum is used

Constant length and width values of the beam cross-section are used throughout the project. The values used for the cross-section are show in the Figure 1

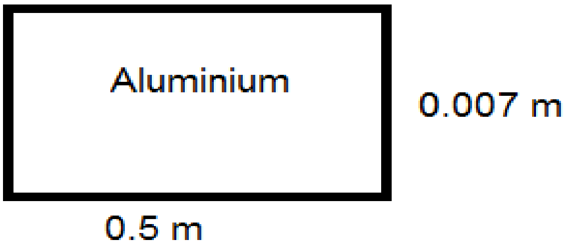

Figure 1: Cross sectional view of beam when only aluminium is considered

Length of the beam, l = 1 m
Modulus of elasticity of aluminium, E = 0.69×10^{11} N/m^2
Density of aluminium, ρ = 2700 kg/ m^3

b. Case 2: When Aluminium-Steel composition is used

Using the same values for the cross-section as shown in Fig 2

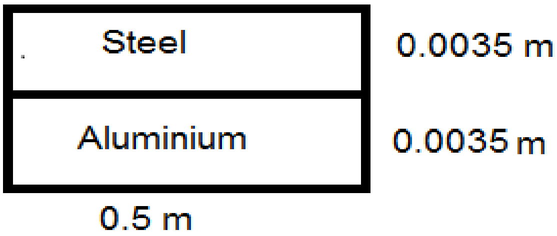

Figure 2: *Cross sectional view of beam when aluminium-steel is considered*

Length of the beam, l = 1 m
Modulus of elasticity of Aluminium, E = 0.69×10^{11} N/m^2
Modulus of elasticity of Steel, E = 2.1×10^{11} N/m^2

Density of aluminium, ρ = 2700 kg/ m^3
Density of steel, ρ = 7850 kg/ m^3

c. Case 3: When aluminium- steel is used with viscoelastic material.

For studying constrained layer treatment, the configuration as shown in Figure 3 is used.

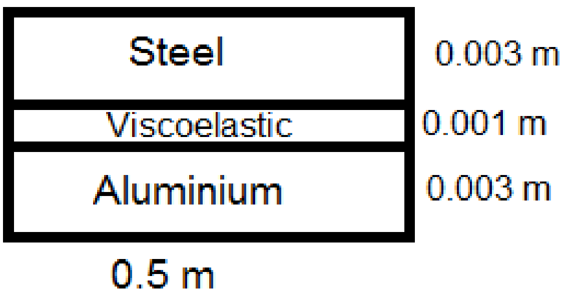

Figure 3: *Cross sectional view of beam with aluminium-VEM-steel configuration*

Length of the beam, l = 1 m
Modulus of elasticity of Aluminium, E = 0.69×10^{11} N/m^2
Modulus of elasticity of Steel, E = 2.1×10^{11} N/m^2

Density of aluminium, ρ = 2700 kg/

Density of steel, ρ = 7850 kg/
Viscoelastic material taken: 3M ISD 112

3M Viscoelastic Damping Polymer 112 has typical range of good damping from 0 to 65°C. Properties of the viscoelastic material used are listed in Table 1.

Table 1

Properties of the material, 3M ISD 112	
Modulus of elasticity (E)	8.3378×10^{6} N/m^2
Shear Modulus (G)	2.8359×10^{6} N/m^2
Poisson's ratio (ν)	0.49
Density (ρ)	1050 kg/
Loss Factor (ξ)	0.5

For constrained layer damping, the notations considered are as shown in the Figure 4

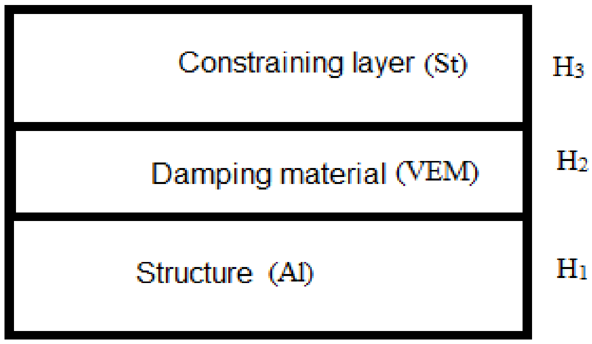

Figure 4: Constrained layer damping treatment

The flexural rigidity, EI, of the three layer system [4] of the Fig.4 can be given by,

EI=

$$\frac{E_1H_1^3}{12}+\frac{E_2H_2^3}{12}+\frac{E_3H_3^3}{12}-\frac{E_2H_2^2}{12}\left(\frac{H_{31}-D}{1+g}\right)+E_1H_1D^2+E_2H_2(H_{21}-D)^2+E_3H_3(H_{32}-D)^2$$

$$-\left[\frac{E_2H_2}{2(H_{21}-D)}+E_3H_3(H_{31}-D)\right]\left(\frac{H_{31}-D}{1+g}\right)$$

………(2)

Where,

$$D=\frac{E_2H_2\left(H_{21}-\frac{H_{31}}{2}\right)+g(E_2H_2H_{21}+E_3H_3H_{31})}{E_1H_1+\frac{E_2H_2}{2}+g(E_1H_1+E_2H_2+E_3H_3)}$$

$$H_{31}=\frac{(H_1+H_3)}{2}+H_2$$

$$H_{21}=\frac{(H_1+H_2)}{2}$$

$$g=Shear\ parameter=\frac{G_2}{E_3H_3H_2p^2}$$

$$p\ is\ the\ wave\ number\ \left(p=\frac{n\pi}{L}\right)$$

B. ANSYS Modelling

In this study a finite element model has been developed for both undamped and damped sandwich beam and frequency response for the same has been found. The finite element modelling of 3D beam with constrained layer damping is done using ANSYS software with 8 node 281 shell elements for all layers.

a. Case 1: When only aluminium was used

Fig. 5 shows the isometric view of the proposed model on ANSYS.

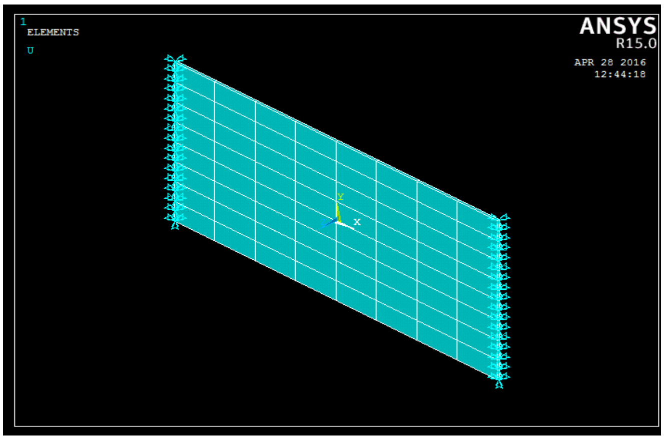

Figure 5: Pure aluminium beam structure on ansys

Fig. 6 shows the displacement – time curve for the simple aluminum beam when transient load is applied.

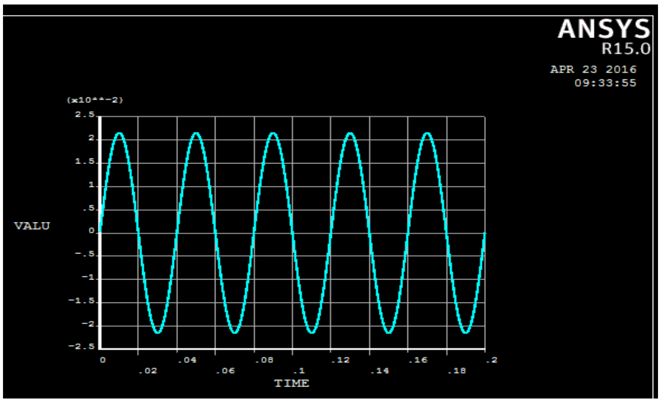

Figure 6: Displacement vs. Time graph for pure aluminium structure.

b. Case 2: Aluminium- steel is used

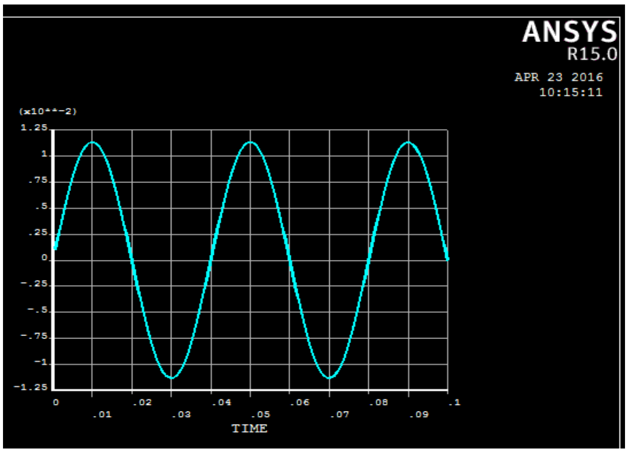

Figure 7: *Displacement vs. Time graph for aluminium-steel structure*

c. Case 3: Aluminium-VEM-steel

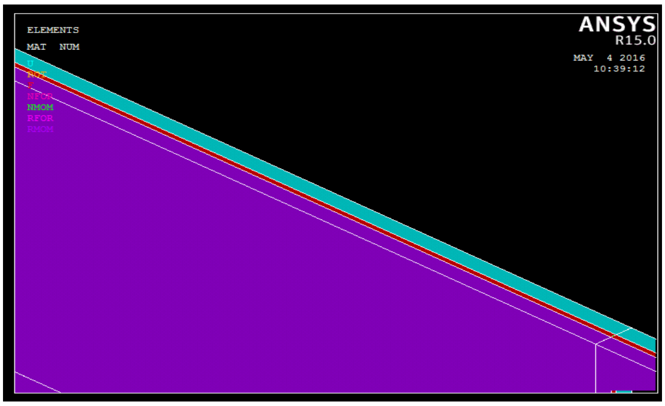

Figure 8: *Close view of sandwich structure modelling on ANSYS*

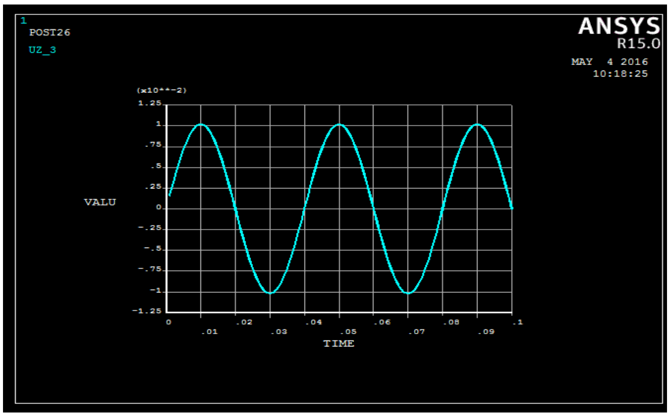

Figure 9: Displacement vs. Time graph for constrained layer structure

III. OBSERVATIONS

The results obtained for all the three cases analytically and from ANSYS can be validated if they are in good agreement with each other. A figure 10, 11, 12 shows the comparison between the results obtained for the three cases above.

A. Case 1: For Aluminium

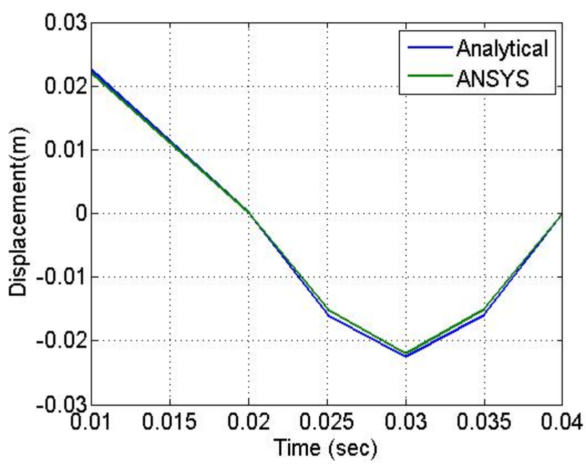

Figure 10: Displacement vs. Time graph for pure aluminium structure

B. Case 2: For Aluminium- steel

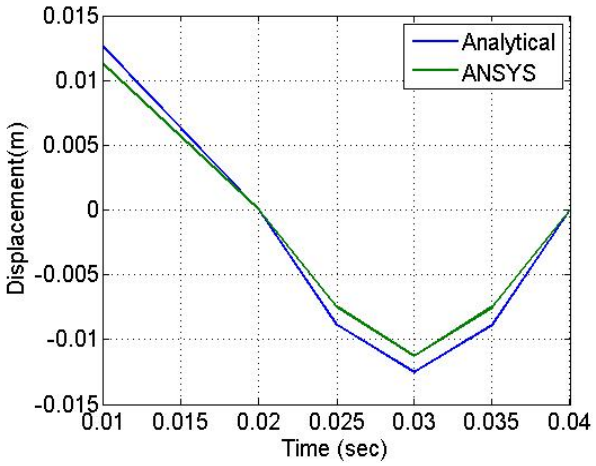

Figure11: Displacement vs. Time graph for Al-St structure

C. Case 3: Aluminium-VEM- Steel

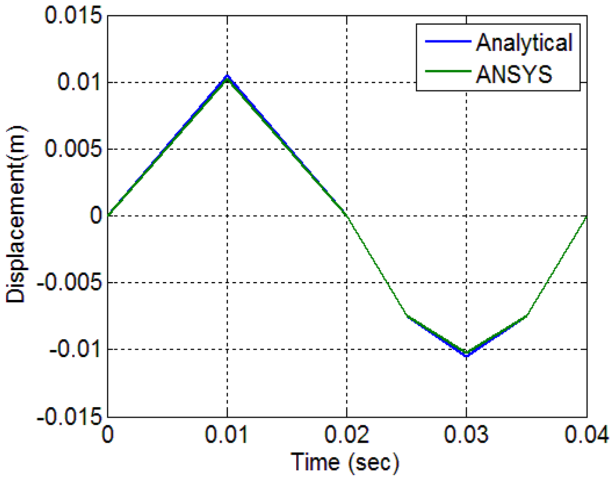

Figure 12: Displacement vs. Time graph Al-VEM-St structure

Plotting the solutions obtained by analytically for all the three cases as show in Fig 13, it is observed that there is a considerable amount of reduction in the amplitude of the displacement at a given time for sandwich layer. Maximum displacements are found for pure aluminium structure.

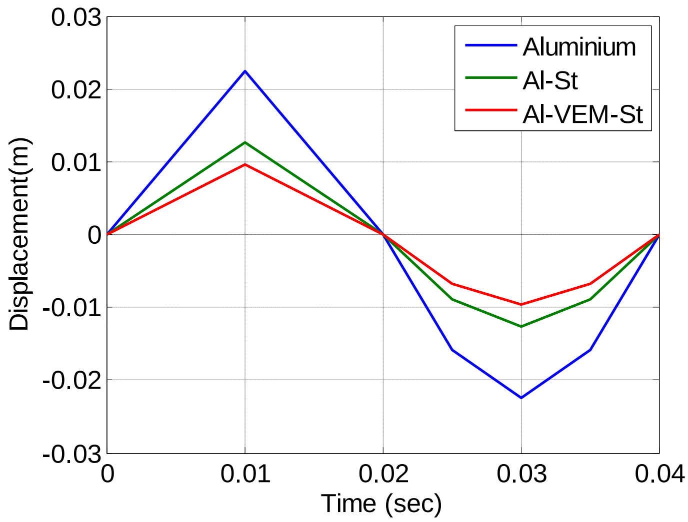

Figure 13: Displacement vs. Time graph for all the three cases calculated analytically.

It can be noted from Equation 1 that the displacement is inversely dependent of the flexural rigidity of the system. Table shows the comparison of EI values from analytical solution.

Table 2

Configuration	Flexural Rigidity (EI)	Maximum Displacement
Aluminium	986.01	0.02245
Aluminium-Steel	2142.2292	0.012556
Aluminium-VEM-Steel	2217.2112	0.01052

Similar results can be shown from the results obtained from ANSYS. Fig 14 shows the comparison between the results obtained in ANSYS for the three cases.

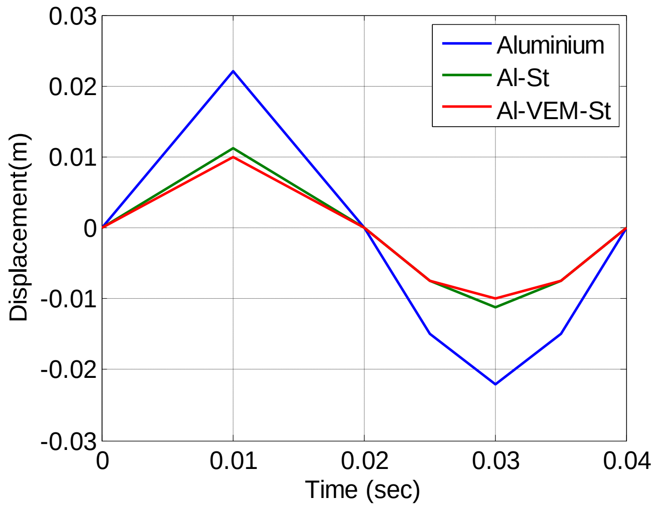

Figure 14: Displacement vs. Time graph for all the three cases calculated by ANSYS

CONCLUSION

In problems concerning constrained layer damping treatment FEA tool can be used effectively. It helps the designer to understand structural behavior of sandwich structure in better fashion. Overall conclusions based on present study are as follows:

1. Use of FEA tools in analysis of constrained layer damping treatment has been demonstrated successfully.
2. Significant reduction in the amplitude of vibration is observed when aluminum is replaced by AL-ST structure.
3. Further decrease in amplitude is observed when viscoelastic material is introduced in between.
4. Equation 1 can be used affective for problems bearing sandwhich structures.
5. From the study it appears that numerical results are in good agreement with the solutions obtained analytically.
6. Displacement- time variations obtained are according to the theory with very less deviation.

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