EXPERIMENTAL INVESTIGATIONS OF THE EFFECT OF CONSTRAINING LAYER PARAMETERS IN VIBRATION CONTROL OF STRUCTURES

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Abstract: *Today, the vibration control of structures is considered as one of the most important and useful study fields, which requires developing the new ways of control and simulating its effect on flexible structures. This study presents a passive vibration control technique applied to a beam type structures. The smart beam consists of an steel beam modeled in cantilevered configuration with surface bonded viscoelastic material and constrained layer. In this study, the effect of constrained layer material in vibration control is studied. In constrained layer damping, the constrained layer material modulus greatly influences the loss factor of the system. Here an attempt has been made to find the loss factor variation due to the constrained layer material modulus with different coverage. Patches of different lengths are bonded on the beam and its effect is analyzed. This study first investigates the effects of constrained layer materials analytically using Commercial software ANSYS 11.0. Then experiments are conducted to verify the ANSYS results. This research proves that there is a considerable increase in the loss factor due to the stiffer constraining layer material as compared with the base layer.*

Keywords: *passive damping, viscoelastic elastic, constraining layer stiffness*

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1. INTRODUCTION

Vibrationcharacteristics of a many structures are influenced by the mass, stiffness, and damping of the structure. The stiffness influences the deformation of the structure when the load applied is static. The mass and the stiffness together influence the fundamental frequencies of the structure. In addition, the damping reduces the peak amplitude of the structure. In designing a structure for vibration performance (e.g., an accelerometer), the common practice is to design based on natural frequencies first. If significant resonance cannot be avoided in the frequency range of operation, damping treatments will be introduced to alleviate the resonance. This design principle is valid for any structure regardless of the structure size. Constrained Layer Damping (CLD) treatments have long provided a means to effectively impart damping to a structure[1]. PCLD treatments can be used as reliable and robust means of damping method compared to more recent active constrained layer damping (ACLD) treatments, although they have the disadvantage of non-adjustable damping [2-3]. A large section of papers have been published in the past decades on the vibration damping analysis of PCLD treated beam and plate structures. Rao calculated Frequency and loss factors of sandwich beams for various boundary conditions[4]. In the past decades many analytical and numerical methods have been employed to determine the damping parameters (loss factor and frequency) [5-7]. The direct frequency response (Johnson 1982)is used to calculate modal damping factors in a frequency range of interest rather than complex eigenvalue method or modal strain energy method which are widely used in existing literatures on damping analysis of PCLD treatments.Kerwin[8] and DiTaranto[9] focused on the mathematical modeling of long, simply supported beams with soft VEC and thin stiff constraining layers. Mead and Markus[10] developed a sixth order differential equation of motion, in terms of the transverse displacement of the beam for arbitrary boundary conditions. The analytical work presented in that paper used the fundamental assumption that shearing of the VEC is the only cause of energy dissipation and that compressional damping does not occur in this system. Douglas and Yang[11] modified or extended the model for different applications. The performance of viscoelastic PCLD(Passive Constrained Layer Damping Treatment) treatments can be maximized by proper choice of materials and geometry. This could be achieved by using some optimization methodology as stated by Hao[12]. The tuned mass dampers can be installed more cheaply than structural stiffening, and often offer the only practical means of vibration control in existing structures[13].optimization of segmented constraining layer damping can be done by using strain energies and modal datas[14]. This is to take into account more easily the frequency-dependence of viscoelastic materials although at higher computational cost. In this paper, an alternative and practical way to attenuate the vibration of structures is proposed. In this paper a finite element analysis and an experimental study of a cantilever beam with aluminum and steel constraining layer and hybrid damping treatment are presented. A viscoelastic layer is fixed on the beam with aluminium and steel constraining layer to analyze the effect of the constraining layer. The cantilever beam with PCLD treatment is modeled with FEM software ANSYS. The FE model is validated by modal experiments.

2. TEST SPECIMENS AND MATERIAL PROPERTIES

A cantilever beam is a basic element for most of the engineering applications such as structural constructions, material handling equipments, automotives, etc. Vibration can be reduced by using passive viscoelastic constrained layer damping method. In this passive constraining layer method, damping layer (ISD112) is bonded between the base and constrained layer to reduce vibration.The base beam for the study is steel beam of dimension 580x40x5 mm. For experimental study six models are preparedwith steel CLD and six withaluminium CLD..Model 1 consists of steel cantilever beam with patch coverage of 25 percentage of the base beam length. Model 2 has 50 percentage coverage. Model 3 has 75 percentage coverage. Model 4 has full coverage, Model5 has multiple patches. Model 6has hybrid configuration in which aluminium and steel constraining layer patches are bonded to the surface alternatively.The dimensions and material properties for the beam, VEM, andconstraining layer are chosen based on easily available materials. Table 1 gives the material properties of the test specimen used in the FEM analysis and experimental study.

Table 1 Material Property

S.No.	Material Type	Young's Modulus(E) [MPa]	Density(ρ) [kg/m^3]	Poisson's Ratio	Shear Modulus (MPa)
1	Steel	$210X10^3$	7850	0.3	$79.3\ X10^3$
2	Aluminium	$70X10^3$	2700	0.35	$25.5\ X10^3$
3	viscoelastic material (3M ISD 112)	8.3378	1250	0.5	2.8359

3. FINITE ELEMENT ANALYSIS FOR DAMPED SANDWICH BEAMS

Finite element analysis has emerged as a very efficient tool for solving complex problem infield of design engineering. In this paper afinite element model has been developed for both undamped and damped sandwich beam and frequency response for the same has been found.The finite element modeling of 2D beam with passive constrained layer damping is done using ANSYS software with plane 183 element for all layers. Planestress with thickness condition has been maintained. There are three basic layers in FE model. They are

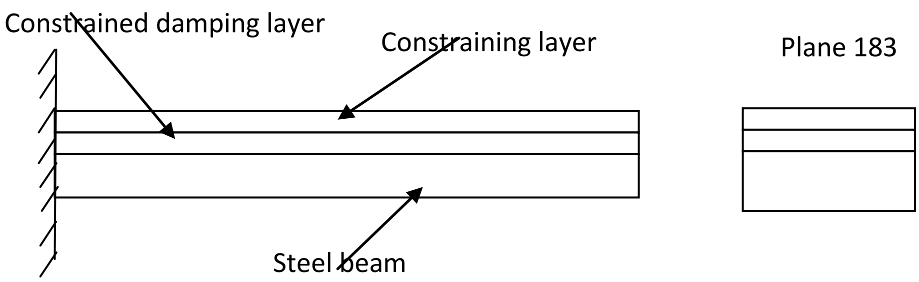

Figure 1 Finite element Modeling of PCLD

Figure1 shows the finite element model of passive constrained layer damping in the cantilever beam. The base layer is steel material with thickness 5mm, the middle layer or damping layer is ISD112 with thickness 1.5mm and constrained layer is either steelor aluminum with thickness 1mm.

3.1 Finite Element modelingdevelopment of beam set up

Plane 183 element has been used to discretize to developed model. PLANE183 is a higher order 2-D, 8-node or 6-node element. PLANE183 has quadratic displacement behavior and is well suited to modeling irregular meshes (such as those produced by various CAD/CAM systems). An important feature of the plane183 element is the possibility to specify damping in terms of a loss factor as a function of frequency and temperature. An element edge length of 0.01 is used for meshing. The mapped mesh option is used to get predefined meshing. The total number of elements after the convergence analysis is 17400. Figure 2 shows the modeling of PCLD using ANSYS software. In this, the beam is fixed at one end and the other end is free. At the free end 10N load is applied on 205th Node to excite to beam in the desired frequency range of 0 to 1000 Hz.

Figure 2Meshed model of untreatedsteebeam using ANSYS

3.2 Mode Shapes of untreated Beam

Modal analysis is the study of dynamic properties of structure under vibration excitation. Based on the above modeling, finite element program is made for the vibration analysis of cantilever beam. Modal extraction method used to extract the modes is subspace method. Equation solver used is frontal solver. The following equation is solved in ANSYS to extract modal and harmonic characteristics of the beam.$[M]\ddot{u} + [C]\dot{u} + [K]u = F$,where M =mass matrix,C=damping matrix and K=stiffness matrix.

First Mode Shape

Second Mode Shape

Third Mode Shape

Fourth Mode Shape

Fifth Mode Shape

Sixth mode shape

Figure 3 Mode shapes of untreated steel beam

In the finite element model of the beam, after applying boundary condition, mode shape and modal frequencies are calculated. Figure3 shows the first six mode shapes of the untreated steel beam. In one end of the untreated beam displacement is arrested in all direction to simulate the cantilever boundary condition in ANSYS. The frequency of excitation is 0 to 1000Hz.

3.3 Finite Element Modeling Results

The test specimens and various configuration used for the FEM study in ANSYS is same as in section 2.Figure4-7 depict the frequency response functions obtained form ANSYS of treated and un treated beam.Figure4 shows harmonic logarithmic graph comparison of untreated steel beam with 25% constrained layer damping of steel and aluminum patches. In this graph steel beam 25% steel CLD, has less amplitude value in all the modes, from this it can be seen that the 25% CLD steel beam has high damping factor compared to untreated beam and 25% CLD aluminum patch. The damping increase may be attributed to the stiffness of the constraining layer.

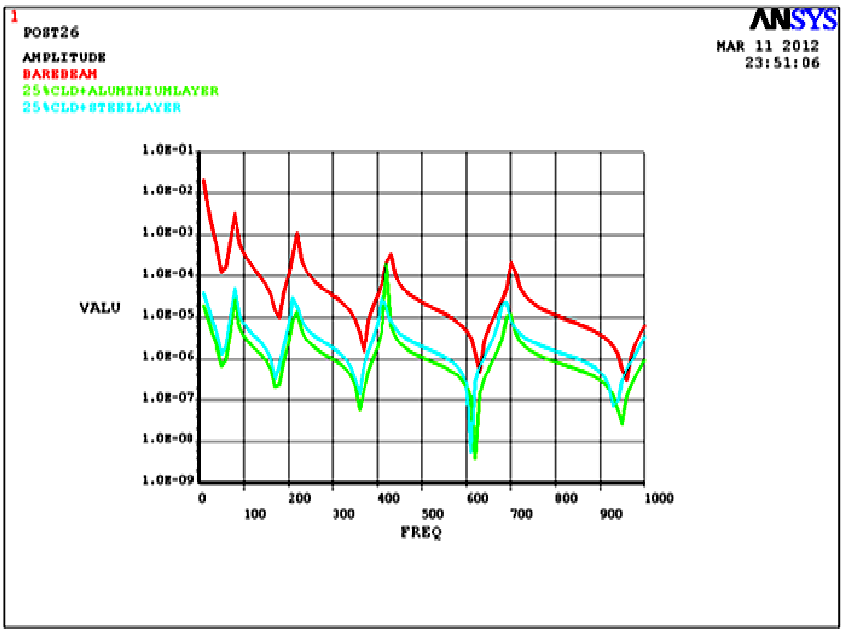

Figure 4 comparison of untreated steelbeam and beam with25% CLD

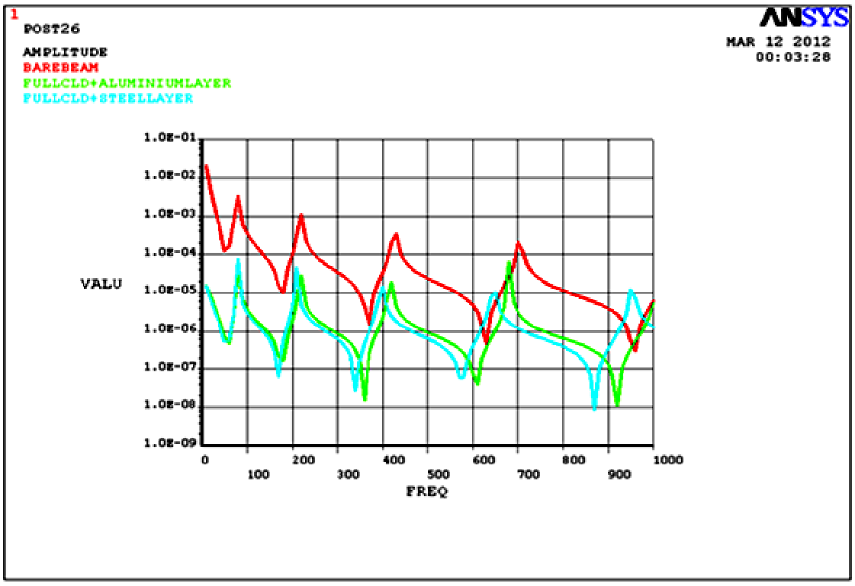

Figure 5 comparison of untreated steelbeam and beam with fully covered CLD

Figure5 shows harmonic logarithmic graph comparison of untreated beam with fully constrained layer damping of steel and aluminum patches. In this graph, fully CLD steel beam amplitude value is less at all the modes, from this it can be seen that the fully CLD steel beam has high damping factor compared to untreated beam and fully CLD aluminium patch.

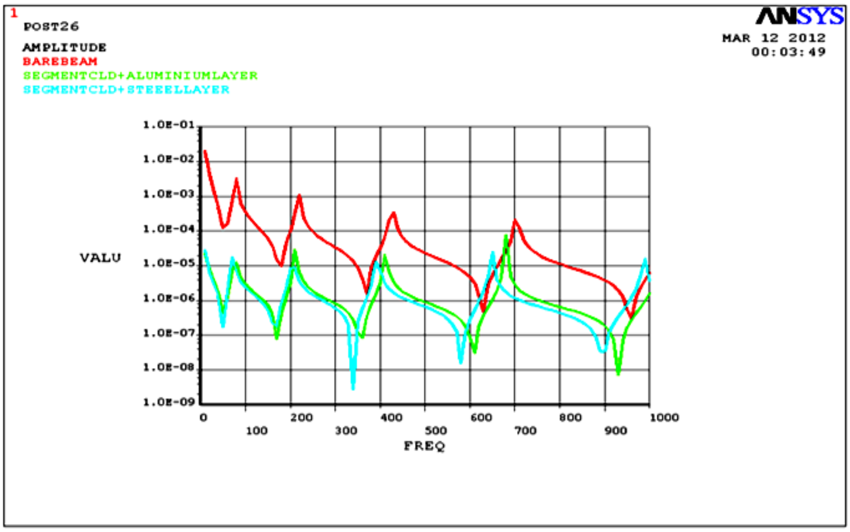

Figure 6 comparison of untreated steel beam with multiple CLD

Figure6 shows harmonic logarithmic graph comparison of untreated beam with segmented constrained layer damping of steel and aluminium patches. In this graph segmented CLD steel beam amplitude value is less at all the modes, from this it can be seen that the segmented CLD steel beam has high damping factor compared to untreated beam and segmented CLD aluminumpatch. The displacement value at the peaks has reduced more in case of beam with multiple patches. This is due to increased shear strain in the viscoelastic layer.

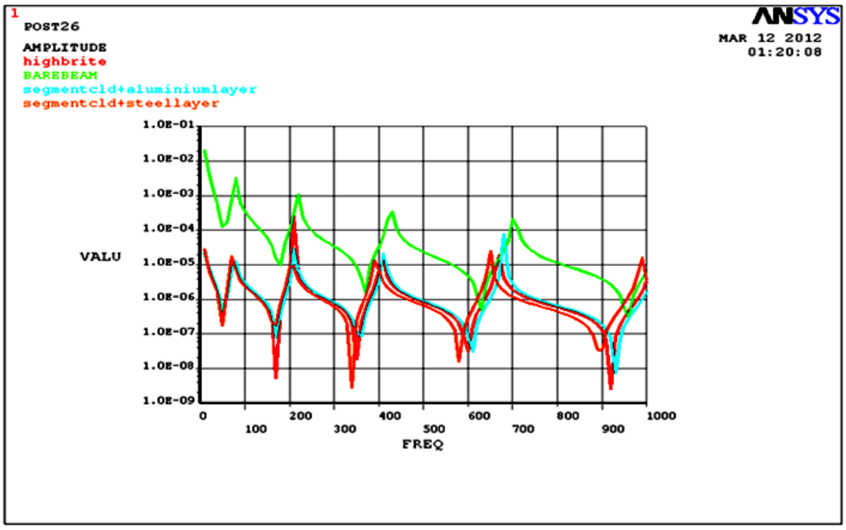

Figure 7 comparison of untreatedsteel beam with Segmented and Hybrid CLD

Figure7 shows harmonic logarithmic graph comparison of untreated beam with segmented constrained layer damping of steel and aluminum patches and hybrid CLD patch. In this graph segmented CLD steel beam amplitude value is less at all the modes. From this it can be seen that the segmented CLD steel beam has high damping factor compared to untreated beam, segmented CLD aluminum patch and hybrid beam. More damping may be achieved by properly placing the stiffer constraining layer at the point where the beam has lager strains.

4. EXPERIMENTAL SETUP

The experimental set-up for estimation of loss factor is shown in Figure8. Steel sample of dimensions 0.58 m×0.04 m×0.005 m covered with viscoelastic material manufactured by 3M Company and constraining layer was tested. Clamping was realized by means of a massive vice. A repeated impulse was applied at the middle of the beam. KISTLER 9722A2000 impact hammer was used for impulse modal testing. KISTLER 9928 force charge mounted on its head, was used to provide random loading of the sample. CTC AC102-1Aaccelerometer measured deisplaccement of the beam along length of the beam by roving accelerometer. The FFT analyzer is connected to the accelerometer and impact hammer. Four points are marked on the beam on which the hammer will be impacted. The accelerometer is fixed at specified point on the beam. The point where force is applied is called drive point. The point where accelerometer is fixed is called response point. The impact hammer is stricken at each point marked on the beam, from this amplitude and displacement values are measured. These obtained values are transferred to PC and graphs are plotted for comparisons by using FFT software. Data was acquired using adash 4300-VA3 dual channel vibration analyzer. Finally the excel data were collected and frequency response functions were calculated using software in PC.

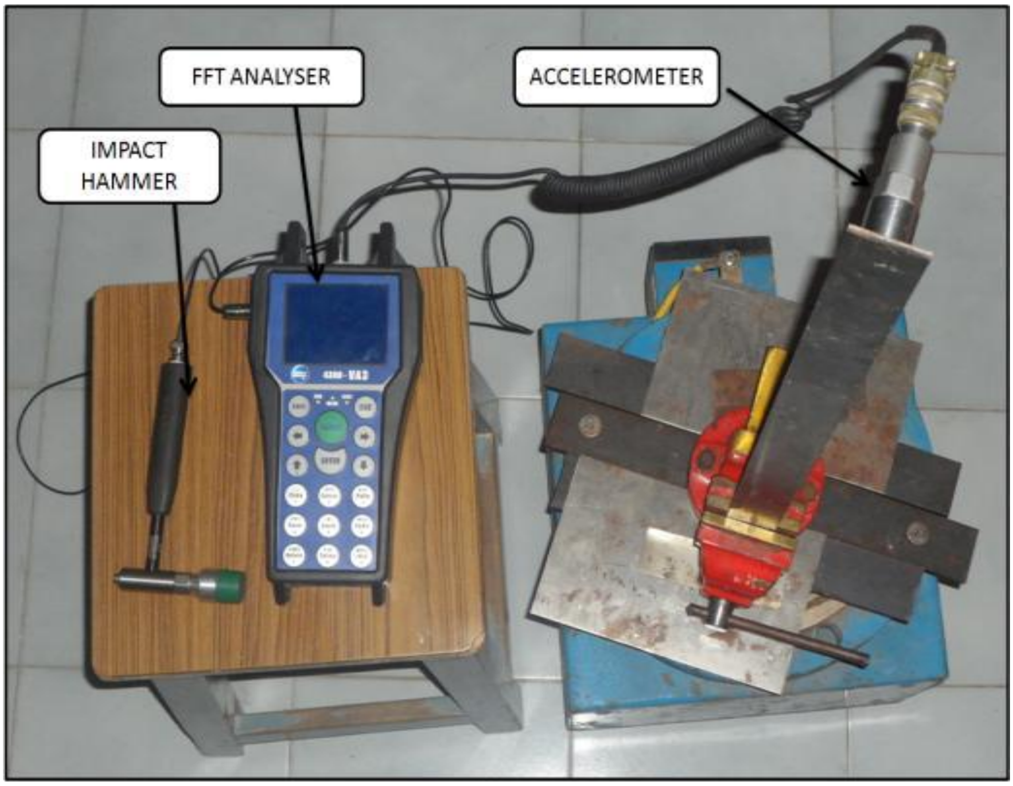

Figure 8 Photograph of the Experimental Setup

4.1 Test Specimens for Experimental Work

Totally 12 specimens are prepared, in that 5 specimen with aluminium constraining layer, 5 specimen with steel constraining layer, one specimen is hybrid constrained layer and one specimen is used as untreated beam. The patch length of viscoelastic layer and constraining layer of beam are varied.

Fig 9(a) steel Beam with full coverage of CLD with Aluminum constraining layer

Figure 9(b) Steel Beam with full coverage of CLD with steel constraining layer

Figure 9(c) Steel Beam with 25% coverage of CLD with aluminum constraining layer

Figure 9(d) Steel Beam with 25% coverage of CLD with steel constraining layer

Figure 9(e) Steel Beam with 50% coverage of CLD with steel constraining layer

Figure 9(f) Steel Beam with 50% coverage of CLD with aluminum constraining layer

Figure 9(g) Steel Beam with 75% coverage of CLD with steel constraining layer

Figure 9(h) Steel Beam with 75% coverage of CLD with aluminum constraining layer

Figure 9(i) Steel Beam with multiple of CLD with steel constraining layer(each patch is of 150 mm length)

Figure 9(j) Steel Beam with multiple of CLD with aluminum constraining layer(each patch is of 150 mm length)

Figure 9(k) Steel Beam with hyrid CLD (middle steel layer and edge aluminum layer)

Figure 9(a-k) Test specimens for experimental study

Figure9 (a-k) shows the various test specimens used in the experimental study. The last three models are beam with multiple patches of aluminium and steel constraining layer and hybrid CLD where the middle constraining layer is steel and end two layers are made of aluminum.

4.2 Calculation of Damping and Loss Factor.

The time graph of each model was taken by exciting the beam at the specified point. Logrithmic decrement method was adopted to calculate the modal damping. The following formula is used for calculating the damping factor and loss factor. Damping factor is an effect that reduces the amplitude of oscillations in an oscillatory system.

$$\text{damping factor } \zeta = \frac{\delta}{\sqrt{(2\pi)^2+\delta^2}} \quad where\ \delta = \frac{1}{n}\ln\frac{x1}{x2} \qquad (1)$$

For lightly damped materials, loss factor is just twice the damping factor 'zeta' which obtained either by log-decrement method or half-power bandwidth method

Loss factor $\eta = 2\,\zeta$ (2)

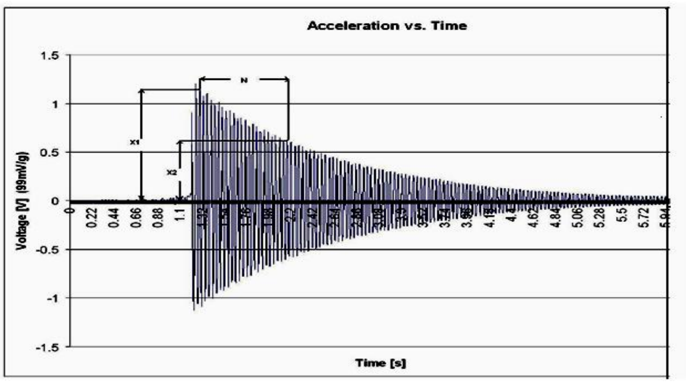

Figure 10 Time- Domain graph used to calculate the logarithmic decrement

4.3 Frequency responses from the experimental study

Figs. 11(a-b) show sample responses of frequency and time for cantilever beams with different damping coverage configurations. Every case treated is compared to the untreated beam for which FEM results were obtained in the section 3.Harmonic responses and time responses are shown in Figure11(a-b) for systems with different damping treatment lengths with aluminum constraining layer respectively. Figure 12(a-b) show the frequency response function and time history functions of the system treated with steel containing layers.

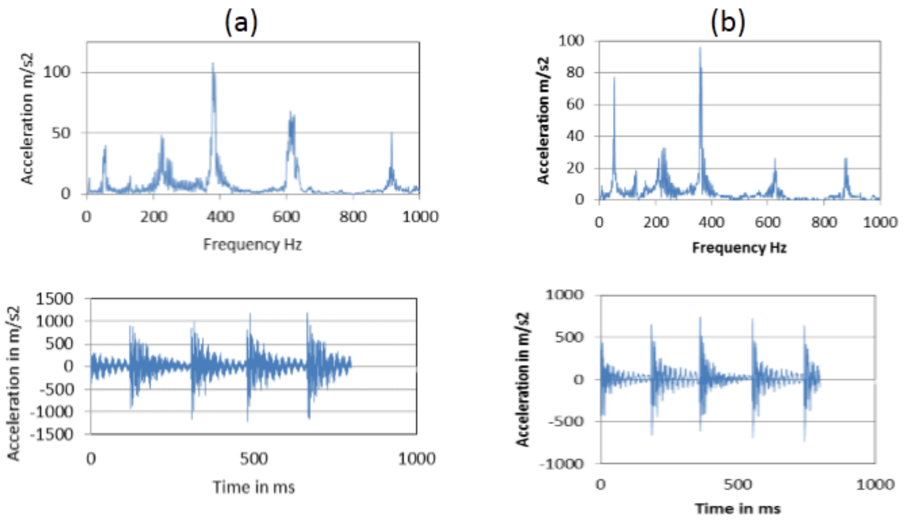

Figure.11 frequency and time history plot(a)25% (b)100% Al constraining layer

Figures 11 &12 show that the CLD treatment with stiffer constraining layer such as steel effectively suppresses the vibration amplitudes at all modes. From these sample frequency and time history responses, It is evident that close agreement can be seen between the Finite element analysis results and experimental study.

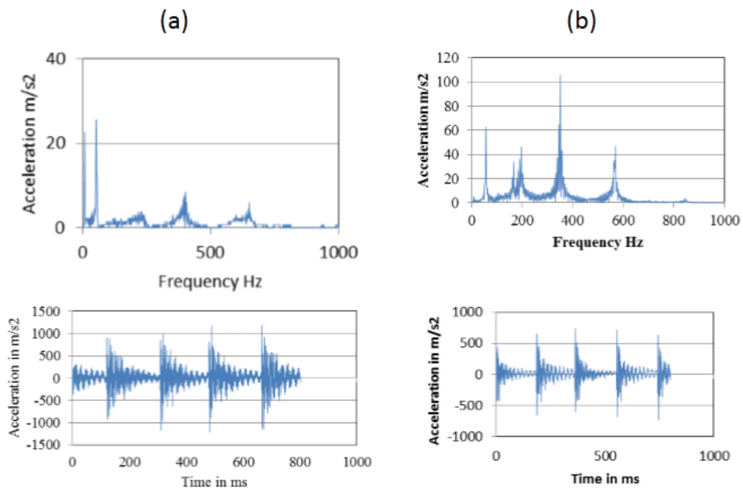

Figure.12 frequency and time history plot(a)25% (b)100% steel constraining layer

4.4 Loss factors of various systems considered for the experimental study

The modal loss factors for the all case considered are shown in the figure13.The loss factors of various modes were obtained from the time responses of experimental study.Figure13(a) shows the comparisons of loss factors beam with 25%coverage of steel and aluminium CLD. From this figure the maximum increase in damping obtained is 18 %.Figure13(b) shows the comparisons of loss factors beam with 50%coverage of steel and aluminum CLD. From this figure the maximum increase in damping obtained is 30 %.

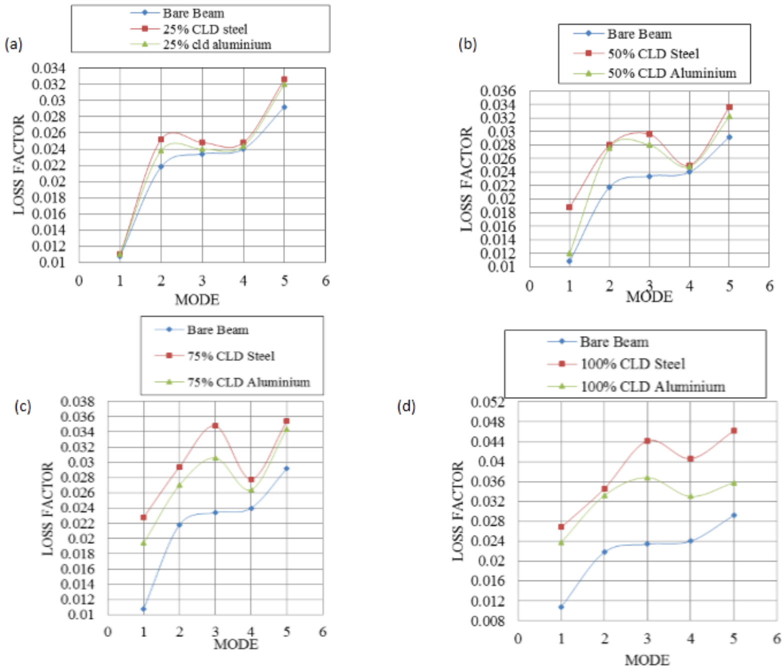

Figure 13 loss factors of various systems

In over all, it is clear that when a stiffer constraining is used that damping could be considerably increased in structures.

5 CONCLUSION

The conventional constraining layer damping treatment is simple and robust method to control the peak vibration amplitudes of structures but this method is effective over a limited range of tempratues and frequencies. This effective range can be increased by simply replacing the constraining layer of CLD by a stiffer constraining layer without affecting the total mass added to the structures..From Experimental and analytical results steel CLD patch has high damping factor than aluminium CLD patch. From the obtained FEA results, the damping factor is high for segmented steel constrained layer damped beam compared to other combination of constrained layer damped beam. From the experimental results Steel CLD patch has high loss factor and damping factor than aluminium CLD patch. From the experimental and analysis result it is identified that the steel segmented damping beam has high damping factor and loss factor.

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