Vibration control of Beam with Composite Constrained Layer Treatment

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Abstract :-In this study the effect of constrained layer materials on the damping characteristics of beam type structures are investigated with the focus of reducing the added weight to the structure. Composite materials are widely used in aeronautical, marine and automotive industries, because of their excellent mechanical properties, low density and ease of manufacture. Commercially available E-glass fibers and polyester resins are used to make to composite laminates. These composite patches are boned on the surface of the beam at different covering length. Finite element software ANSYS has been used to model the sandwiched beam. Harmonic response analysis is carried out to get the frequency response function of the system analyzed. Modal loss factors are predicted by half power bandwidth method. Finally experiments are conducted to validate the numerical results. With the use of composite materials the added weight has been reduced to nearly 33% as compared with the isotropic materials such as aluminium. The comparisons are made between the loss factor of composite constraining layer and aluminium and steel constraining layer to show the efficiency of proposed method.

Keywords: Passive constrained layer damping, Composite Layer, loss factor

I .INTRODUCTION

Conventional passive constrained layer damping (PCLD) treatments have demonstrated an effective measure in suppressing such a vibration-induced noise.The vibration energy is dissipated via cyclic shearing of the viscoelastic layer (VL).The first analysis of the problem of constrained layer damping treatmentpresented [1]. In earliest comprehensive design study, dominant design parameters were outlined [2]in that all layers vibrate with the same sinusoidal spatial dependence.Experimentalworkwas performed on the damping of composites [3].The finding of showed that the damping rate of a glass fiberbeam is almost five times larger than the one of an aluminium beam [4]. Gibson [5] performed experimental and analytical analysis to estimate their damping properties under flexural vibrations of composite laminates. Adams [6]proved that the damping ratio decreases as the fiber volume content increases. Moser [7] analyzed the composite structures with integrated damping layers to predict their performances. Adams also compared experimental results with theoretical investigations.Plagianakos [8] proposed a high-order discrete-layer theory and the corresponding finite element for the calculation of the damping of laminated composite sandwich beams and plates.Kung [9] developed an energy-based approach of multiple constrained layer damping patches. They only analyzed the effect of constrained layer damping patches at several modes separately.Liu [10] investigated the distribution of passive and active constrained layer damping patches. In their paper, no length optimization of the damping treatment was performed. In all the studies performed on the passive constrained layer damping treatments, constraining layer material used was same as the base metal. In this research work an attempt has been made to reduce the added weight to the existing system without compromising the damping given by the CLD (Constrained layer damping) treatment. The finite element study was done using FEM software ANSYS. Finally experiments were performed to compare the numerical prediction.

II. TEST SPECIMENS AND MATERIAL PROPERTIES

A steel cantilevered beam is considered and the VEM is assumed to be ISD 112. The dimensions for the beam material, VEM, and constraining layer are chosen based on easily available materials. Table.1 gives the material properties of the test specimen used in the FEM analysis.

Table 1 Material Property.

S.No.	Material Type	Young's Modulus(E) (MPa)	Density(ρ) [kg/m^3]	Poisson's Ratio	Shear Modules (MPa)
1	Steel	208X10^3	7850	0.3	79.3 X10^3
2	viscoelastic material 3M ISD 112	8.3378x10^3	1250	0.5	2.8359

III. PREPARATION OF THE LAMINATES SPECIMENS FOR CONSTRAINING LAYER

E-glass chopped stand mat of 300 g/m2 (mass per unite area) is used as reinforcement is used as reinforcement in the form of random fabric and general purpose polyester resin as matrix for the composite material of the laminates specimens. The test specimens are cut from the sheet of 3 ply laminate of the size 1000 mm x 1000 mm x 2.1 mm by using a diamond impregnated wheel, cooled by running water. All the test specimens are finished by abrading the edges on fine carborundum paper.The mechanical properties of constituents of the test specimens, E-glass random fibers and polyester matrix are listed in Table 1. The material elastic properties of the laminate of test specimens are determined through the simple rule-of-mixtures. These properties are Young's moduli (E1 – in x direction, E2 – in y direction, E3 – in z direction), Poisson's ratios (ν12, ν13, and ν23), In plane shear modulus (G12) and transverse shear moduli (G13 and G23).

Table 2 Mechanical properties of constituents of test specimens

Material	Properties	Value
Glass fibre	Elastic modulus(GPa)	74
	Shear modulus(GPa)	30
	Density(Kg/m^3)	2600
	Poisson's ratio	0.25
Polyester resin	Elastic modulus(GPa)	4
	Shear modulus(GPa)	1.4
	Density(Kg/m^3)	1200
	Poisson's ratio	0.4

Table 3 Elastic properties of woven fabric Composite laminate

Properties	Value
Elastic modulus E_X=E_y(GPa)	15.70
Elastic modulus E_z(GPa)	7.85
Shear modulus in plane x-y G_{xy}(Gpa)	2.45
Shear modulus in plane x-z G_{xz}(Gpa)	2.37
Shear modulus in plane y-z G_{xz}(Gpa)	2.37
Poisson ratio in plane x-y ν_{xy}	0.15
Poisson ratio in plane x-z ν_{xz}	0.46
Poisson ratio in plane y-z ν_{yz}	0.46

IV. FEM MODELING OF THE SYSTEM

The structure to be analyzed is a cantilever beam on which is bonded a constrained layer. Fig 1 shows the cantilever model of the structure. In the Fig.1 't' denotes the thickness. Subscripts b, c and v refer to base beam, constraining layer and Viscoelastic layer, respectively. ForFEM study seven models were prepared. The finite element modeling of base beam and viscoelastic layer is done using ANSYS software with SOLID 45. SOLID46 element has been used for composite constrained layer. Fig 2 shows the cross section view of passive constrained layer damping in the cantilever beam. The base layer is steel with thickness 5mm, the middle layer or damping layer is ISD112 with thickness 1.5mm and constrained layer is E-glass fiber with thickness 2 mm.

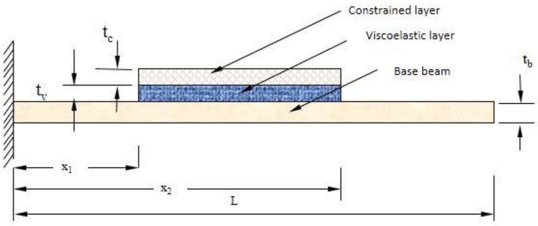

Fig.1 cantilever model of the structure

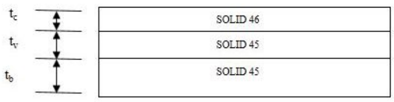

Fig.2 Modeling of PCLD Cross Section View with elements used

For a given displacement vector the equation of motion is derived as

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F\} \qquad (1)$$

Where [M] and [K] is mass and stiffness matrix of given element respectively and [F] is the load vector acting on the element.[C] is the damping matrix. In ANSYS its general form is

$$[C] = \alpha[M] + \beta[K] + \sum_{j=1}^{N_{mat}} \beta_j[K_j] + \beta_c[K] + [C_\zeta] + \sum_{k=1}^{N_{ele}}[C_k] \qquad (2)$$

whrer

α- constant mass matrix multiplier

β- constant stiffness matrix multiplier

β_i- constant stiffness matrix multiplier material dependent damping

β_c=variable stiffness matrix multiplier, expressed as follows

$$\beta_c = \frac{\zeta}{f\pi} = \frac{2\zeta}{\omega} = \frac{\eta}{\omega} \qquad (3)$$

SOLID 45 is used for the 3-D modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element have plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

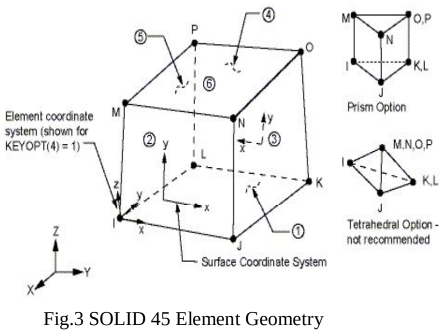

Fig.3 SOLID 45 Element Geometry

SOLID46 is a layered version of the 8-node structural solid (SOLID45) designed to model layered thick shells or solids. The element allows up to 250 different material layers. If more than 250 layers are required, a user-input constitutive matrix option is available. The element may also be stacked as an alternative approach. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions.

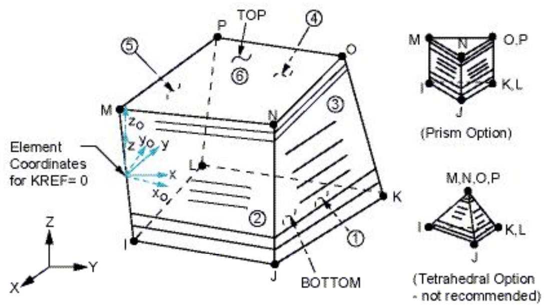

Fig. 4 SOLID 46 Element Geometry

The total number of nodes after the convergence analysis is 2500.After convergence study the total no of division in width side is 5 and length side is 25 and in thickness direction it is 2.

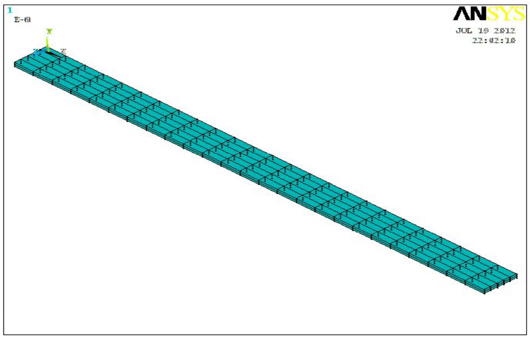

Fig.5 Meshed model of untreated steel beam using ANSYS

Fig.5 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 1N load is applied on 425th Node to excite to beam in the desired frequency range of 0 to 2000 Hz.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.

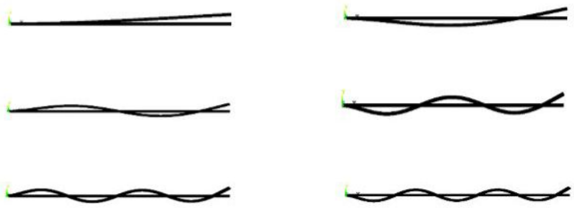

Fig.6 Mode shapes of untreated steel beam

In the finite element model of the beam, after applying boundary condition, mode shape and modal frequencies are calculated. Fig.6shows 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 1600Hz.

V. EXPERIMENTAL SETUP

Fig.7shows the experimental setup; initially the specimens are prepared for required dimensions and then clamped in the fixture. 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.

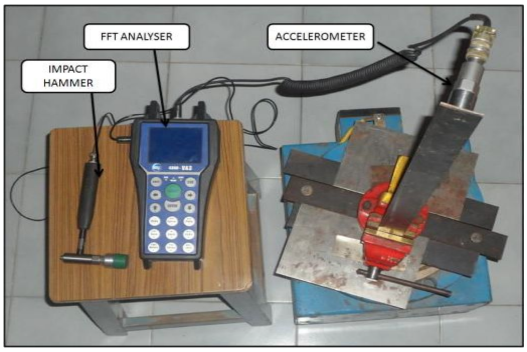

Fig.7 Photograph of the Experimental Setup

Test specimens of various patch lengths were fabricated from 25 % to 100%.Fig.8 shows the various test specimens used in the experimental study. The surface of the beam is first cleaned using corborundum paper to remove dirt. Then the treatment is bonded on the surface of the beam for various coverage lengths using araldite resin.

Fig.8 steel Beam with full coverage of CLD with E-glass composite (from top: multi patch, 100%coverage, 75%, 50%, 25%, untreated beam)

VI. FEM AND EXPERIMENTAL RESULTS

Fig.7 (a) shows frequency response functions comparison of untreated steel beam with various coverage constrained layer damping of steel and aluminum patches with composite CLD from FEM study. In this graph steel beam with25% steel CLD, has less amplitude value in all the modes.Aluminum CLD is also effectively suppresses the peak amplitudes. But with the use of composite material as constraining layer the added weight to the system has been drastically reduced. The suppression of peak amplitudes is also in the same level as the aluminium. When steel is used as constraining layer the maximum peak values reduction in the low frequency range (0 -500 Hz) 8dB and in the high frequency range (501 – 200 Hz) 13 dB.when aluminium CLD is used 4dB and 6dB in the low and high frequency range. When composite constrained layer is used the vibration reduction level is 5dB and 6dB in the low and high frequency range. Fig.7(b) shows the FRF of the system from experimental study. It also gives the same result as obtained from the FEM study.

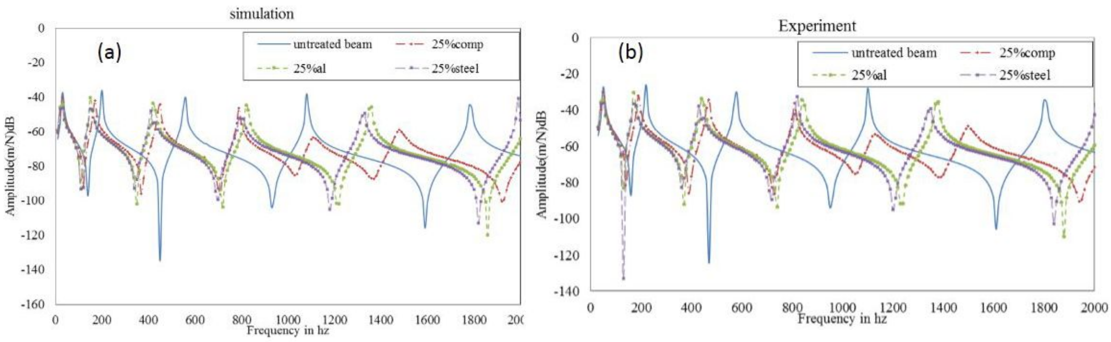

Fig.7 comparison of untreated steel beam with 25% CLD(a) Simulation (b) Experiment

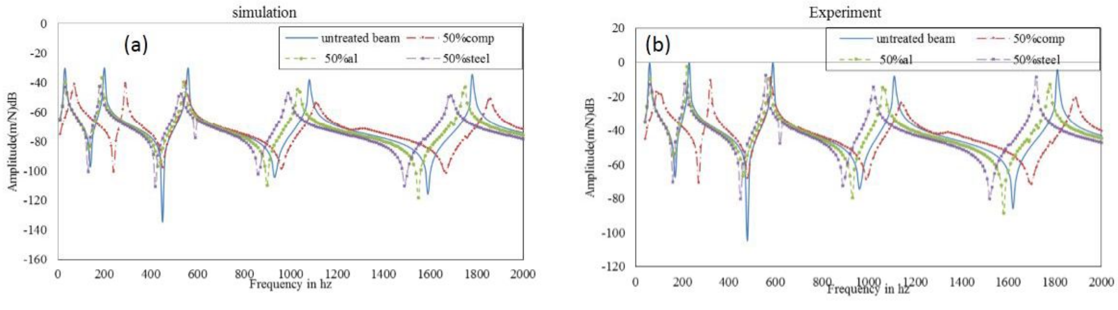

Fig.8 comparison of untreated steel beam with 50% CLD(a) Simulation (b) Experiment

Fig8(a) shows harmonic results comparison of untreated beam with 50% constrained layer damping of steel and aluminum patches and composite patches from FEM study. In this graph 50% CLD steel beam amplitude value is less at all the modes. When steel constraining layer is used the reduction level in the low and high frequency range is 17dB and 14dB .when aluminum constraining layer is used 15dB and 11dB in low and high frequency range respectively. When composite constrained layer is used the reduction level is 14dB and 10dB in low and high frequency range. Fig8(b) shows the FRF obtained from experiments. This is in close agreement with FEM study.

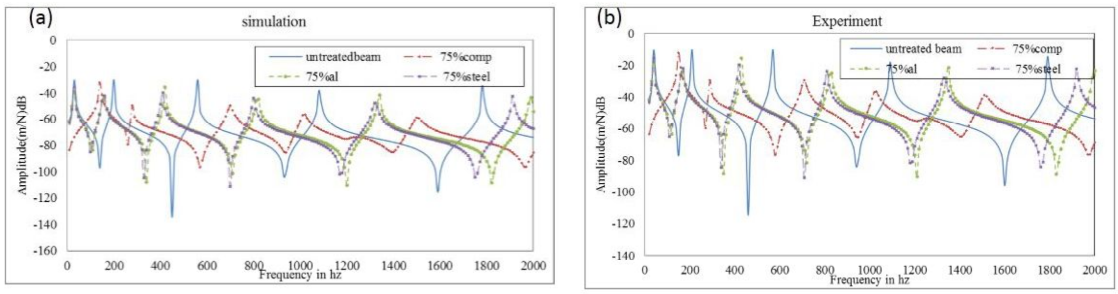

Fig.9 comparison of untreated beam with 75% CLD(a) Simulation (b) Experiment

Fig.9(a) shows harmonic results comparison of untreated beam with 75% constrained layer damping of steel and aluminium patches and composite CLD. When steel constraining layer is used the reduction level in the low and high frequency range is 15dB and 13dB .when aluminum constraining layer is used 12dB and 10dB in low and high frequency range respectively. When composite constrained layer is used the reduction level is 11dB and 12dB in low and high frequency range. Fig.9(b) shows the FRF obtained from experiments. This is in close agreement with FEM study.

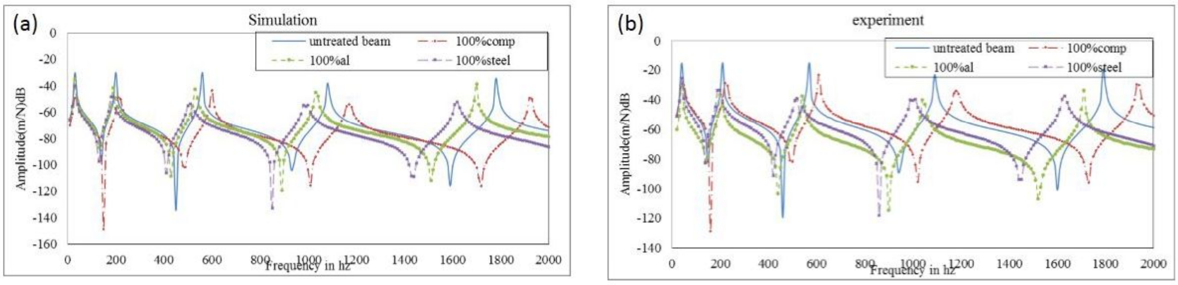

Fig.10 comparison of untreated beam with 100% CLD (a) Simulation (b) Experiment

Fig.10(a) shows harmonic results comparison of untreated beam with 75% constrained layer damping of steel and aluminium patches and Composite CLD. When steel constraining layer is used the reduction level in the low and high frequency range is 15dB and 13dB .when aluminum constraining layer is used 12dB and 10dB in low and high frequency range respectively. When composite constrained layer is used the reduction level is 11dB and 12dB in low and high frequency range. Fig10(b) shows the FRF obtained from experiments. This is in close agreement with FEM study.

VII. CALCULATION OF DAMPING AND LOSS FACTOR.

The frequency response functions of each model were taken by exciting the beam at the specified point. Half-power bandwidth 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.

$$\zeta = \frac{\omega_1 - \omega_2}{2\omega_n} \quad (4)$$

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

$$\eta = 2\,\zeta \quad (5)$$

Fig.11 shows comparison of FEM loss factor of untreated beam with 25%, 50%, 75% and 100 % coverage CLD of steel and aluminium and composite patches. In the Fig gf refers glass fibre, al refers aluminium . From this graph it can be seen that beams covered with steel constrained layer damping patch has a high loss when compared to untreated beam and beam with other treatments. From the loss factor comparison it can be seen that when a stiff constraining layer is used the damping performance is more. But high dense material such as steel compared with either aluminum or composite glass fibre reinforced polymer adds more weight to the system. When steel constraining layer is used for 25% coverage, the loss factor is 0.017 in the first mode. Whereas for aluminium and composite constraining layer the loss factor is 0.013.when the beam is fully covered by damping treatment the loss factor values in the first mode are 0.028, 0.026, 0.027 for steel, aluminium and composite constraining layers respectively.

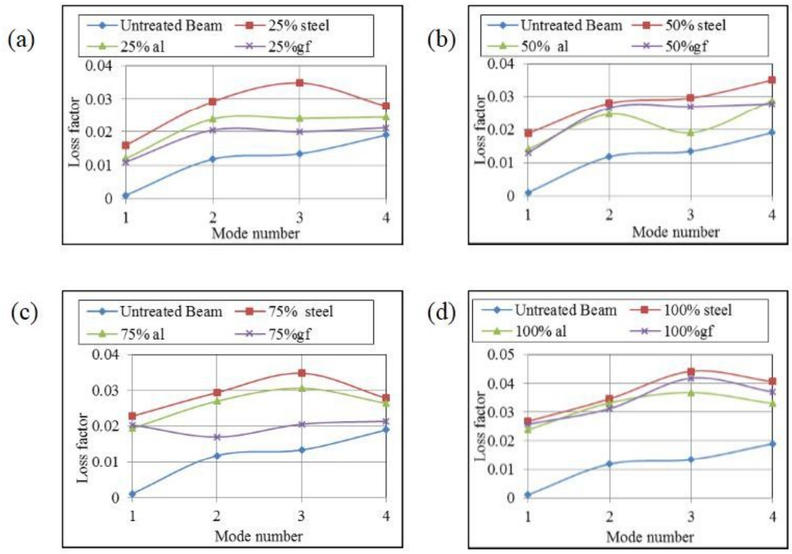

Fig.11 Comparison of FEM Loss factors of untreated steel beam with various coverage range of CLD. (a) 25% (b) 50% (c) 75% (d) 100%coverage

Fig.12 shows comparison of Experimental loss factor of untreated beam with 25%, 50%, 75% and 100 % coverage CLD of steel and aluminium and composite patches. From this comparison also we can draw same conculusion.the experimental and FEM loss factors are in close agreement with each other. Fig.13 compares the loss factors of various systems with respect to the coverage of the PCLD for four modes. It is clearly seen that the loss factors of the system gets increased as the coverage increases. In all the coverage ,the mode 3 was effectively suppressed. Its loss factor values are 0.03, 0.04, 0.038 and 0.052 for 25%,50%,75% and 100% coverage of the length when steel constraining layer is used.

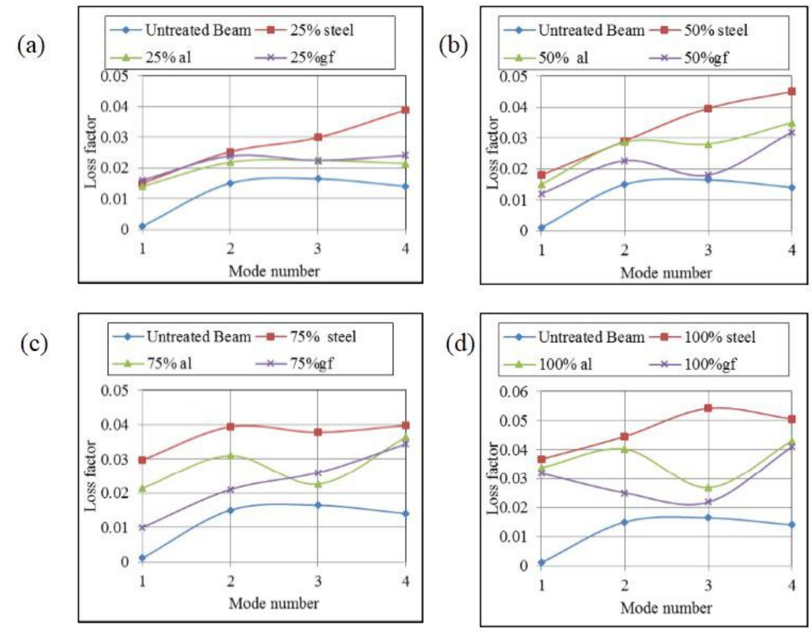

Fig.12 Comparison of Experimental Loss factors of untreated steel beam with various coverage range of CLD. (a) 25% (b) 50% (c) 75% (d) 100%coverage

Fig.13 compares the modal loss factors of first four modes. In all modes the steel constraining layer achieves more loss factor. This due to the reason that the steel constraining layer is stiffer than the other layers. As the coverage increases the loss factor also increases. The composite and aluminium constraining layer has the same loss factor values in all modes. So when composite constraining is used the same damping as aluminium constraining layer can be achieved without adding more mass to the system.

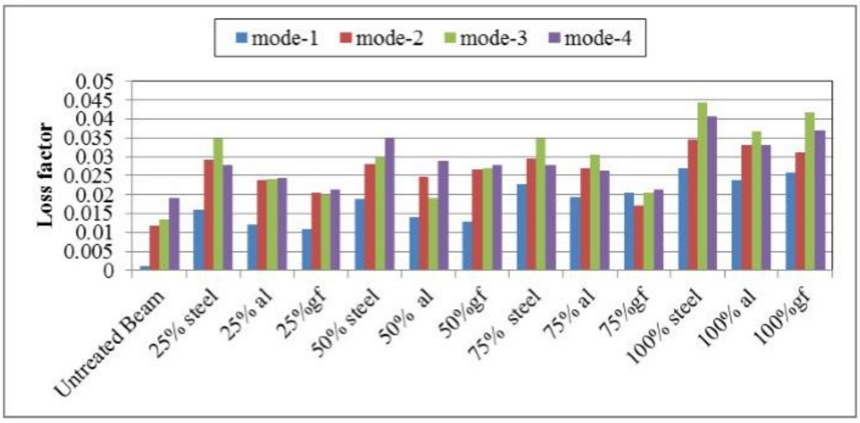

Fig.13 Effect of coverage of PCLD of structural damping

VII. CONCLUSION

In this paper, extensive studies were conducted on a cantilever beam partially covered with passive constrained layer damping. The PCLD treatment is modeled by using finite element method and the theoretical predictions are compared with experimental results. The trends obtained in numerical study corroborate well with the experimental. Some of the conclusions from the studies on cantilever beams are (i) For the case of beam with PCLD treatment of steel constrained layer, the maximum damping is obtained compared with the beam treated with aluminum constraining layer. This due to the reason that the stiffness of the constraining layer increases the shear strain in the viscoelastic layer. ii) The full coverage gives the maximum loss factor as expected in both the case. (iii) Placing the constrained layer patch on the more straining area effectively reduces the resonance peaks. (iv)Adding more weight to the structure shifts the fundamental frequency of the original system more. (v) The use of composite materials as constraining layer reduces the added weight of the system by 33%.

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