Passive Viscoelastic Constrained Layer Damping Technology for Structural Application

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***Abstract*— The intention behind this study is to foresee damping effects using method of passive viscoelastic constrained layer damping. Beams are modeled for passive viscoelastic damping to predict damping effects in constrained layer sandwich cantilever beam. Passive damping treatment is widely used for structural application in many industries like automobiles, aerospace, etc. In this method of damping a simple cantilever beam is treated by making sandwich structure to make the beam damp, and this is done by using viscoelastic material as a core to ensure the damping effect. For past few years, viscoelastic materials has been significantly identified as the best damping material for damping application which are usually polymers. Here viscoelastic materials have been used as a core for making sandwich beam to ensure damping effect. Due to complex properties of viscoelastic materials, its modeling has been the matter of talk. So in this modeling of viscoelastic materials has been shown. The experimental results show how the amplitude decreases with time for damped system compared to undamped system and further it has been extended to finite element analysis with various damping material.**

***Index Terms*— Finite element analysis, Damping, Viscoelastic**

I. INTRODUCTION

The damping of structural components is often overlooked while deciding criterion for good mechanical design. The absence of damping in structural components has led to mechanical failures over infinite number of structures. For accounting the damping effects, lots of research have been done in this field to minimize vibration and to reduce mechanical failures.

The common damping materials available in current market are Viscoelastic materials. Viscoelastic materials are generally polymers, which allow wide range of different compositions resulting in different material properties and behavior. Thus, Viscoelastic damping materials can be developed and applied efficiently for a specific application.

Finite element analysis is a very efficient tool for solving complex problem in field of design engineering. The experimental procedure is a very difficult task and lot of assumptions must be taken care off for precision of the work and using finite element method we can minimize this complexity of the problem and get rid of calculations. In this a finite element analysis will be done for both undamped and damped sandwich structures and frequency response for the same will be shown.

Vibrations in structures have become increasingly problematic in low margin design, where structures are built to have a minimum amount of weight. Frequently, solutions have poor modal characteristics due to other constraints such as geometry or weight. In many cases poor modal characteristics can be done away with the use of passive, active or hybrid damping techniques.

Much experimental work has been carried out to study the effects of passive & active damping materials to structures. Experimental modal analysis indicates that while damping treatments have a small effect on the modal frequencies; they have a significant effect on the amount of damping achieved and the modal amplitude. Due to these effects, all three types of damping treatments have been applied to many structures.

A proper material understanding is essential for damping to occur. There is need to study the complex behavior of viscoelastic materials before material selection for particular application. Based on a literature review, there is a need to develop and implement a solution/ method that can predict the effects of applying passive damping treatments to structures.

The main focus of this is to study the complex behavior of the viscoelastic materials. To predict damping effects using method of passive viscoelastic constrained layer damping experimentally and to show the nature of response of structures. The main objective is to model the viscoelastic sandwich beam for the modal analysis using the Finite Element Method. The face and core layers are varied to model the different configuration of the sandwich beams and these modeled sandwich beams are investigated for natural frequencies using FEA and Experiment for cantilever boundary condition. The damping effect on the sandwich beams has to be studied by increasing the core layer thickness.

Controlling vibration [1] is a major concern in several industries such as aeronautics and automobiles. Passive damping technology [2, 3] using viscoelastic materials are used to control vibration. The industry proposes damped sandwich sheets in which a layer of viscoelastic material is sandwiched between two elastic face layers. In the early, Kerwin et. al. [4] presented damping effective of the constrained viscoelastic layers and mentioned that the damping effect depends on the wavelength of bending waves, thicknesses and elastic moduli and formulated the complex shear modulus for the damping layer and he predicted that the heat dissipation takes place through the shearing phenomenon. For a number of constraining layers damping factors have determined experimentally by neglecting the boundary condition. Ditoranto [5] has derived auxiliary equation for the effect of viscoelastic layers. They formed the six orders, complex, homogeneous differential equation of the viscoelastic layered finite length beam and determined the natural frequencies and loss factors for the freely vibrating beam. Mace [6] modeled the viscoelastic sandwich beams by using the finite element model, in the layer wise displacement field for studying the dynamic behavior. The model developed is applicable duly to the very thin core layer of viscoelastic sandwich beam and the model which he made was in 3D model approach it is very difficult and costly for the implementation and it also generates the difficulties in the mesh for the analysis.

Damping is extraction of mechanical energy from a vibrating system, by converting the mechanical energy into heat energy by means of dissipation mechanism. Mostly all materials show some amount of internal structural damping. Most of the time it is not effective to minimize the vibration around resonant frequencies. Hence, by bringing these materials in vicinity with the highly damped and dynamically stiffed material it is possible to control the vibration.
Viscoelastic materials are such that they are capable of storing strain energy when they are deformed; these types of materials exhibit the material characteristics of both viscous fluid and elastic solid. In Viscoelastic material the mechanical energy is released through normal deformation and cyclic shear.

Normally Sandwich construction includes a relative thin core of low density material, sandwiched between the bottom and top face sheets (face layers) of relatively thin in size.

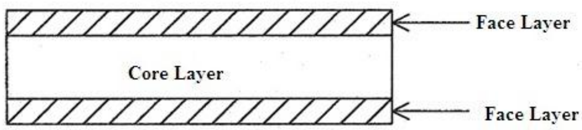

Fig. 1 Sandwich beam model

The fundamental work in this domain was pioneered by Ross, Kerwin and Ungar (RKU) [7], who used a three-layer model to calculate damping in plates with constrained layer damping treatments. Kerwin was the first to present a theoretical approach of damped thin structures with a constrained Viscoelastic layer. He stated that the energy dissipation mechanism in the constrained core is responsible to its shear motion & presented the first analysis of the simply supported sandwich beam using a complex modulus to represent the Viscoelastic core.

In practice it is necessary to design damped structures with complicated geometry, so it is natural to look to the finite element method (FEM) for a solution. The accuracy of the FEM is determined by the element model. An earlier review in this domain can be found in references by Nakra. [8]

II. FINITE ELEMENT METHOD

Finite element method has become a very effective tool for a wide range of engineering problems. Applications range from deformation and stress analysis of automotive, aircraft, building and bridge structures.
In this method of analysis, a complex region defining a continuum is discretize into simple geometric shapes called finite elements. The element material property and the governing relationships are considered over these elements and expressed in terms of unknown values at nodes. An assembly process, duly considering the loading and constraints, results in the set of equations. Solution of this equation gives an approximate behavior of the continuum. The main rule that involved in finite element method is “DIVIDE and ANALYZE”. The greatest unique feature which separates finite element method from other methods is “It divides the entire complex geometry into simple and small parts, called “finite elements”.

Steps in FEM

1. Modeling
2. Discretization of the structure
3. Derivation of element displacement models
4. Derivation of element stiffness matrix
5. Assemblage of elemental equations to obtain overall equilibrium equations
6. Solution of unknown nodal displacement / Field variables
7. Computation of results
8. Interpret the results

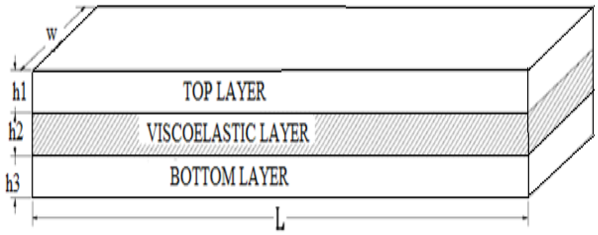

Fig. 2 Sandwich Beam model

Table 1 CAD Models

Sr. No.	Specimen Name	Dimensions of Specimen (in mm)		
		Length	***Width***	***Thickness***
1	A0	450	50	0
2	A15NR	450	50	1.5
3	A20NR	450	50	2
4	A30NR	450	50	3
5	A15NP	450	50	1.5
6	A20NP	450	50	2
7	A30NP	450	50	3

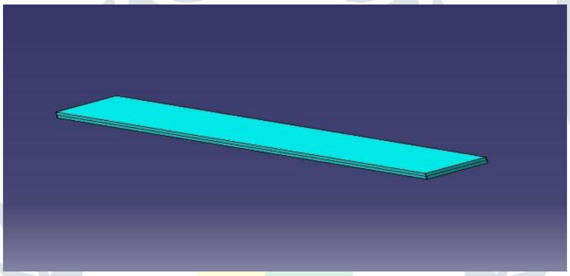

Fig. 3 Undamped Aluminium Plates

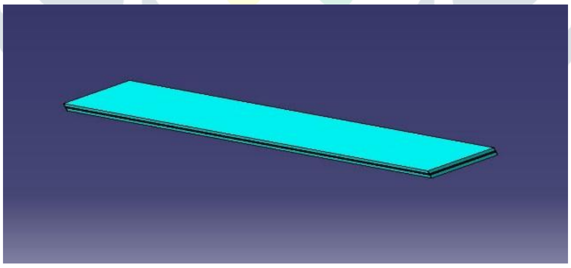

Fig. 4 Aluminium Plates with Sandwich Material Thickness 1.5 mm.

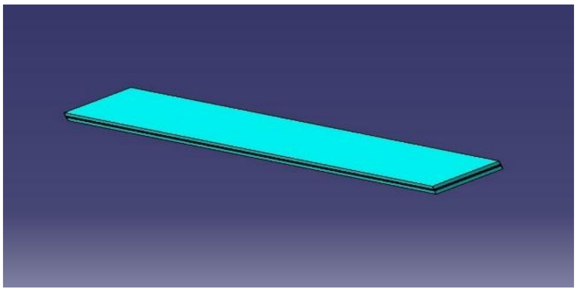

Fig. 5 Aluminium Plates with Sandwich Material Thickness 2.0 mm

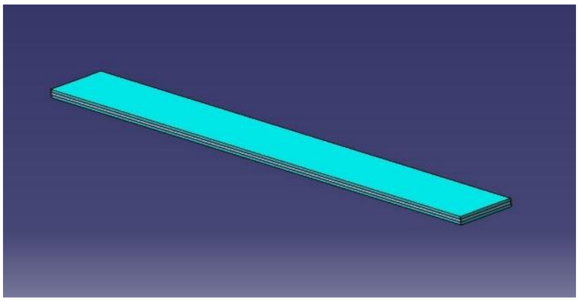

Fig. 6 Aluminium Plates with Sandwich Material Thickness 3.0 mm

Meshing of Sandwiched Beam

The meshing of sandwich beam is done using solid elements. Hex elements are used to mesh the beam and the meshing quality and connectivity are maintained as per meshing standards. Then the material properties are applied as shown in the below table.

Table 2 Material Properties

Sr. No.	Type of Material	Young's Modulus(GPa)	Shear Modulus(GPa)	Density(Kg/m^3)	Poisson's Ratio
1	Aluminium	71	27.3	2700	0.33
2	Nat. Rubber	0.00154	0.005	950	0.45
3	Neoprene	0.0008154	0.000273	960	0.49

Table 3 Mesh Details for A0 specimen

Type of Element	Hex
Element size	3
No of elements	5100
No of nodes	8154

Meshing on Model A0

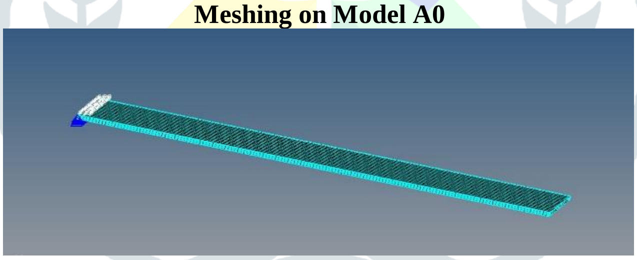

Fig. 7 Final meshed specimen with application of boundary condition

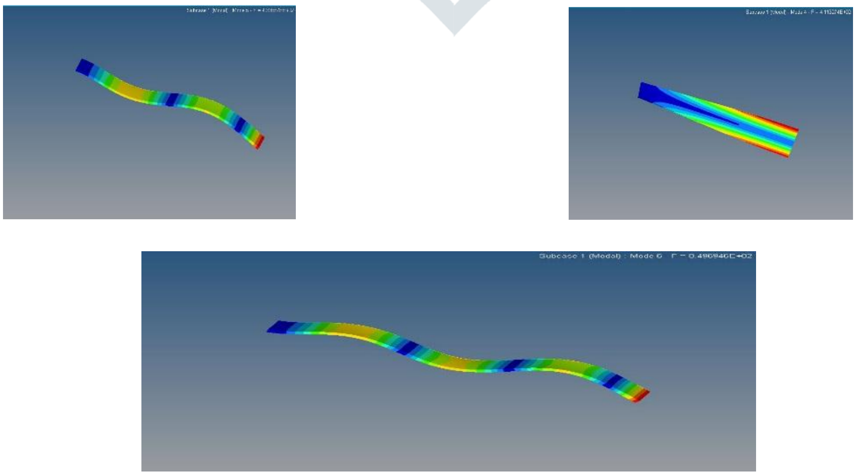

Fig. 8 Modes Shapes for A0

Likewise modes shapes for all the seven beams were found out.

III. Experimentation

The experimental setup consists of:
1) Vibscanner 2) Hammer
3) Accelerometer 4) Vice

The experimental vibscanner system consists of three main components; (i) portable data collectors (ii) accelerometer (iii) data acquisition system. The vibscanner is used for the diagnosis and recording of conditions of test specimens. The accelerometer is used to convert the mechanical motion of the structure into an electrical signal. The data acquisition system is used to convert the analog signals into digital format. Software called OMNITREND is then used to execute signal processing and analysis.

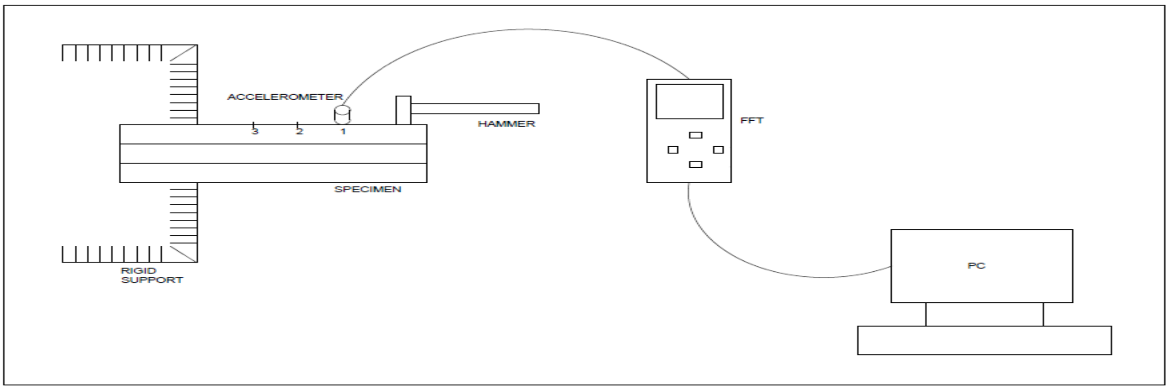

Fig. 9 Schematic Experimental Set-up

Three different types of sandwich beam combinations of varying thicknesses were made for experimental investigation which consists of
Combination1: Aluminum – Aluminum (Damping Layer Absent)
Combination 2: Aluminum-Neoprene- Aluminum
Combination 3: Aluminum-Natural Rubber- Aluminum
The natural frequencies for all the specimens were determined experimentally for the cantilever boundary conditions.

Fig. 10 Neoprene Beams

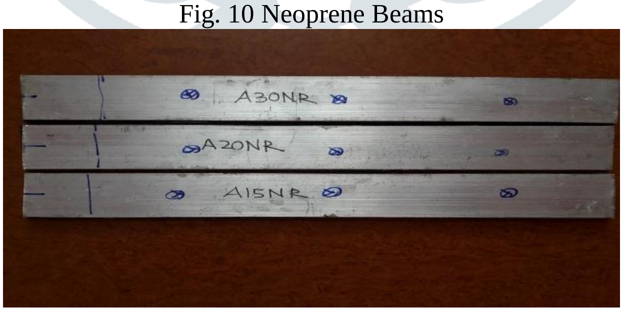

Fig. 11 Natural Rubber Beams

Fig. 12 Specimen held as Cantilever Beam

The natural frequencies obtained from the experimental analysis are as follows:

For A0

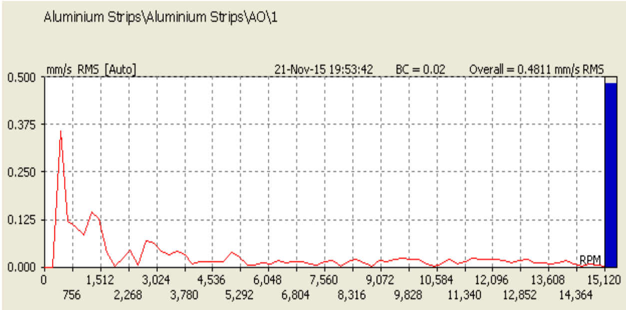

Fig. 13 Reading at point 1

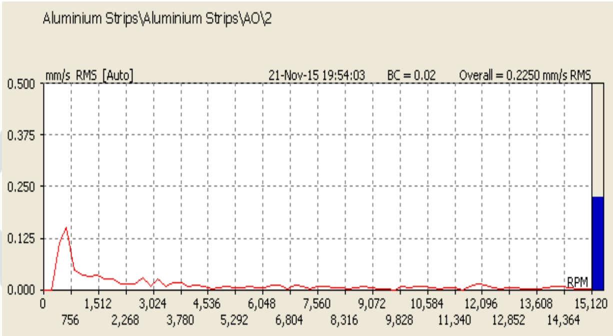

Fig. 14 Reading at point 2

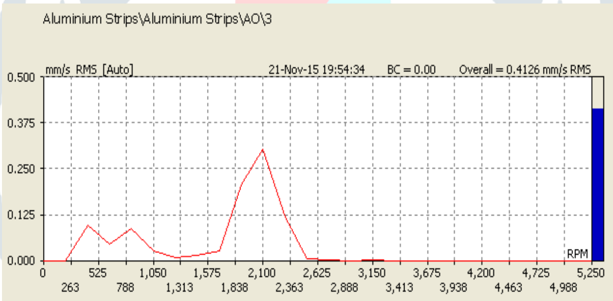

Fig. 15 Reading at point 3

IV. RESULT AND DISCUSSION

In this section the thickness of the damping layer has varied to study the damping effect on the sandwich beam for the specimens which are modeled. It represents the natural frequencies obtained by FEA. The results are compared for 4th, 5th & 6th modes ignoring 1st three modes.

Comparison of Natural Frequencies of Natural Rubber & Neoprene on the basis of FEA

Natural Rubber

Table 4 Natural frequencies of Natural Rubber for various thicknesses

Mode No.	0mm	1.5mm	2mm	3mm
4	411.627	287.480	282.585	597.916
5	433.657	433.314	438.519	647.973
6	849.69	745.761	742.131	1205.593

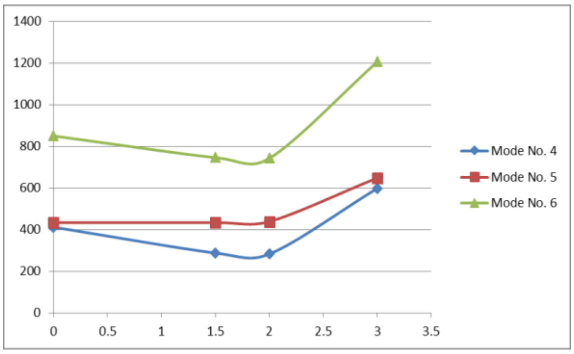

Fig. 16 Comparison of Natural frequencies of Natural Rubber for various thicknesses

Table 5 Natural frequencies of Neoprene for various thicknesses

Mode No.	0mm	1.5mm	2mm	3mm
4	411.627	256.418	251.889	246.987
5	433.657	381.007	379.708	380.856
6	849.69	645.423	635.117	625.233

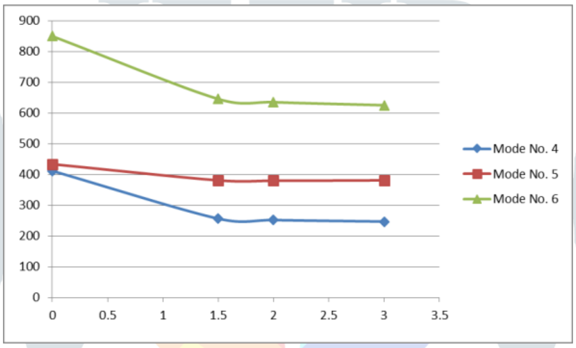

Fig. 17 Comparison of Natural frequencies of Neoprene for various thicknesses

Observations made:

1. As the thickness of damping material increases, the natural frequency goes on decreasing, except for Natural Rubber for 3mm case.
2. The natural frequency of undamped specimen is higher as compared to damped specimen suggesting that damping in material decreases natural frequency, thereby minimizing vibrations induced.
3. The results obtained clearly shows that the beams modeled with Neoprene as a core layer has more damping effect as compared to the rubber for the cantilever boundary conditions.

Experimental Results

Validation of FEA Results with Experimentation

Specimen 1: - A0

Table 6 Comparison of Natural Frequencies for A0

Modes	FEA Results(Hz)	Experimental Results(Hz)	% Variance
Mode 4	411	430	4.42
Mode 5	433	500	13.4
Mode 6	849	2100	59.57

Specimen 2: - A15NR

Table 7 Comparison of Natural Frequencies for A15NR

Modes	FEA Results(Hz)	Experimental Results(Hz)	% Variance
Mode 4	287	325	11.7
Mode 5	433	480	9.8
Mode 6	745	750	0.66

Specimen 3: - A20NR

Table 8 Comparison of Natural Frequencies for A20NR

Modes	FEA Results(Hz)	Experimental Results(Hz)	% Variance
Mode 4	282	350	19.42
Mode 5	438	452	3.09
Mode 6	742	770	3.63

Specimen 4: - A30NR

Table 9 Comparison of Natural Frequencies for A30NR

Modes	FEA Results(Hz)	Experimental Results(Hz)	% Variance
Mode 4	231	350	34
Mode 5	597	470	21.27
Mode 6	647	650	0.46

Specimen 5: - A15NP

Table 10 Comparison of Natural Frequencies for A15NP

Modes	FEA Results(Hz)	Experimental Results(Hz)	% Variance
Mode 4	256	350	26.85
Mode 5	381	360	5.51
Mode 6	645	672	4.02

Specimen 6: - A20NP

Table No. 11 Comparison of Natural Frequencies for A20NP

Modes	FEM Results(Hz)	Experimental Results(Hz)	% Variance
Mode 4	251	440	42.95
Mode 5	379	441	14.05
Mode 6	635	500	21.26

Specimen 7: - A30NP

Table 12 Comparison of Natural Frequencies for A30NP

Modes	FEA Results(Hz)	Experimental Results(Hz)	% Variance
Mode 4	246	400	38.5
Mode 5	380	420	9.52
Mode 6	625	630	0.793

From the tabular results one can infer that the values obtained using experiment and theoretical are in good agreement with acceptable errors except for some cases where % variance is above 20%. This may be due to improper meshing, improper mounting of specimens into the vice, etc.

V. Conclusion

The developed model has been validated with the experiment performed. Experimental verification has been done for the different types of sandwich beams modeled. The sandwich beams are modeled here with varying of core layers.

The sandwich beams modeled here are carried out for modal analysis using finite element method by varying the core thickness to study the damping effect on the beams for the cantilever boundary conditions.

The natural frequency of undamped specimen is higher as compared to damped specimens which suggest damping in the form of VEM helps in reduction of vibration. The results obtained from the modal analysis clearly shows that with increase in the thickness of the core layer there is a decrease in the natural frequency for the same mode except in some cases which may be due to improper meshing, incorrect mounting of specimen into the vice etc. From the results one can infer that damping characteristics for neoprene viscoelastic material has significant effect when compared with the rubber viscoelastic material. Finally the frequency responses of modeled sandwich beams have been plotted for the cantilever boundary conditions. Results show that the viscoelastic constrained layer damping has a great significance in controlling the vibration of structures like beams, etc.

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