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Nvh characterization of composite material for commercial vehicle frame components

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ABSTRACT

Noise and vibration is one of the important considerations in development of vehicle. This paper discusses NVH (Noise Vibration and Harshness) characterization of composite material for vehicle parts. Carbon composites are gaining popularity over sheet metal due to its high strength, damping and low mass density, although they are relatively costlier. Moreover their properties can be controlled by tuning fiber orientation angle, layer thickness and material composition. Vehicle parts as front cage are evaluated for their modal and dynamic response. Simulation is carried out using 2D PCOMP element of HYPERMEH and NASTRAN. Model is divided in to finite zones based on similarity in number of layers and fiber orientation angle. Predicted modal and dynamic responses are validated with experimental results in free- free boundary condition. CAE (Computer Aided Engineering) results show good correlation with that of experimental results. Composite material shows nearly 50% weights saving in component weight.

Keywords— **front cage, carbon composite, experimental modal analysis, zone based composite modeling**

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I. INTRODUCTION

The development in technology demands engineering design field to be competitive and creative to meet the challenging competition. Nowadays, careful attention in meeting precision, ecofriendly products and modularity in designing are gaining importance. Transportation is identified as the major sector contributor to the accidents and the CO2 emissions. The greatest challenge faced by the automotive industry has been to provide safer vehicles with high fuel efficiency at competitive cost. Composite materials are gaining popularity in industries due to its high strength, stiffness, damping and low mass density over existing sheet metals, although they are costlier. Noise and vibration is one of the important considerations in development of vehicle. Amplitude of vibration is high at resonant frequencies, as two or more parts vibrate at same frequencies resulting into annoying noise and vibration. To avoid resonance one should know resonant natural frequencies of all mating parts [7]. Noise Vibration and Harshness (NVH) is the branch of science that deals with the noise and vibration refinement. NVH plays an important role in comfort level and safety of any vehicle. NVH performance of any component can be estimated by modal analysis to evaluate NVH parameters.

Composite materials are use in automobile and aerospace industry due to its light weight and good energy absorption capacity. Simple replacement of composite parts by composite material leads to problem with new manufacturing techniques, component design and assembly. Change from homogeneous isotropic steel alloys to inhomogeneous orthotropic fiber reinforced composite causes those problems, as a result restrict use of composite in automobile [1, 2]. It has been observed that, during working of composite components, micromechanical damages, delamination and fiber pullout are highly depend on fiber orientation angle. Selection of design parameters as fiber length, fiber orientation angle and lamination thickness have effect on natural resonant frequency and modal damping [5].

Finite Element Analysis being the practical application of the finite element method (FEM) is used by engineers and scientist to mathematically model and numerically solve very complex structural, fluid, and multi physics problems scenario. Computational tools are used when experimental study becomes complex and expensive. Computational tools of FEA helps in saving cost and time in studying economic design and enable alternative study on various materials and its properties under varying loads [9]. So Finite Element Analysis is considered for analysis in this work.

Front cage is experimentally tested for its modal and dynamic response to predict modal parameters. Simulation is carried out using 2D PCOMP element of HYPERMEH and NASTRAN. Model is divided in to finite zones based on similarity in number of layers and fiber orientation angle. Simulated modal and dynamic responses will be compared with experimental results in free- free boundary condition.

Nomenclature

E_{11}	Longitudinal modulus	E_f	Modulus of elasticity for fiber
E_{22}	Transverse modulus	V_f	Volume by percent of fiber
σ_{11}	Longitudinal tensile stress for composite	Em	Modulus of elasticity for matrix
σ_f	Longitudinal tensile stress for fiber	Vm	Volume by percent of matrix
σ_m	Longitudinal tensile stress for matrix	μ_f	Poisons ratio for fiber
μ_{12}	Poisons ratio for composite	μ_m	Poisons ratio for matrix

II. COMPOSITE MATERIAL

Composite materials are made from two or more constituent materials (matrix and reinforcement) with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. Mostly fibers are used as the reinforcing phase and are much stronger than the matrix and the matrix is used to hold the fibers intact. Examples of such composites are an aluminums matrix embedded with boron fibers and an epoxy matrix embedded with glass or carbon fibers. As composites are multi-layered, they are much stronger and break resistant than single layer sheet metals.

A. Fabrication Process

The reinforcing and the matrix elements undergo a molding method, in which these materials are combined and compacted. There are various types of molding methods, including autoclave molding, vacuum bag molding, and resin transfer molding, among others. In automobile engineering, tooling materials used for the manufacture of composites include invar, aluminum, carbon fiber, steel and reinforced silicon rubber. Here UD HM CFRP (Uni-Directional High module Carbon Fiber Reinforced Polymer) material with injection molding process has been selected for front cage.

B. Fundamental Property Relationship

The physical properties of composite materials are orthotropic. When a unidirectional continuous-fiber lamina or laminate is loaded in a direction parallel to its fibers (0°) the longitudinal modulus can be estimated from its constituent properties by using the rule of mixtures:

= + (1)

The longitudinal tensile strength also can be estimated by the rule of mixtures:

= + (2)

When the lamina is loaded in the transverse (90° or 22-direction), the fibers and the matrix functions in series, with both are carrying the same load. The transverse modulus of

elasticity is given as:

(3)

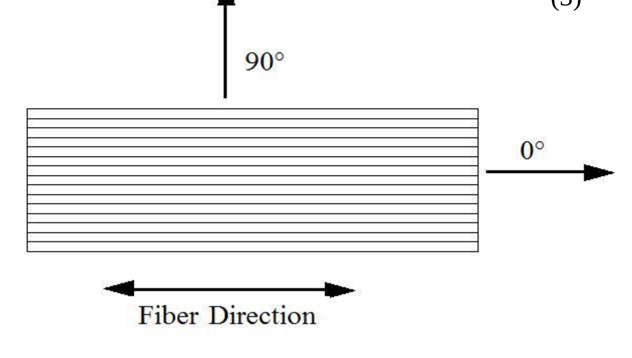


Fig. 1: Unidirectional continuous-fiber lamina or laminate

Poisons ratio can be found out by following equation 4

= + (4)

While these micromechanics equations do not yield sufficiently accurate values for design purposes and are useful for a first estimation of lamina properties when no data are available. For design purposes, basic lamina and laminate properties should be determined using actual mechanical property testing.

C. Composite Over Traditional Material

The physical characteristics of composites and metals are significantly different. Table 1 compares some properties of composites and metals. Because composites are highly anisotropic, their in-plane strength and stiffness are usually high and directionally variable, depending on the orientation of the reinforcing fibers. Properties that do not benefit from this reinforcement are comparatively low in strength and stiffness. Metals typically have reasonable ductility, continuing to elongate or compress considerably when they reach a certain load (through yielding) without picking up more loads and without failure. Because of this ductility, metals have a great capacity to provide relief from stress concentrations when statically loaded also it provides great energy-absorbing capability. As a result, when impacted, a metal structure typically deforms but does not actually fracture. In contrast, composites are relatively brittle.

TABLE 1
COMPARISON BETWEEN METAL AND COMPOSITE

Condition	Composite	Metal
Load-strain relationship	More	Less
Static Notch sensitivity	High	Low
Fatigue Notch sensitivity	Low	High
Transverse properties	Weak	Strong
Mechanical properties	Higher	Lower
Fatigue strength	Higher	Lower
Hydrothermal Sensitivity	High	Low
Sensitivity to corrosion	Much less	High

III. MODAL ANALYSIS

Modal analysis is the field of measuring and analyzing dynamic response of the structure or fluid under vibration. The usual first step in performing a dynamic analysis is determining the undamped natural frequencies and mode shapes of the structure. These results characterize the basic dynamic behavior of the structure to loading. Natural frequencies and mode shapes are functions of the structural properties and boundary conditions.

A. Experimental Modal Analysis

The purpose of performing test based modal analysis on a

component is to find its natural resonant frequencies and mode shapes for free-free boundary condition. Front cage geometry is assumed to be symmetric and maintained during the free-free boundary conditions. Front cage is excited with a known input and the output is measured at multiple locations. The Frequency response function (FRF) is obtained as the ratio of the Fast Fourier Transformation of Response/Excitation. An accelerometer measures the response at several points on the front cage and a dynamic signal analyser computes the FRFs. Frequency response functions are properties of linear dynamic systems and independent of the excitation function.

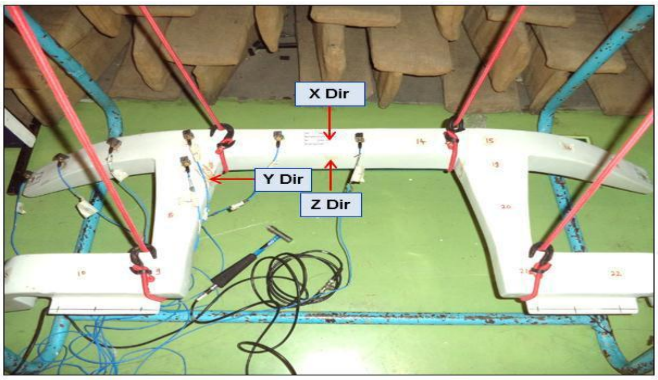


Fig. 2: Experimental test set-up for front cage

Fig. 2 shows experimental setup for front cage. It is suspended horizontally using the four elastic (bungee) cables. Multichannel Data Acquisition system is connected to a six tri-axial accelerometers. Component is excited by Hammer in X, Y, Z direction on twenty five measurement points. Mode shapes will be accurate, smooth and clear if more measurement points are considered. Hammer rresponse obtained from accelerometers are sends to LMS SCADA digital signal analyzer and FRFs are stabilized by stabilization techniques. Each peak in stabilization diagram is related to single mode of vibration with some resonant frequency value.

Red curve in the Fig. 3 is response of front cage in frequency domain. Frequencies corresponding to peaks in the curve are the natural frequency. Green curve shows the amplitude of vibration of a particular mode corresponding to that natural frequency. Total eleven resonance frequencies observed in experimental measurements. Table 2 shows frequencies, mode shape description and modal damping for first six modes excluding rigid body modes.

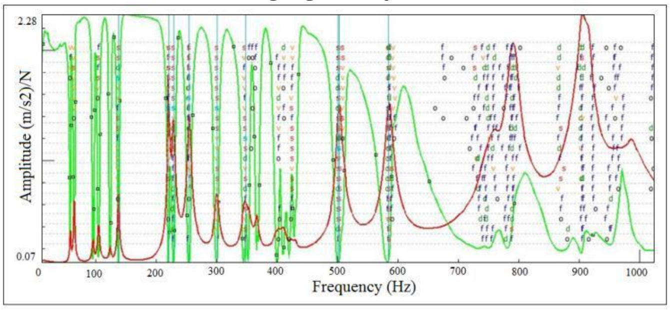


Fig.3: Stability index diagram for front cage

TABLE 2
RESONANCE FREQUENCIES AND MODAL DAMPING RATIOS FOR FRONT CAGE

Frequency [Hz]	Mode Shape	Damping [%]
67.53	Vertical bending mode	1.10
94.739	Torsional mode	1.02
123.23	longitudinal bending mode	1.03
228.3	Lateral bending mode	1.04
254.2	Second longitudinal mode	1.02
300.3	Second vertical bending	0.94

B. FEA Model Building and Simulation

Modelling of composite involves surface modeling and meshing. Composite part is not as simple as isotropic sheet metal, it consist of many layers with variable thickness. Composites are either orthotropic or anisotropic. Part is divided into finite zones with similar number of plies and ply properties.

Simple CAD model is prepared in CATIA V5. CAD model contains only surface geometry, no any data about type of material, property and composite laminate (layer) details. This CAD model (.igs) is then imported in HYPERMESH 13. Then model is mesh with 2D 1st order elements, quad and triangle. Model is divided in eight zones based on composite layers for front cage as given in table 3.

TABLE 3
LAYER WITH ZONES FOR FRONT CAGE

Zone	1	2	3	4	5	6	7	8
Front cage	8	13	12	25	7	38	8	2

Each zone is having some specific number of layers, layer sequence, layer thickness, fiber orientation angle, element normal and material orientation vector. Material orientation is very important in composite modeling. It orients modulus of elasticity for fiber in that particular direction. Fig. 4 shows front cage model with zone details.

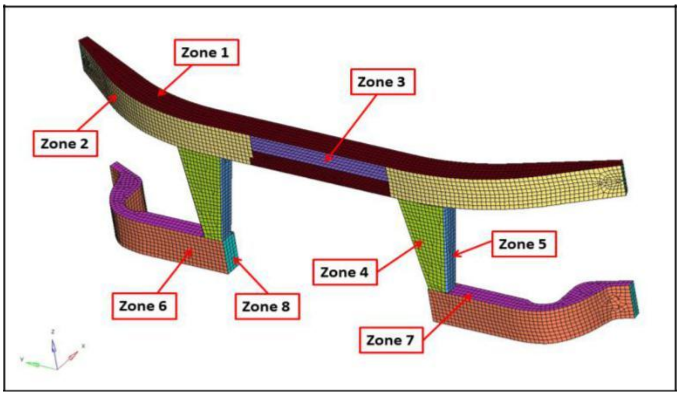


Fig.4: Front cage model with zone

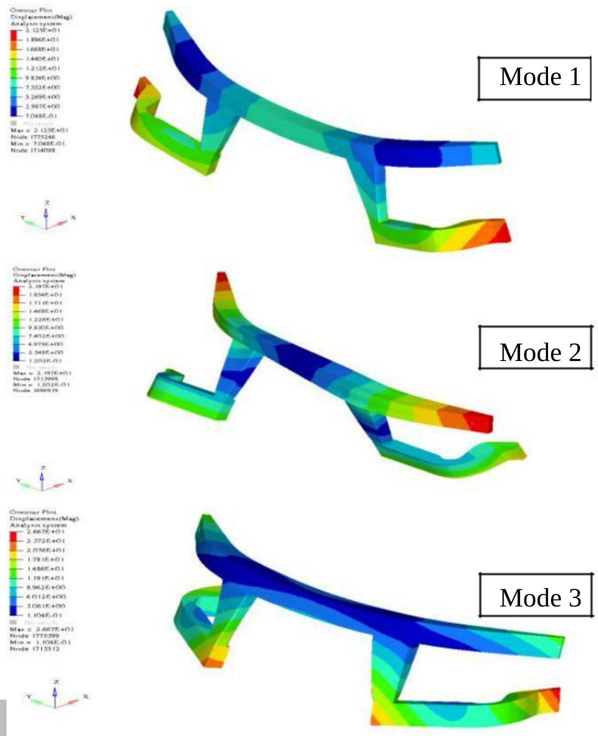
TABLE 4
PROPERTY DETAILS FOR FRONT CAGE

Properties	
Material Card	MAT8
Property Card	PCOMP
Modulus of Elasticity for Matrix (E_1)	30E3 N/mm^2
Modulus of Elasticity for Fiber (E_2)	400E3 N/mm^2
Poison's Ratio (μ_{12})	0.02
Mass Density (ρ)	3.2E-9 Tones/mm^3
Layers thickness	
t_1	0.25mm
t_2	0.15mm
t3	0.3mm
Fiber orientation angles	
θ_1	45°
θ_2	-45°
θ_3	0°
Front cage mass	9.201 kg

Meshed model is then export with (.bdf) file format and solved for FEA modal and dynamic response analysis in NASTRAN over the frequency range of 0 Hz to 1000 Hz, result files are seen in HYPERVIEW (.op2). First six modes are considered for study. Fig. 5 shows mode shapes and table 5 gives modal frequency and mode shape description.

TABLE 5
RESONANCE FREQUENCIES AND MODE SHAPES FOR FRONT CAGE

Mode	Frequency(Hz)	Mode Shape
1	71.70	Vertical bending mode
2	84.63	Torsional mode
3	132.9	longitudinal bending mode
4	187.5	Lateral bending mode
5	256.2	Second longitudinal mode
6	286.3	Second vertical bending



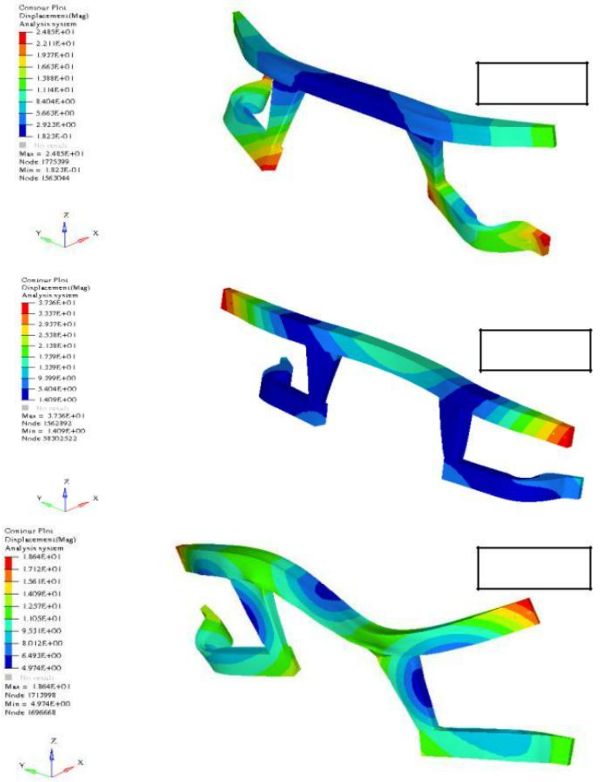


Fig.5: Front cage mode shapes

IV. CONCLUSION

The comparison between simulated and experimental results shows that FEM models are well suited for calculating the frequencies and modes of different composite parts. The maximum frequency difference of 5% is obtained at first (67.53 Hz) and the fifth (254.2 Hz) mode and less than 10% for the modes two, three and six. Maximum frequency difference 17.8% obtained at fourth mode (228.3 Hz) for front cage as shown in Fig 6. The results of the equivalent model presented in this analysis are obtained with good accuracy which presents an efficient approach during the development of the composite parts leading into the reduction of the cost and the time of analysis.

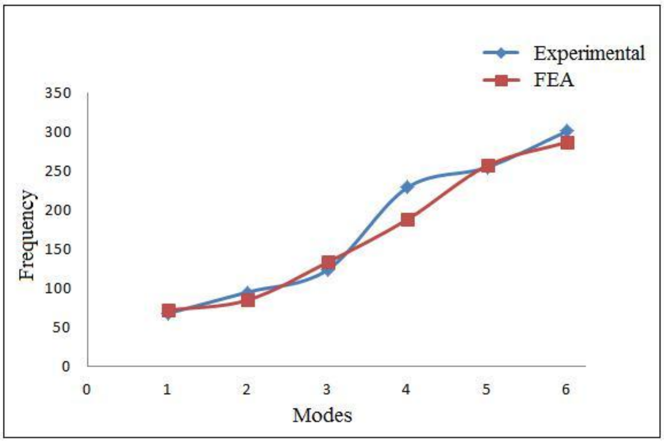


Fig. 6: Experimental and FEA modes for front cage

The present research work can be evaluated to analyze NVH performance for composite front cage.

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