

# An Experimental and Numerical Approach to Free Vibration Analysis of Glass/Epoxy Laminated Composite Plates

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**Abstract** - The present study involves extensive experimental work to investigate the free vibration analysis of Glass/Epoxy composite plates. The plates are prepared in the laboratory using vacuum bag technique with bi-woven glass fibers as reinforcement and general type epoxy as a matrix. An experimental investigation is carried out using modal analysis technique with Fast Fourier Transform Analyzer, MEscape software, impact hammer and contact accelerometer to obtain the Frequency Response Functions like natural frequency, mode shapes and modal damping for three different boundary conditions that is free-free, one end fixed and both ends fixed. Also, this experiment is used to validate the results obtained from FEA using ANSYS software. From both the results, the effects of boundary conditions on different modal parameters including natural frequency, mode shapes and modal damping of woven glass fiber composite laminated plates are studied in details. This study may provide valuable information for researchers and engineers in design applications.

**Keywords**- Bi-woven composite, Frequency Response Function, Modal Analysis, Finite Element Method.

## I. INTRODUCTION

Literature review is focused on the different types of analysis of composite materials[1]. Due to the requirement of high performance of materials in aerospace and marine structures, the prospect of future research of composite materials, such as FRP is very bright. Composite materials are manufactured from two or more materials to take advantage of desirable characteristics of components. A composite material, in mechanical in the sense is a structure with an ingredients as element transforming forces to adjacent members.

Glass-resin forced plastics (GRP) is a composite material made of plastic (resin) matrix reinforced by fine fibers made of glass [2]. GRP is a light weight, strong material with very many uses including boats, automobiles, roofing and water tanks. By laying the multiple layers of fiber on top of one another with each layer oriented (staking) is various preferred directions, the stiffness and strength properties of the overall material can be controlled in an efficient manner [3]. With woven fabrics or bidirectional layers, directionality of stiffness and strength [4] can be more precisely controlled within the plane. The extensive review on plate vibration can be found in the literature provided by Leissa [5] provided some review on thick plate vibration problems.

To better understand any structural vibration problem, the resonant frequencies of a structure need to be identified and quantified. Today due to the advancement in computer aided data acquisition systems and instrumentation, experimental modal Analysis has become an extremely important tool in the hands of an experimentalist [6,7]. A number of researchers have been developed numerous solution methods to analysis the dynamic behaviour of laminated composite laminates. However experimental investigations on woven fabric composite laminated structures are still limited. The affects of different parameters on natural frequency is important analysis [8].

This work presents an experimental study of modal testing of woven fiber Glass/Epoxy laminated composite plates using FFT analyzer. The main objective of this work is to contribute for a better understanding of the dynamic behavior of components made from industry driven woven fiber composite materials, specifically for the case of plates. The effects of different modal parameters including natural frequency, mode shapes and modal damping of industry driven woven fiber composite plates in free-free, one end fixed and both ends fixed boundary conditions are studied in details.

### 1.1 Scope

The scope of the study includes the following:

1. Fabrication of bi-woven Glass/Epoxy composite laminated plates using vacuum bagging technique.
2. Experimental Modal analysis work carried out on FFT analyser.
3. Affecting parameters are different boundary conditions and manufacturing methods.

## II. METHODOLOGY

In the present study, it is necessary to develop a proper composite laminated plate fabrication method[10]. A variety of manufacturing methods can be used according to the end-item design requirement. The most commercially produced composites use a polymer matrix with textile reinforcements such as glass, aramid and carbon.

Vacuum bagging techniques have become popular in manufacturing of these composites. In this the same technique

is used to fabricate the Glass/Epoxy composite plates [11]. Proper experimental plan is necessary to achieve good results in conducting research. Simulation is carried out using ANSYS software. FRF results and simulation results are carried out.

## 2.1 Experimentation

### 2.1.1 Geometrical properties:

In choosing the type of specimens to construct and test, woven fibered glass composite plates are taken. Three types of plates are prepared for three different boundary conditions. The following are the geometrical properties of the plates.

TABLE 1: Geometrical properties of test specimen

Composite plate	Height (mm)	Width (mm)	Thickness (mm)
Glass /Epoxy	150	110	2

#### Specifications:

- No. of layers: 7
- Thickness of each layers: 0.3mm
- Thickness of plate: 2.1mm (approx.)
- Orientation: Bi-woven cloth (0/90)

### 2.1.2 Fabrication of E-Glass Epoxy Laminate Composites:

The resin serves as the matrix for the reinforcing glass fibers, much as concrete acts as the matrix for steel reinforcing rods. The percentage of fiber and matrix was 50:50 in weight. Glass fiber material consisting of extremely thin fibers about 0.005–0.010mm in diameter. The bi-woven cloths are available in the standard form of 0.3mm thickness. Bi-Woven cloths are cut to the required size & shape. These cloths are stacked layer by layer of about 07 layers to attain the thickness of 2.0mm. Bonding agent (epoxy resin) is applied to create bonding between 07 layers of sheet, in the ratio of 07:1. Epoxy is a copolymer; that is, it is formed from two different chemicals. These are referred to as the "resin" and the "hardener". The process of polymerization is called "curing", and can be controlled through temperature and choice of resin and hardener compounds; the process can take minutes to hours. Some formulations benefit from heating during the cure period, whereas others simply require time, and ambient temperatures. Process of vacuuming will be done to remove air traps exist between the layers [11]. Vacuuming & Room curing to be done about 3hrs. Post Curing is done after vacuuming & Room curing the material at a temperature of about 100°C up to 2hrs. After curing process the materials cut as per required standard shape and size.



Fig 1: Vacuum bagging process



Fig 2: Bi-Woven cloths of Glass fiber

### 2.1.3 Material Properties of Test Specimens

TABLE 2: Material Properties of Glass Plate

Properties	Value
Density( $\rho$ )	2.4 gm/cc
Ex	46.2 Gpa
Ey	14.7 Gpa
Ez	14.7 Gpa
Gxy	5.35 Gpa
Gyz	5.35 Gpa
Gxz	5.22 Gpa
vxy	0.31
vyz	0.31
vxz	0.41

## 2.2 Testing:

### 2.2.1 Test setup:

The plates are marked with 35 nodes taking 2.5\*2.5 cm square array as shown. The connections of data acquisition system, laptop, accelerometer(model 3032A), FFT analyzer(company-Data Physics, model-QUATRO), modal hammer(ENDEVCO model-2031) and cables to the system are done as per the guidance manual.

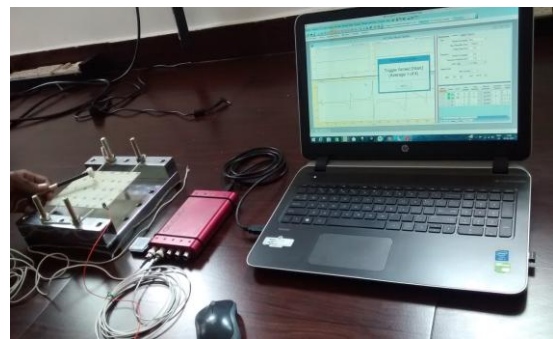


Fig 3 : Vibration testing of glass plate

### 2.2.2 Test procedure:

The plate was excited in a selected point by means of a small impact hammer (Model 2031), preferably at the free end. The input signals captured by a force transducer, fixed on the hammer. The resulting vibrations of the plate in a selected points are measured by an accelerometer. The accelerometer (DYTRAN, TYPE 3032A) was mounted on the plate to the free end by means of bees wax. The signal was then

subsequently input to the second channel of the analyzer, where its frequency spectrum was also obtained. The response point was kept fixed at a particular point and the location of excitation was varied throughout the plate. Both input and output signals are investigated by means of spectrum-analyzer and resulting frequency response functions are transmitted to a computer for modal parameter extraction.

The output from the analyzer was displayed on the analyzer screen by using MEScope VES software. Various forms of Frequency Response Functions (FRF) are directly measured. However, the present work represents only the natural frequencies and mode shape of plates. The spectrum analyzer provided facilities to record all the data displayed on the screen to a personal computer's hard disk or laptop and the necessary software. Normally in order to determine the natural frequencies of a system, recording the response spectrum for an excitation, where the excitation level is constant over the frequency band under consideration will sufficient. However, it was observed, from the auto-spectrum of the excitation force, that it was not possible to maintain such uniform excitation in case of composite plates. So, test should be within linear range.

### 2.3 Boundary conditions:

In the present study vibration analysis is done for three different boundary conditions like free-free, one end fixed and both ends fixed.

The following figures shows the three boundary conditions for glass plate

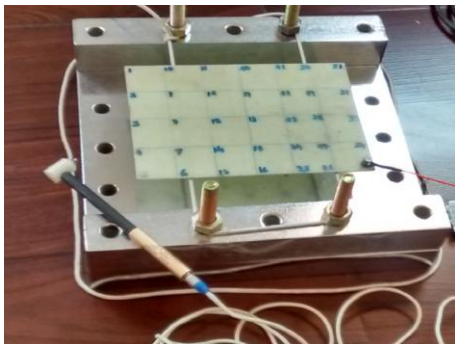


Fig 4: Free-Free condition

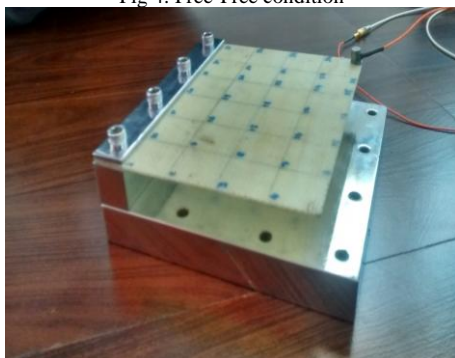


Fig 5: one end fixed condition

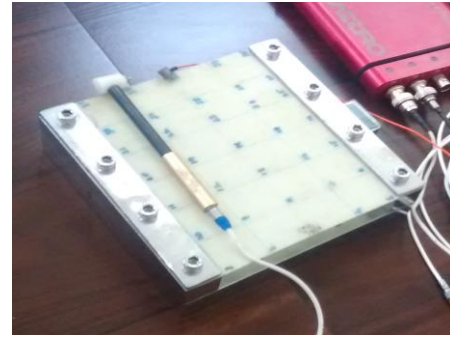


Fig 6: both ends fixed condition

### 2.4 Ansys FEA model:

FEA involves three stages of activity:

- Preprocessing,
- Processing and
- Post processing.

In this study modal analysis is done using ANSYS and to model the plates as linear layer SHELL99 element is used. To mesh the modal element edge length of 25 is used. The meshed modal is shown below

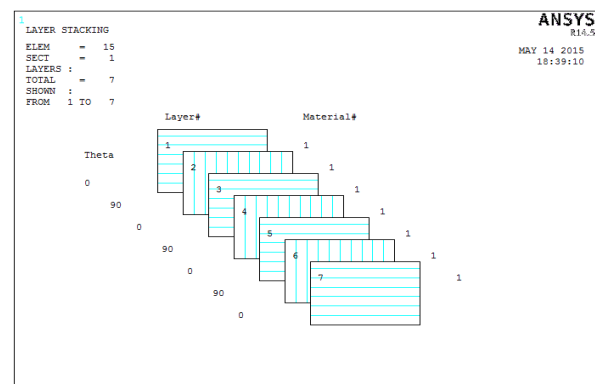


Fig 7: fiber orientation

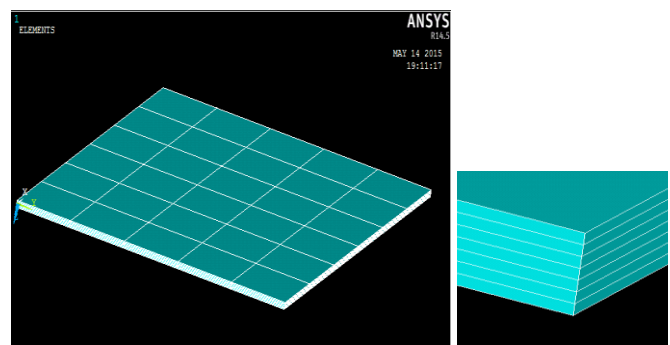


Fig 8: meshed modal and showing 7 layers

### III. DATA ANALYSIS

Table 3: Results obtained from experiment for glass plate at different boundary conditions

Boundary condition	Mode no.	Frequency Hz	Damping (%)
Free-Free condition	1	189	1.68
	2	349	0.439
	3	418	1.37
Cantilever condition	1	80	0.694
	2	134	1.2
	3	383	1.55
Both ends fixed condition	1	482	1.64
	2	539	0.861
	3	708	1.07

Table 4 comparison of experimental results with FEA

Boundary Condition	Mode no.	Experimental Hz	ANSYS Hz	% Error of Experiment with ANSYS
Free-Free condition	1	189	210.22	10.09
	2	349	363.72	4.07
	3	418	453.16	7.75
Cantilever condition	1	80	89.323	10.43
	2	134	149.88	10.59
	3	383	450.77	15.03
Both ends fixed condition	1	482	566.40	14.90
	2	539	603.92	10.74
	3	708	815.67	13.27

### IV. RESULTS AND DISCUSSION

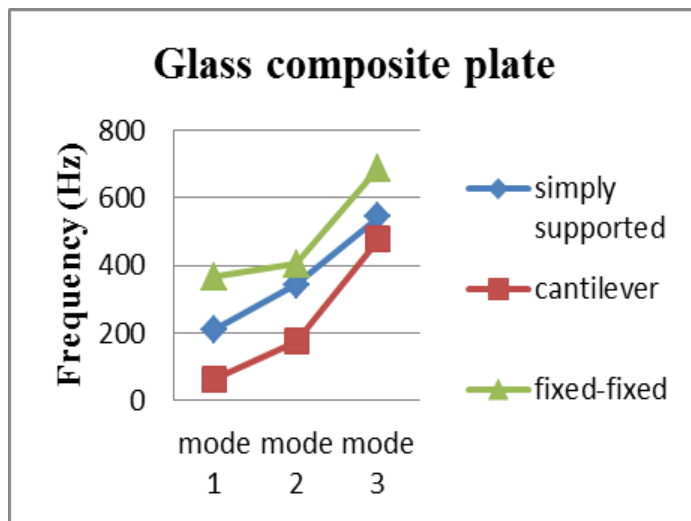


Fig 9: Effect of Mode No. on Natural frequency

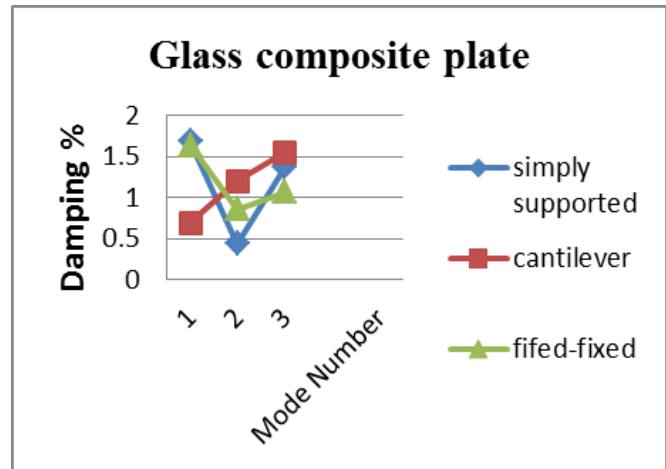


Fig 10: Effect of Mode No. on Damping ratio

From the above figure we came to know that natural frequency incises with increasing mode number and it is highest for both ends fixed condition followed by free-free boundary condition. The natural frequency is lowest for one end fixed glass plate.

The natural frequency from ANSYS with experimental results are compared. The program value is closely agree with the ANSYS value. Percentage error of experimental value and ANSYS value is within  $\pm 15\%$ . As the mode no increases, the percentage error between experimental value and programming value decreases.

Un-damped natural frequency is considered in the program and damping was present in the system. So, the natural frequency from the experiment should less than the actual value. But the difference between both the results is reasonable. The percentage of difference between numerical results and experimental results are due to non-uniformity in the specimen's properties (voids, variation in thickness, non uniform surface finish) and also positioning of the accelerometer.

Since we have taken rectangular pieces of specimen, elastic modulus may decrease than the exact value. So, natural frequency can be decreased.

### V. CONCLUSIONS

#### 5.1 Parametric study

Glass/Epoxy laminated composite plates are fabricated and modal testing is done for three different boundary conditions like free-free, one end fixed and both ends fixed conditions using data acquisition system. Frequency response functions are obtained by FFT. Quantitative results are presented to show the effect of different boundary conditions on modal parameters.

From different boundary conditions (free-free, one end fixed and both ends fixed), it is found that the natural frequency of fixed-fixed glass plate is high followed by free-free glass plate. Program results show clearly that changes in elastic properties yield to different dynamic behaviour of the plates. The natural frequency increases with the increase in mode number.

## Glass composite plate

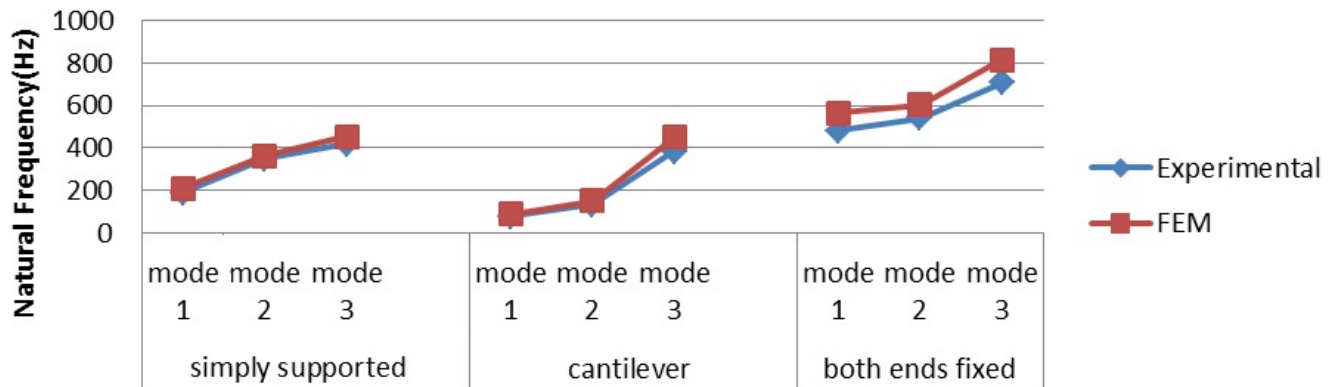


Fig 11: Experimental results vs results obtained from ANSYS for three boundary conditions.

The Natural frequency is lowest for the one end fixed glass plate. Damping ratio changes from mode to mode and as boundary condition changes damping ratio also varies. Also the natural frequency increases with increase in constraints.

### 5.2 Future scope

The present approach involving the effect of boundary conditions on natural frequency, mode shapes and modal damping. Manufacturing methods plays an important role in design part. We have to analyse the affect of different parameters like aspect ratio, fiber orientation, number of layers and volume fractions on the modal parameters.

## VI. ACKNOWLEDGMENT

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