Dynamic Response Analysis and Mechanical Properties of Composite Plate Having Different Orientation

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ABSTRACT

Now, fiber reinforced composite materials are gradually becoming more popular for several applications, either as components of complete technical systems, as complete structures or as structural elements. Their resistance to weight ratio is the main advantage of composite over metal components. The purpose of this study is to determine dynamic analysis and mechanical properties of the composite plate having different orientations (0 degree and 45 degree). In this experimental study, Epoxy/ E-Glass composite plate was first manufactured by pouring process. By using simple formulaeshear modulus, poison's ratio, andlongitudinal transverse Young Modulus were determined. The experiment was carried out on a FFT analyzer, which was built specifically to investigate dynamic characteristics of composite plate. The transverse &longitudinal vibrations were obtained experimentally. Inspection of the dynamic behavior of the composite beam for various end conditions is made by both experimental and theoretical analysis.The experiment was carried on Compression Testing Machine with different orientations and volume fraction.

KEYWORDS-COMPOSITE MATERIAL, FIBER ORIENTATION, STRENGTH OF COMPOSITE MATERIALS, VOLUME FRACTION,

1.INTRODUCTION

Rapid technological advances in engineering brought the engineers andscientists to a point, where they became limited by the capabilities of traditional materials. Scientist and Researchers in materials technology are constantly looking for solutions to provide durable andstronger materials which will answer the needs of their fellow engineers. The Composite materials are the most favored solutions to this problem in the field.Composite materials technology is providing compromising solutions and alternatives to many engineering fields by combining the stronger properties of traditional materials and eliminating the disadvantages they bear. Now a day Problems born from material limitations like structural strength,heavy weight. Many more alternatives are being introduced to readily use engineering applications.Composite materials are being used in many engineering applicationsDue to the high specific stiffness and strength. However, the mechanical properties of composite materials may degrade severely in the presence of damage. The Failures of structures, particularly aircraft structures, often have tragic consequences. So that, an especially very important issue to damage detection on-line. Common damage for composite materials isfiber breakage, matrix cracking, delamination between plies andfiber-matrix deboning. Delamination may be induced during in service loading, such as by foreign object by fatigue orimpact. Delamination may not be visible or barely visible on the surface, they are embedded within the composite structures. However, they may significantly reduce the strength and stiffness of the structures. Reduction in the stiffness will affect some design parameters such as the vibration characteristics of the structure (e.g. mode shape andnatural frequency). Delaminations reduce the natural frequency as a direct result of reduction of stiffness. It may cause resonance if the reduced frequency is close to the working frequency. Thereforeit is important to understand the influence of the vibration characteristics of the structures.

What is composite material?

Two or moreMaterials are combined on a macroscopic scale to form a useful third material is termed as composite material. Key is the macroscopic examination of a material wherein the components can be identified by the naked eye. The Different materials can be combined on a microscopic scale, such as in alloy of metals, but the resulting materials is, for all practical purposes, macroscopically homogeneous, i.e. essentially act together and the components cannot be distinguished by the naked eye. The constituents are combined at a macroscopic level. A composite is a structural material which consists of combining two or more Constituents. The reinforcing phase material may be in the form of flakes, particles, fibers. Composite constituents are combined at a macroscopic level and are suitable in each constituent is called reinforcing phase. The matrix phase materials are generally continuous. concrete reinforced with steel, epoxy reinforced graphite fibers are examples of composite system.The composite materials usually exhibitbest qualities of their components or constituents. The properties that can be improved by forming a composite material are:Strength,Corrosion resistance,fatigue life, acoustical insulation, thermal insulation,Wear resistance, Attractiveness,Stiffness,temperature dependent behavior, thermal conductivity, weight.

Examples of composites are as follows
1. Naturally found composites:
Bones: The matrixes made of minerals are reinforced with collagen fibers.
Wood-Lignin matrix reinforced with cellulose fibers.
2. Advanced composites: these are composite materials which are traditionally used in the aerospace industries.E.g. boron aluminum composites, Kevlar/epoxy and Graphite/epoxy

2.CLASSIFICATION OF COMPOSITE MATERIALS

Mostly accepted composite materials are:
2.1 Laminated composite materials
It consists of layers of at least two or more different materials that are bonded together. The Lamination is used to combine best aspects of the constituent layers and bonding material.E.g. Plastic based laminates,Bimetals, clad metals, laminated glass.

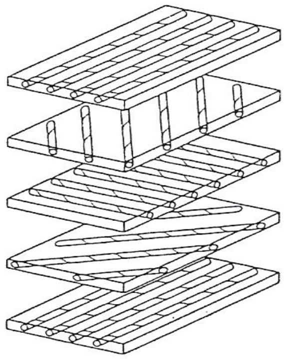

Fig 2.1 Unbonded view of laminate construction

2.2 Particulate composite materials
The particulate composite materialsconsist of particles of one or more materials suspended in matrix of another material. The Four possible combinations for them are as nonmetallic particles in Metallic particles in nonmetallic matrix, nonmetallic matrix,Metallic particles in metallic matrix andnonmetallic particles in metallic matrix,E.g. -Tungsten carbide in cobalt matrix,Concrete.According to the particular application, the need for fiber placement in different directions has led to various types of composites as shown in Figure.

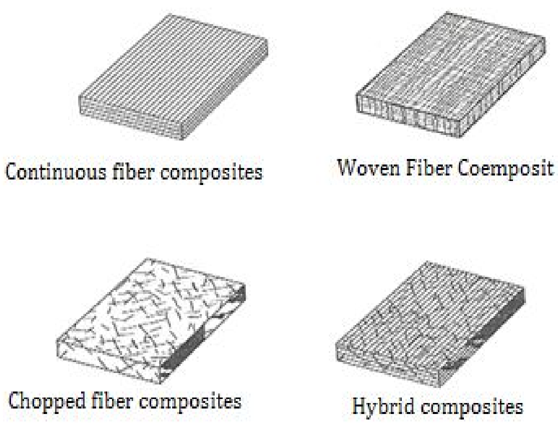

Fig 2.2: Types of fiber-reinforced composites

2.3 Fibrous composite materials
It consists of fiber reinforced matrix. They can be further classified as,Ceramics matrix composites, Carbon- carbon composites, Polymer matrix composites, Metal matrix composites.e.g. Graphite epoxy, carbon reinforced aluminium composites, and Glass epoxy.

3. STRENGTH OF COMPOSITE MATERIALS

To select the composite materials for various applications such as,space vehicles, aircraft, automotive, the factors that might be generally considered first & for most are stiffness and strength. Out of these we consider strength of composite material which mainly depends upon Fiber volume fraction & Fiber orientation.

3.1 The Effect on Strength of Fiber Orientation
A tensile strength of a unidirectional composite loaded at an angle to the fiber direction related to the transverse and longitudinaltensile strengths (σ_m and σ_t) and in plane shear strength.For compressive loading the effect of fiber orientation follows a similar pattern, the strength and failure mode being governed by the longitudinal and transverse compressive strengths and the shear strength.The failure mode, and hence the controlling strength parameter, depends on the angle between the fiber and loading axes.This description of the effect of fiber orientation is based on the theory of maximum principal stresses which makes the reasonable assumption that failure in any one mode is not influenced by the magnitude of the stress in any other mode. The corresponding theory of maximum principal strains, which is based on similar assumptions concerning the independence of principal strains, results in slightly different curves due to Poisson's ratio effects. Both of these theories have the advantage of simplicity, but they indicate abrupt changes in the relationship between fiber orientationand strength at the points of transition between failure modes. The failed specimens corresponding to the transition points exhibit features of both modes suggesting that they are not entirely independent. Moreover, since a single continuous curve is generally preferred for analysis and computation, a variety of interaction theories have been proposed. Most of these theories are modifications of the various yield criteria developed for homogeneous materials and are therefore used purely empirically.

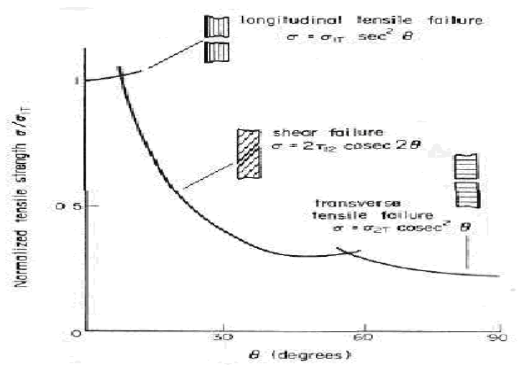

Fig 3.1. Tensile Strength Vs Fiber Orientation

3.2 Fiber volume fraction
Fiber volume fraction indicatesthe fraction of total volume of composite material occupied by fibers.Consider a composite consisting of fiber and matrix.

$$\text{Fiber volume fraction } (V_f) = \frac{\text{volume of fibers}}{\text{total volume of composite material}}$$

Take the following symbol /-notations:
v_c, v_f, v_m= volume of composite, fiber, and matrix

Let, the matrix volume fractionV_m andfiber volume fraction V_f as,

$$V_f = v_f/v_c \qquad (1)$$

$$V_m = v_m/v_c \qquad (2)$$

Note that of volume fractions is

$$V_f+V_m = 1 \qquad (3)$$

And also…..............

$$v_f+v_m = v_c \qquad (4)$$

3.3 Variation of Strength with Fiber Volume Fraction

1. Longitudinal tensile strength increase with increase in fiber volume fraction.
2. Compressive strength varies in direct proportion to fiber volume fraction.
3. Longitudinal compressive strength increases initially with fiber volume fraction and then decreases for further increase in fiber volume fraction. As shown in following graph.
4. shear strength and Transverse tensileshow slight increase with fiber volume fraction.

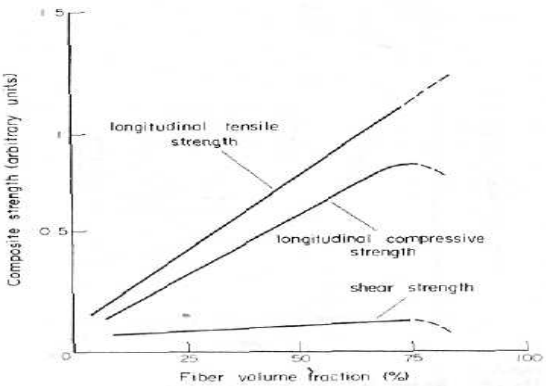

Fig 3.2 Effect of fiber volume fraction on strength

3.4 Fiber orientation

The angle made by fibers with loading axis is known as Orientation. When all fibers are oriented in same direction gives high strength and stiffness in that direction.The properties of fiber composite are but weak in shear parallel to the fibers,the properties of the matrix, and very weak indeed in tension perpendicular to the fibers. The fibers may be randomly arranged in a plane or in three dimensions, such arrangementslimit the obtainable fiber packing density. The stiffness and strength of a composite buildup dependson the orientation sequence of the plies. The practical rangeof stiffness and strength of carbon fiber extends from valuesas low as those provided by fiberglass to as high as thoseprovided by titanium. This range of values is determinedby the orientation of the plies to the applied load.The fibers in a unidirectional material run in one directionand the stiffnessand strength is only in the direction of thefiber. A plain weave fabric is an example of a bidirectional ply orientation. The fibers in a bidirectional material run in two directions,typically 90° apart. These ply orientations have strength in both directions but not necessarily the samestrength.

4. MATERIAL PROPERTIES

Table 3.1Material properties of composite

Material	Properties	Symbol	Value
Glass fibers	Elastic modulus	E_f	51.05589e6 (N/m^2)
	Density	ρ_f	1095.26 (kg/m^3)
	Poisson's ratio	v_f	0.25
Epoxy resin	Elastic modulus	E_m	2.5702e9 (N/m^2)
	Density	ρ_m	273.35 (kg/m^3)
	Poisson's ratio	v_m	0.38

Simple Calculation to obtain Volume Fraction:
1) For 0^0
V_F = Volume Fraction
v_F= Volume of fibers
v_C= Volume of Composite
$V_F = v_F/v_C$

$$\mathrm{Vf} = \frac{(\pi \ x \ d^2 x \ No.of \ fibers) \ x \ L}{\mathrm{l} \times \mathrm{b} \times \mathrm{t}}$$

Dimension of plate,
d= diameter of fiber= 3mm
No of Fibers= 24
Length of fiber = 160mm

2) For 45^0

$$\mathrm{V_f} = \frac{\mathrm{VF1 + VF2 + VF3 + \ldots\ldots}}{\mathrm{l \times b \times t}}$$

d= diameter of fiber= 3mm
No of Fibers = 17
Length of fiber = 160mm
From above formulae we obtained volume fraction 5% and 10%.

5. FABRICATION

For preparation of Model procedure is divided in to three major parts:
1. Mould preparation
2. Casting

1. Mould preparation:

1. Mould is prepared from transparent sheet of acrylic. The acrylic sheet is having thickness 4mm.
2. The acrylic sheet is cut at required dimension as 160mm×160mm×20mm.
3. The equispaced holes of diameter 3mm are drilled on both sides of the sheet.
4. The entire assembly of transparent sheet is stick to each other using fevistick. Upper side of the mould is open for pouring the mixture.
5. The plastic clay or wax is applied to outer surface of the mould to make joints airtight and leak proof.
6. All the moulds were cleaned with carbon-tetrachloride which acts as a releasing agent. It avoids chemical reaction.
7. The glass fiber stings were tightened in holes drilled in spacer.
8. Thus mould is to be prepared.

Fig 5.1 Acrylic Moulds with woven glass fiber

2. Casting

a) Solution Preparation

1. In the solution preparation 100 parts of araldite mixed with 10 parts of hardener by weight is used.
2. This solution is kept in the oven at 75°c for one hour to remove air bubble and moisture.
3. The hot solution is kept in air for 4 hours for cooling.
4. The araldite and hardener is mixed with each other.
5. During mixing the mixture is stirred in one direction for 15 min. for proper and through mixing. Now the mixture is ready to pouring to mould.

b) pouring

1. The mixture is poured into the mould very cautiously to avoid formation of air bubble.
2. At the time of pouring precaution was taken so that fibers will not stick to each other. The mould was continuously tapped to remove air bubble.The mould is completely filled with mixture as shown in the fig.
3. At this position, the mould is kept for curing at room temperature. For easy removal of sheet from the mould the curing time of 16 to 18 hours is sufficient.
4. It is kept on the perfect flat plate for further curing. The total curing time is about 24 hours as shown in the fig 4.4

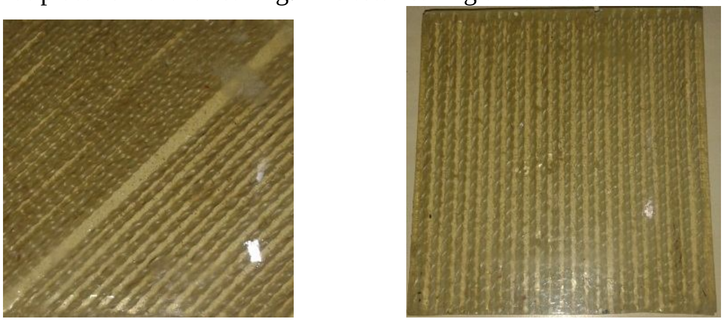

Fig 5.2completely poured mould

6. EXPERIMENTAL MODEL ANALYSIS

6.1 Experimental set up

The FRFs(Frequency Response Function) was determined Through an impact experimental test, which relate the response given by the specimen when loaded with a signal, allowing for the determination of the natural frequencies as shown in Fig 5.1. This was done by fixing the laminate specimen in a different support conditions namely,

1. Free free
2. Cantilever

The input load (pulse) is given to the specimen with The impact hammer (3). The Spectral Analyzer was set from 0 Hz to 2000 Hz. The output was captured by the accelerometer (2) and together with input sign were amplified (4) using the spectrum,

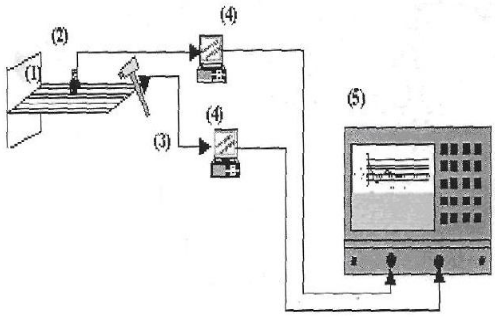

Fig 6.1: Experimental set up

The Analyzer BRUEL&KJAER (B&K) (5), giving the FRF known as accelerance that is given by the acceleration/force relationship.It was investigated the most attractive points to excite (input) and to get response (output) in the specimens. It wasSelectedthe points 1 (input), 2 and 3 (output) for the determination of two KRFs (H21 e H31)Due to their high flexibility. Since the specimens are lightand very flexibility, to avoid undesirable influences on the measurementspecial care should be given to choose the accelerometer.

6.2. Measurement Preparations

Pre-preparation are very important to ensure that the measurement will be as satisfactory. How well the pre-preparation done will definitely determine the betterment of the expected data in experiment. These are significance checks that have been done:

1. Identification of experimental model
2. Position of the Accelerometer on the Plate
3. Point of Excitation
4. The marked point on the plate sample
5. Measuring method

7. EXPERIMENTAL RESULTS

a) Free-free condition

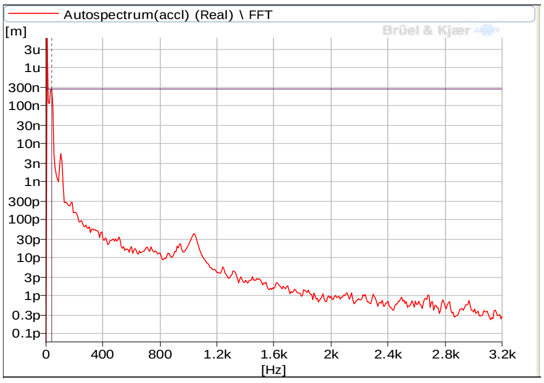

Fig 7.1 - 0 deg single ply (5% volume fraction) free free Condition

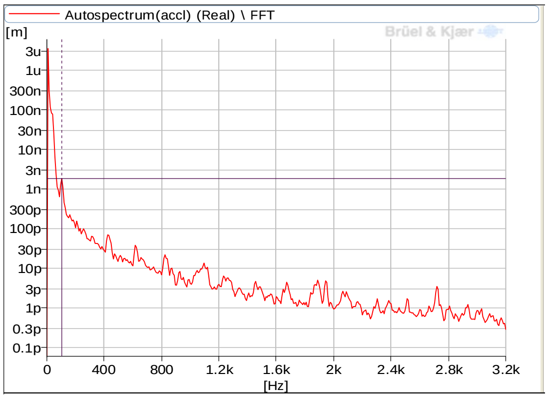

Fig 7.2 - 0 deg Double plies (10 % volume fraction)free free Condition

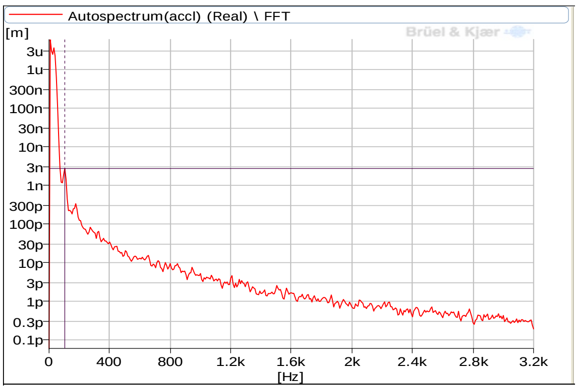

Fig 7.3- 45 deg Single ply (5% volume fraction) free free Condition

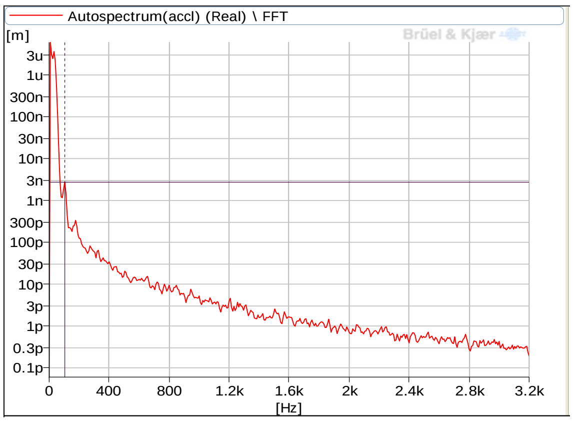

Fig 7.4 - 45 deg Double plies (10 % volume fraction)free free Condition

Free-free condition at point 1

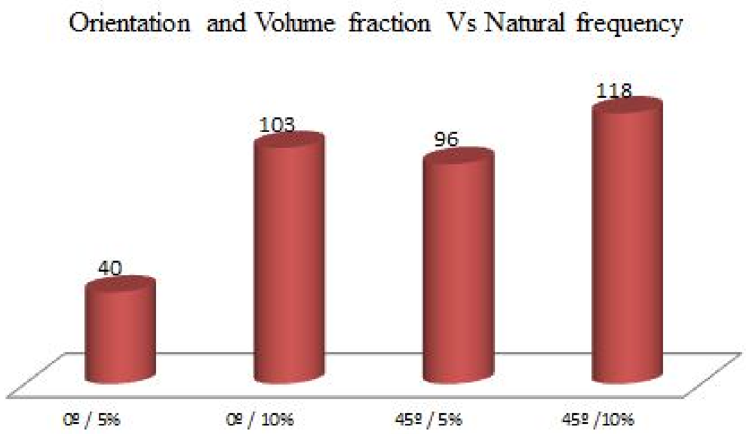

Fig 7.5 Orientation and volume fraction Vs Natural Frequency.

Table 7.1 Orientation and volume fraction Vs Natural Frequency

Orientation and Volume fraction	ω_1 (Hz)
0º / 5%	40
0º / 10%	103
45º / 5%	96
45º /10%	118

There is no major variations in reading that we saw in free free conditions.
Natural frequency increases with increase in volume fraction and for 45º orientation volume fraction is increases with increase in natural frequency as compared to 0º orientation.

b) Cantilever Condition

Fig 7.6 - 0 deg Single ply(5% volume fraction) Cantilever Condition

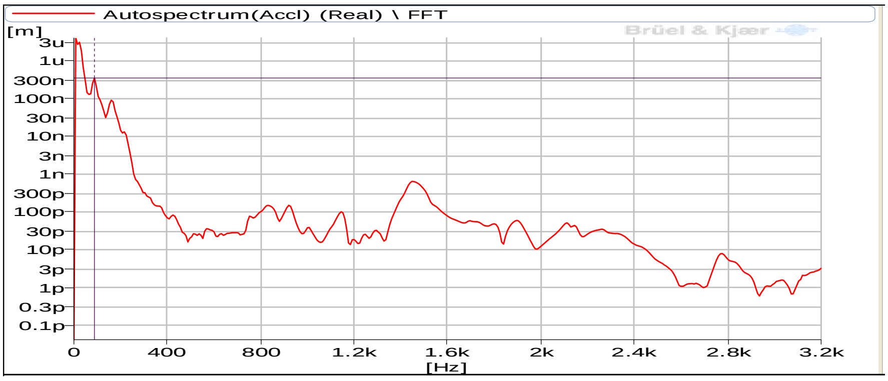

Fig 7.7 - 0 deg Double plies(10 % volume fraction) Cantilever Condition

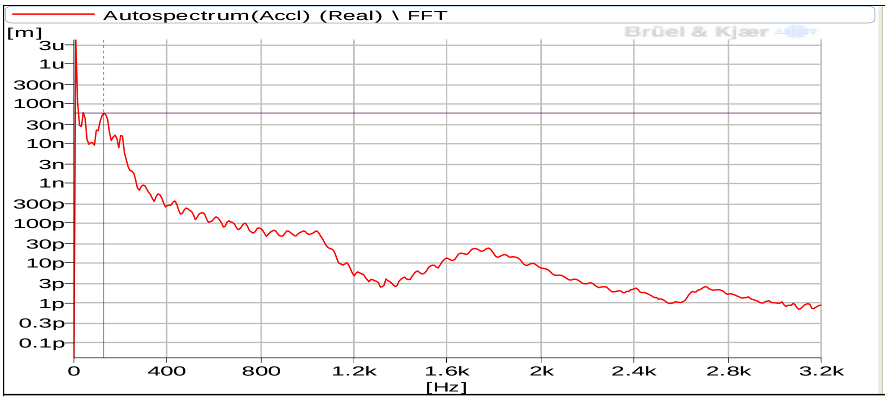

Fig 7.8 - 45 deg Single ply(5 % volume fraction) Cantilever Condition

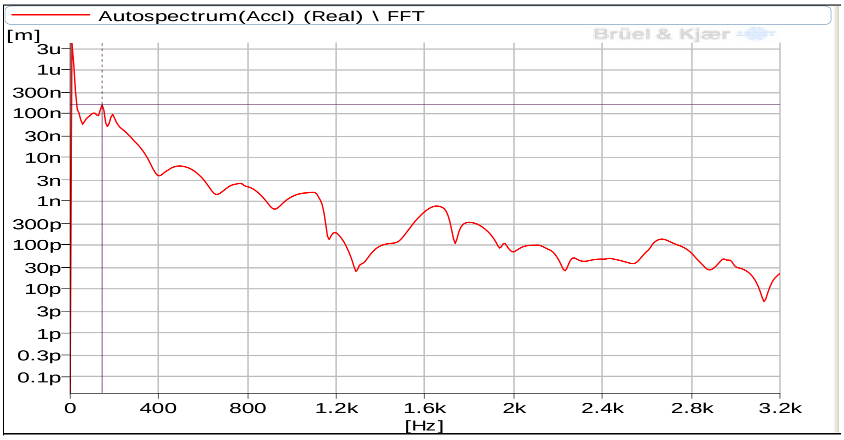

Fig 7.9 - 45 deg Double plies(10 % volume fraction) Cantilever Condition

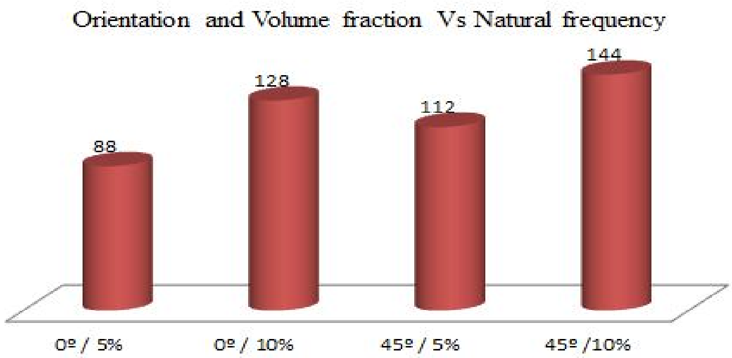

Fig 7.10 Orientation and volume fraction Vs Natural Frequency

Table 7.2 Orientation and Volume fraction Vs Natural frequency

Orientation and Volume fraction	ω_1 (Hz)
0º / 5%	88
0º / 10%	128
45º / 5%	112
45º /10%	144

Natural frequency increases with increase in volume fraction and for 45º orientation volume fraction is increases with increase in natural frequency as compared to 0º orientation.
Dimension of composite specimen
Height - 160mmWidth - 30mm
Thickness - 20mmTotal Area – 600mm^2

Table 7.3 Orientation and Volume fraction

Sr No	Orientation and Volume fraction	Max Load(KN)	KN/mm^2
1	0º / 5%	32.2	18.6
2	0º / 10%	25.0	24
3	45º / 5%	16.4	36.58
4	45º /10%	12.5	48

Longitudinal compressive strength increases with fiber volume fraction and then decreases for further increase in fiber volume fraction. Here we see that we get maximum compression stress at 10% volume fraction and 45º fiber orientation.

8.CONCLUSION

1. From table 7.1 it is observed that the natural frequency increases with increase in volume fraction and for 45º orientation volume fraction is increases with increase in natural frequency as compared to 0º orientation
2. In Cantilever condition Natural frequency increases with increase in volume fraction and for 45º orientation natural frequency is more as compared to 0º orientation.
3. Longitudinal compressive strength increases with fiber volume fraction and then decreases for further increase in fiber volume fraction. The maximum compression stress at 10% volume fraction and 45º fiber orientation. the compressive strength varies with different load conditions and to the direction of fiber.
4. Today, a major challenge relating to composite design is the lack of general composite material characterization and availability of simulation tools. The commercial software developers have not yet solved this problem. Current composite material models within commercial design software require very long solution times. Another essential requirement is the development of the tools required for product design, simulation, manufacturing and regulation.

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