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# Dynamic Response Analysis of Fiber Reinforced Composite Beam

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***ABSTRACT:*** *Fiber reinforced composite materials are gradually becoming more popular for several applications, either as components of elaborate technical systems, as structural elements or even as complete structures. Their main advantage over metal components is their resistance to weight ratio which is very important for many applications. The purpose of this study is to investigate dynamic analysis of the composite beam. In this study, longitudinal transverse Young Modulus, poison's ratio and shear modulus were determined by using simple formulae. The longitudinal & transverse vibrations were obtained theoretically and analytically. Numerical study was performed by finite analysis software by using ANSYS 11. In this software, the test specimens were modeled in accordance to experimentally tested specimens. The boundary conditions were applied to the model. These outputs were transferred to the graphs. Inspection of the dynamic behavior of the composite beam for various end conditions is made by both FEM and theoretical analysis.*

**Key Words- ANSYS, Composite Material, Fiber Orientation, Volume fraction,**

## I.INTRODUCTION-

Rapid technological advances in engineering brought the scientists and engineers to a point, where they became limited by the capabilities of traditional materials. With the limits of the technology pushed, the materials failed to answer the requirements of the designers or manufacturers. Researchers in materials technology are constantly looking for solutions to provide stronger, durable materials which will answer the needs of their fellow engineers. Composite materials are one of the most favored solutions to this problem in the field. By combining the stronger properties of traditional materials and eliminating the disadvantages they bear, composite materials technology is providing limitations like heavy weight, structural strength, and thermal resistance are being solved by the compromising solutions and alternatives to many engineering fields. Problems born from material composite material alternatives, and many more alternatives are being introduced to readily used engineering applications Due to the high specific stiffness and strength, composite materials are being used increasingly in many engineering applications. However, the mechanical properties of composite materials may degrade severely in the presence of damage. Failures of structures, particularly aircraft structures, often have tragic consequences. Therefore, damage detection, especially on-line, becomes a very important issue. Common damage for composite materials are matrix cracking, fiber breakage, fiber-matrix de-bonding, and de-lamination between plies. Alternatively, delamination may be induced during in-service loading, such as by foreign object impact or by fatigue. De-laminations may not be visible or barely visible on the surface, since they are embedded within the composite structures. However, they may significantly reduce the stiffness and strength of the structures. A reduction in the stiffness will affect some design parameters, such as the vibration characteristics of the structure (e.g. natural frequency and mode shape). De-laminations reduce the natural frequency, as a direct result of the reduction of stiffness, which may cause resonance if the reduced frequency is close to the working frequency. It is therefore important to understand the influence of the vibration characteristics of the structures.

Currently available non-destructive evaluation (NDE) methods are mostly non-model methods, i.e., either visual or localized experimental methods, such as acoustic or ultrasonic methods, magnetic field methods, radiographs, eddy-current methods or thermal field methods. Accessing these techniques is time consuming and costly. Some of them are also impractical in many cases such as in service aircraft testing, and space structure. Almost all of these techniques require that the vicinity of the damage is known in advance and that the portion of the structure being inspected is readily accessible for human beings. Subject to these limitations, these non-model methods can provide only local information and no indication of the structural strength at a system level. This requirement has led to the development of model-based (experimental) methods that examine changes in the vibration characteristics of the structure.

## PAPER OVERVIEW:

The main objective of this work is to study and compare the theoretical, and FEM results of dynamic behavior of the fiber reinforced beam of araldite. Special attention is given to the responses of a beam due to dynamic test (impact excitation) results compared with theoretical results and analytical results. The results thus obtained are presented and discussed.This report contains theoretical analysis of a composite specimen beam, effect of volume fraction variation on the mechanical properties and frequency response of the specimen. Report contains calculations for E1 and E2. Report also contains calculations for natural frequency. All the results thus obtained are presented on the graph.

## WHAT IS COMPOSITE MATERIAL?

The word composite in the term composite material signifies that two or moreMaterials are combined on a macroscopic scale to form a useful third material. The key is the macroscopic examination of a material wherein the components can be identified by the naked eye. Different materials can be combined on a microscopic scale, such as in alloying of metals, but the resulting material is, for all practical purposes, macroscopically homogeneous, i.e., the components cannot be distinguished by the naked eye and essentially act together. (Jones, R.M; 1998; 2)Composites, which consist of two or more separate materials combined inmacroscopic structural unit, are made from various combinations of the other treeMaterials. (Gibson R.F; 1994; 1)

A composite is a structural material which consists of combining two or moreConstituents. The constituents are combined at a macroscopic level and are not soluble in each other. (Kaw A.K; 1997; 2) These constituents are combined at a macroscopic level and are suitable in each constituent is called the reinforcing phase and one which it is embedded in is called the matrix. The reinforcing phase material may be in the form of fibers, particles, flakes. The matrix phase materials are generally continuous. Examples of composite system include concrete reinforced with steel; epoxy reinforced graphite fibers etc.

The key is the macroscopic examination of a material wherein the components can be identified by the naked eye. Different materials can be combined on a microscopic scale, such as in alloying of metals, but the resulting materials is, for all practical purposes, macroscopically homogeneous, i.e. the components cannot be distinguished by the naked eye and essentially act together. The advantage of composite materials is that, if well designed, they usually exhibit the best qualities of their components or constituents and often some qualities that neither constituent possesses. Some of the properties that can be improved by forming a composite material are - Strength ,fatigue life , Stiffness ,temperature dependent behavior, Corrosion resistance ,thermal insulation, Wear resistance, thermal conductivity, Attractiveness, acoustical insulation, weight.

Naturally, not all of these properties are improved at the same time nor is thereusually any requirement to do so. In fact, some of the properties are in conflict with one another, e.g., thermal insulation versus thermal conductivity. The objective is merely to create a material that has only the characteristics needed to perform the design task.

## II.CLASSIFICATION OF COMPOSITE MATERIALS:

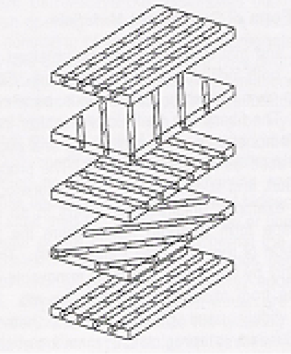
Mostly accepted composite materials are as follows:

### 2.1. Fibrous composite materials:

It consists of fiber reinforced matrix. According to type of matrices they can be further classified as, Polymer matrix composites, Metal matrix composites, Ceramics matrix composites, Carbon- carbon composites. E.g. Glass epoxy, graphite epoxy, and carbon reinforced aluminum composites.

### 2.2. Laminated composite materials:

They consist of layers of at least two different materials that are bonded together. Lamination is used to combine best aspects of the constituent layers and bonding material .E.g. Bimetals, Clad metals, laminated glass,

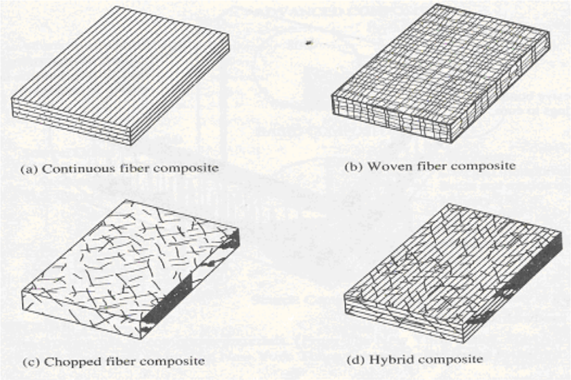


Plastic based liminates
Unbonded view of laminate construction

### 2.3. Particulate composite materials:

They consist of particles of one or more materials suspended in matrix of another material. Four possible combinations for them are as nonmetallicparticles in nonmetallic matrix, Metallic particles in nonmetallic matrix, nonmetallic particles in metallic matrix, and Metallic particles in metallic matrix. E.g. - Concrete, Tungsten carbide in cobalt matrix.

The need for fiber placement in different directions according to the particularApplication has led to various types of composites, as shown in Figure.



(a) Continuous fiber composite
(b) Woven fiber composite
(c) Chopped fiber composite
(d) Hybrid composite

Types of fiber-reinforced composites

### 2.4. Strength of composite materials:

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

**Fiber volume fraction:**

Fiber volume fraction indicate fraction of total volume of composite material occupied by fibers. Mathematically,

**[Fiber volume fraction, Vf = volume of fibers/ total volume of composite material]**

Consider a composite consisting of fiber and matrix.

Take the following symbol /-notations:

$v_{c\ f\ m}$= volume of composite, fiber, and matrix, respectively

Now define the fiber volume fraction Vf and the matrix volume fractionVm as,

$\mathbf{V_f = v_f / v_c}$ (1)

$\mathbf{V_m = v_m / v_c}$ (2)

Note that of volume fractions is

$\mathbf{V_f + V_m = 1}$ (3)

$\mathbf{v_f + v_m = v_c}$ (4)

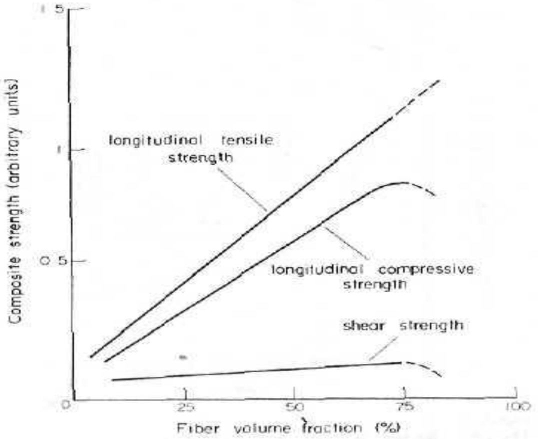
## FIBER ORIENTATION:

Angle of orientation is the angle made by fibers with loading axis. When all fibers are oriented in same direction gives very high strength and stiffness in that direction.

A set of aligned fibers in a pliant matrix is only useful as an engineering material under direct tensile forces parallel to the fibers. The salient-properties are represented by those of a pocket handkerchief which is stiff in the direction of the warp and weft (parallel to the fibers) but shears easily parallel to these. Hence the properties of fiber composites are very directional being very strong and stiff parallel to the fibers, but rather weak in shear parallel to the fibers (because this property depends principally upon the shear, properties of the matrix, and very weak indeed in tension perpendicular to the fibers. In order to overcome this, the fibers are arranged in laminae, each containing parallel fibers, and these are stuck together. Alternatively, the fibers may be randomly arranged in a plane or in three dimensions; such arrangementslimit the obtainable fiber packing density. Fibers arealso often woven into mats before incorporation intothe composite because this aids the handling of fiberaxis.

## VARIATION OF STRENGTH WITH FIBER VOLUME FRACTION

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

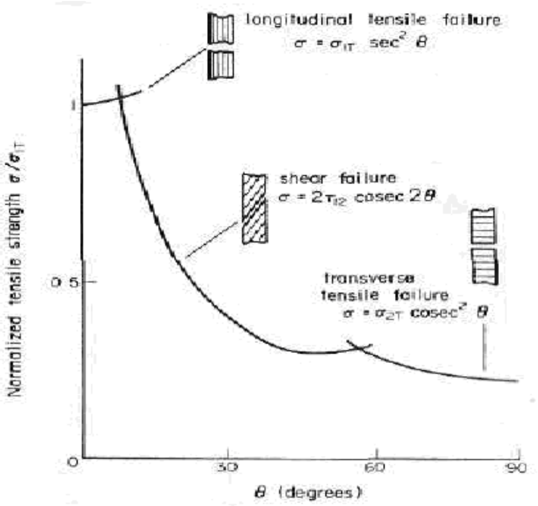


Effect of fiber volume fraction on strength

## THE EFFECT ON STRENGTH OF FIBER ORIENTATION:

The tensile strength of a unidirectional composite loaded at an angle to the fiber direction may be related to the longitudinal and transverse tensile strengths ($\sigma_m$and $\sigma t$) and in-plane shear strength. The failure mode, and hence the controlling strength parameter, depends on the angle between the fiber and loading axes. 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.

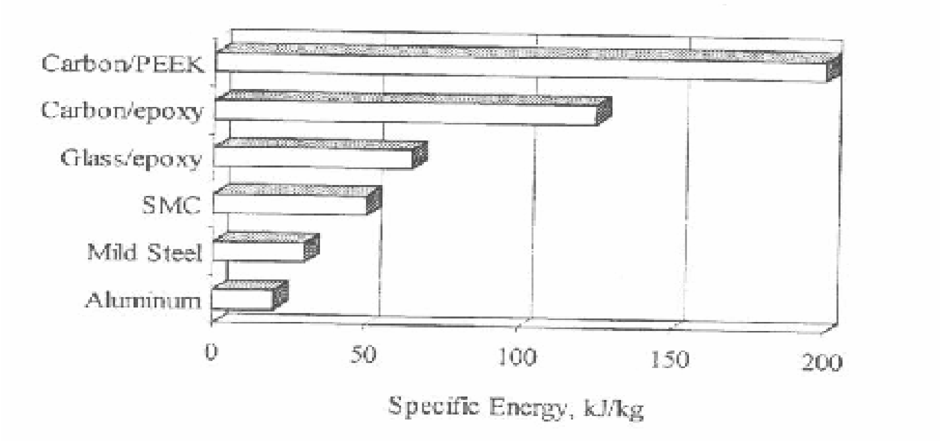
This description of the effect of fiber orientation is based on the theory of maximum principal stresses which makes the reasonable assumption that failure in any one mode is not influenced by the magnitude of the stress in any other mode. The corresponding theory of maximum principal strains, which 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 strength and fiber orientation at the points of transition between failure modes. 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.



Effect on tensile strength of fiber orientation

## ENERGY ABSORPTION CAPABILITIES OF COMPOSITES:

The energy absorption capability of the composite structure mainly depends on the,
1] Fiber Material – Physical properties of the fiber material directly influences the specific energy absorption of the composite. The brittle nature of the fiber results in more energy absorption rather than the ductile nature of the fiber, which fails by Progressive folding.
2] Matrix Material – Specific energy absorption linearly increases with the matrix compressive strength.
3] Fiber and Matrix Combination – Due to crushing by high energy fragmentation, matrix material with a higher failure strain has high energy absorption than the fiber material.
4] Fiber Orientation and Lay-up – High energy absorption composites consist of layers of specified orientation and sequence plies.



## III. THEORETICAL ANALYSIS:

### Overview:

In composite material glass fiber was used as reinforcement in form of bidirectional fabric and epoxy resin with catalyst addition as matrix. Mechanical properties were calculated analytically using the simple formulae.

### Formulae:

1. $E_1 = E_f V_f + E_m V_m$
2. $\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m}$
3. $v_{12} = v_f V_f + v_m V_m$
4. $G_f = \frac{E_f}{2(1+v_f)}$

5. $G_m = \frac{E_m}{2(1+v_m)}$
6. $\frac{1}{G_{12}} = \frac{V_f}{G_f} + \frac{V_m}{G_m}$

Where,

$E_1$ = Longitudinal Young's modulus in direction of fibers
$E_2$,$E_3$ = Transverse Young's modulus normal to fibers.
$E_f$,$E_m$= Young's modulus for fibers and matrix resp.
$V_f$, $V_m$ = volume fractions for fibers and matrix resp.
$v_f$,$v_m$ = Poisson's ratios for fibers and matrix resp.
$v_{12}$ = Poisson's ratio for composite beam.
$G_f$, $G_m$= shear modulus of fibers and matrix resp.
$G_{12}$ = Shear modulus of composite beam.

3.1 Material properties:

**Table 3.1**

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

3.2 Composite beam properties

| Volume fraction | $E_1$ $(N/m^2)$ | $E_2$ $(N/m^2)$ | $v_{12}$ | $G_{12}$ $(N/m^2)$ |
|---|---|---|---|---|
| 30% | 1.81e9 | 163.26e6 | 0.341 | 64.76e6 |
| 36% | 1.66e9 | 136.98e6 | 0.333 | 54.59e6 |
| 40% | 1.56e9 | 123.95e6 | 0.328 | 49.42e6 |

3.3 Analytical model analysis:
a) Free-free support condition:

$$\boldsymbol{\omega_1 = \frac{22a}{2\pi L^2}}$$

$$\boldsymbol{\omega_2 = \frac{61.7a}{2\pi L^2}}$$

$$\boldsymbol{\omega_3 = \frac{121a}{2\pi L^2}}$$

Where,

$$a = \sqrt{\frac{EI}{\rho A}}$$

I=$\frac{bd^3}{12}$
A=b*d
E=Young's modulus parallel to fiber $(^{N}/_{m^2})$
I= moment of inertia $(m^4)$
A=cross sectional area of beam $(m^2)$
$\rho$=density of beam $(^{kg}/_{m^3})$

3.4 Sample calculation:

Volume fraction = 30%
Dimensions :
L=35cm, b=4.5cm, d=1.8cm
E=1.8145e9 $(^{N}/_{m^2})$
I= 21.87e-9 $(m^4)$
A= 810e-6 $(m^2)$
$\rho$=1368.61$(^{kg}/_{m^3})$
a=5.9830

1. **Free – free condition:**
$\omega_1=\frac{22a}{2\pi L^2}$ = 171.01Hz
$\omega_2=\frac{61.7a}{2\pi L^2}$ = 479.61Hz
$\omega_3=\frac{121a}{2\pi L^2}$ = 953.502 Hz

**3.5 Observation table:**

Theoretical results are tabulated as follows.

| End condition | Natural frequency | | |
|---|---|---|---|
| | $\omega_1$ | $\omega_2$ | $\omega_3$ |
| Free - free | 171.0123 | 479.61 | 940.56 |

## IV. RESULT AND DISCUSSION:

4.1 Effect of volume fraction on the Young's modulus:

The table 4.1 shows the variation of the various mechanical properties with respect to fiber volume fraction. The longitudinal and transverse Young's modulus and also shear modulus increases with % increase in volume of fibers as shown in the table 4.1 below. But with increase in volume fraction Poisson's ratio decreases.

Table 4.1 various mechanical properties

| Volume fraction | $E_1$ | $E_2$ | $v_{12}$ | $G_{12}$ |
|---|---|---|---|---|
| 8 | 7.858e9 | 2.784e9 | 0.369 | 1.009e9 |
| 16 | 13.14e9 | 3.038e9 | 0.359 | 1.101e9 |
| 24 | 18.43e9 | 3.3423e9 | 0.348 | 1.212e9 |
| 30 | 22.400e9 | 3.613e9 | 0.341 | 1.311e9 |
| 36 | 26.366e9 | 3.933e9 | 0.333 | 1.427e9 |
| 40 | 29.010e9 | 4.179e9 | 0.328 | 1.517e9 |
| 50 | 35.620e9 | 4.954e9 | 0.315 | 1.801e9 |

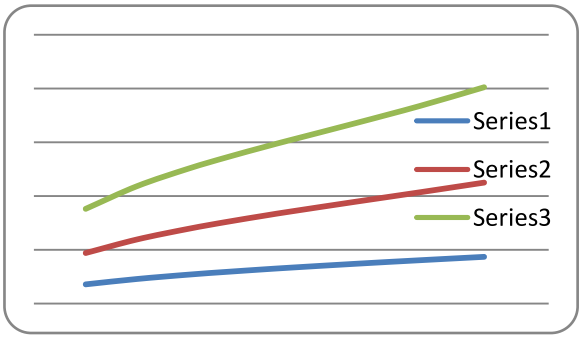
| | | | | |
|---|---|---|---|---|
| 60 | 42.230e9 | 6.083e9 | 0.302 | 2.215e9 |
| 70 | 48.840e9 | 7.879e9 | 0.289 | 2.876e9 |

## 4.2 Theoretical Results

**Table 4.2**

| Volume fraction | Natural Frequency | | |
|---|---|---|---|
| | $\omega_1$ | $\omega_2$ | $\omega_3$ |
| 8 | 356 | 998 | 1957 |
| 16 | 460 | 1290 | 2531 |
| 24 | 545 | 1528 | 2997 |
| 30 | 600 | 1685 | 3304 |
| 36 | 657 | 1828 | 3585 |
| 40 | 683 | 1917 | 3760 |
| 50 | 757 | 2125 | 4167 |
| 60 | 825 | 2313 | 4536 |
| 70 | 887 | 2488 | 4879 |

Above table 4.2 shows the variation of natural frequency calculated analytically with respect to fiber volume fraction. As shown in graph value of natural frequency increases with the % increase in volume fraction of fibers.



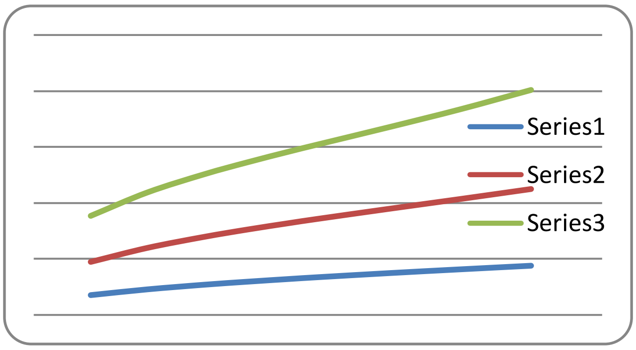
Graph 4.1 Frequency Vs volume fraction Theoretical results.

## 4.3 ANSYS RESULTS:

**Table 4.3**

| Volume fraction | Natural Frequency | | |
|---|---|---|---|
| | $\omega_1$ | $\omega_2$ | $\omega_3$ |
| 8 | 355 | 945 | 1765 |
| 16 | 457 | 1196 | 2187 |
| 24 | 539 | 1393 | 2513 |
| 30 | 592 | 1522 | 2725 |
| 36 | 641 | 1640 | 2922 |
| 40 | 672 | 1715 | 3048 |
| 50 | 744 | 1894 | 3358 |
| 60 | 811 | 2069 | 3678 |
| 70 | 875 | 2248 | 4026 |

Above table 4.3 shows the variation of natural frequency determined from FEM with respect to fiber volume fraction. As shown in graph value of natural frequency increases with the % increase in volume fraction of fibers.



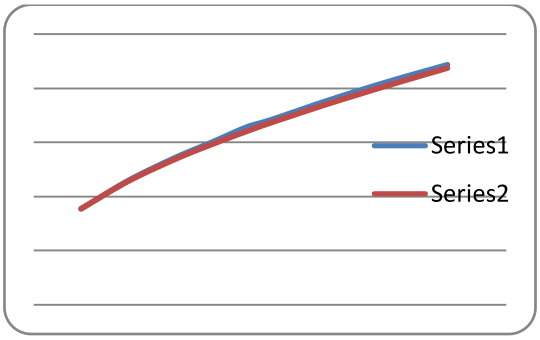
Graph 4.2 Frequency Vs volume fraction for FEM results.

### 4.4 Comparison between ANSYS and theoretical results:

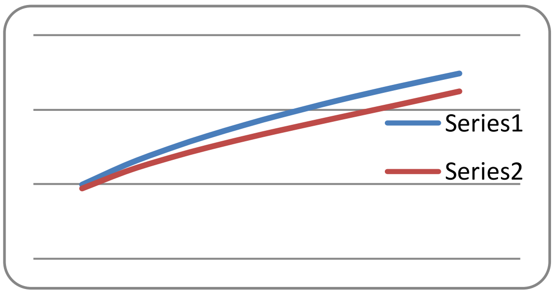
**Table 4.4**

| Volume Fraction | Theoretical natural frequency | | | ANSYS natural frequency | | |
|---|---|---|---|---|---|---|
| | $\omega_1$ | $\omega_2$ | $\omega_3$ | $\omega_1$ | $\omega_2$ | $\omega_3$ |
| 8 | 356 | 998 | 1957 | 355 | 945 | 1765 |
| 16 | 460 | 1290 | 2531 | 457 | 1196 | 2187 |
| 24 | 545 | 1528 | 2997 | 539 | 1393 | 2513 |
| 30 | 600 | 1685 | 3304 | 592 | 1522 | 2725 |
| 36 | 657 | 1828 | 3585 | 641 | 1640 | 2922 |
| 40 | 683 | 1917 | 3760 | 672 | 1715 | 3048 |
| 50 | 757 | 2125 | 4167 | 744 | 1894 | 3358 |
| 60 | 825 | 2313 | 4536 | 811 | 2069 | 3678 |
| 70 | 887 | 2488 | 4879 | 875 | 2248 | 4026 |

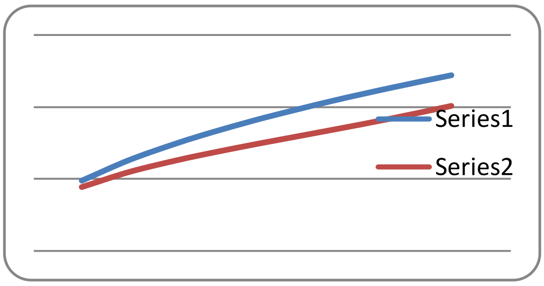
From above table 4.4 and following graph it is observed that natural frequencies obtained analytically and from ANSYS are approximately closed to each other for lower volume fractions. Difference in the theoretical and ANSYS frequencies increases with increase in fiber volume fraction.



Graph 4.3 Frequency$\boldsymbol{\omega_1}$ Vs volume fraction.



Graph 4.4 Frequency $\boldsymbol{\omega_2}$Vs volume fraction.



Graph 4.5 Frequency $\boldsymbol{\omega_3}$Vs volume fraction.

## V. CONCLUSION AND FUTURE SCOPE:

1. From table 4.1 it is observed that the longitudinal and transverse Young's modulus and also shear modulus increases with % increase in volume of fibers. But with increase in volume fraction Poisson's ratio decreases.

2. From the graph 4.1 it is observed that natural frequency obtained analytically Vs fiber volume fraction, as % of fiber volume increases, the natural frequency increases. Same trend is observed in case of natural frequency obtained from ANSYS as shown in graph 4.2.

3. From the graph 4.3, 4.4, 4.5 it is observed that natural frequencies obtained analytically and from ANSYS are approximately closed to each other for lower volume fractions. Difference in the theoretical and ANSYS frequencies increases with increase in fiber volume fraction.

4. Today, a major challenge relating to composite design is the availability of simulation tools and a lack of general composite material characterization; the commercial software developers have not yet solved this problem. Another issue is the computational time required to model composite structures and components. 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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