Modeling and Simulation of Carbon Fiber Reinforced Polymer Plate with Application of Hanning Wave Loading

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Abstract - *An attempt is made to compare response of Hanning wave loading acting on CFRP and Aluminium plate. For the calculation of deformation values modeling is done on FEM software with and without different stiffeners arrangements. As the CFRP material is an orthographic in nature, the spreadsheet for properties calculations of CFRP material is made. In properties calculation the elastic constant values are calculated in all three X, Y and Z directions with respect to X direction are obtained. Then the data of spreadsheet is used as input for the material properties for the analysis of stiffened plate. The CFRP plate and stiffeners actually placed in eight layers with different Fiber orientations. As the stiffeners placed in perpendicular directions to the actual plate, the calculations for properties also conducted for stiffeners. The plate with different stiffeners spacing are modeled and analysis is carried out on the model. Analysis of Systems (ANSYS) software was used for the analysis of plates. Matrix Laboratory (MATLAB) Software ware used for calculation of Hanning wave loading coordinates. The Hanning wave is calculated for five waves of sine wave for different frequencies. This finite element analysis software have utilized to create model and to perform analyses. Numerous models used for this comparative study, Also models with Aluminium as material for comparison of the data as Aluminium is an isotropic material. In addition, analysis has performed on Aluminium plate with same stiffeners positions as of CFRP plate. This comparative study reveals that with increase in number of stiffeners and position of the load application of the plate, how the deformation values changes.*

Key Words: **ANSYS, MATLAB, Sine wave, Hanning wave, Lamb waves, Stiffeners, Deformation, and Signals.**

1. INTRODUCTION

The requirements for lightweight constructions are continually increasing. In order to open up the full potential of such structures, new safety and maintenance concepts are needed. Current research focuses on calculation of deformations of stiffened plates while application of five cycle Hanning wave. These integrated systems ensure high level security of lightweight structures and allow for the growing economical demands. Historically, the development of the stiffened structural form is one of slow growth of experiments by anonymous builders. It has known that the Egyptians, at least 5,000 years ago, developed a craft made of planks fastened around a wooden framework using much the same principles as are employed today. In addition, ancient Viking ships were made of planks, which tied on the inside to ribs. The stiffened plate panel (or simply "stiffened plate") forms the backbone of most of the structures. It is by far the most commonly used structural element. Due to their simplicity of fabrication and excellent strength to weight ratio, stiffened plates are also widely used for construction, rail/road bridges, aircraft structures and many other applications [1].

1.1 Carbon Fiber Reinforced Polymer (CFRP)

The use of Fiber Reinforced Plastics (FRP) is experiencing an increased growth, namely in the aeronautical, naval and automotive industries, because of their excellent mechanical properties in conjunction with their low weight and easy shaping. Nevertheless, composite materials are very different. Carbon Fiber Reinforced Polymer (CFRP) is one of the advanced non-metallic composite materials, which is made of a polymer resin reinforced with carbon fibers. The Carbon Fiber Reinforced Polymer (CFRP) materials are well suited to the rehabilitation of civil engineering structures due to their corrosion resistance, high strength, high modulus, lightweight, high fatigue resistance and workability. As the price of CFRP goes down, more and more investigators devote their efforts to the test and analysis of the properties of the structural members strengthening with CFRP materials. In recent years, the design guidelines are developing in many nations, such as Japan, Canada, and the Great Britain. All these Design Codes or Recommendations become the basis of the application of CFRP to strengthen the concrete structures [2].

2. OBJECTIVES

1. Formulation of problem statement, development of methodology with high quality research article.
2. Validation and simulation of Stiffened CFRP and Aluminium plates subjected to Transient load by using FEM software.

3. Theoretical modeling of various stiffener placements.
4. Analysis of Stiffened CFRP plates subjected to Transient load with different configurations.

3. METHODOLOGY

The methodology includes creating models for CFRP and Aluminium plates with and without stiffeners in FEM software. For inputting CFRP properties in FEM software a excel sheet is created and Creating the MATLAB code for converting five cycle sine wave into Hanning wave. The wave is then passed through the sample and response is recorded, the recorded response was observed and imported in excel for conclusion interpretation. Graphs of deformation with respect to volume of plates was plotted and observation is concluded.

4. Properties of Aluminium and CFRP Plates

In the modeling and analysis of a stiffened plate, we created models of CFRP plate with the plate having layers of uni-directional Carbon fibers containing of eight layers which having different orientations. The orientation of layers are considered in such a way that the overall plate should be in equilibrium for the calculations of elastic constants.

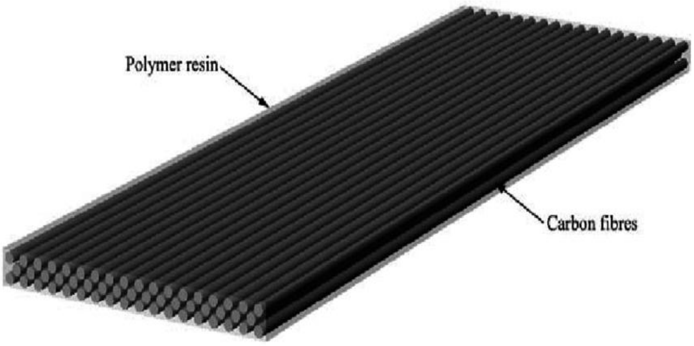

Fig -1: Typical Structure of Uni-Directional Carbon Fiber Reinforced Polymer (Google).

The layers of uni-directional carbon fiber are provided in the angle orientation format, which are given as follows: -

0^o, 45^o, 90^o, -45^o, -45^o, 90^o, 45^o, 0^o.

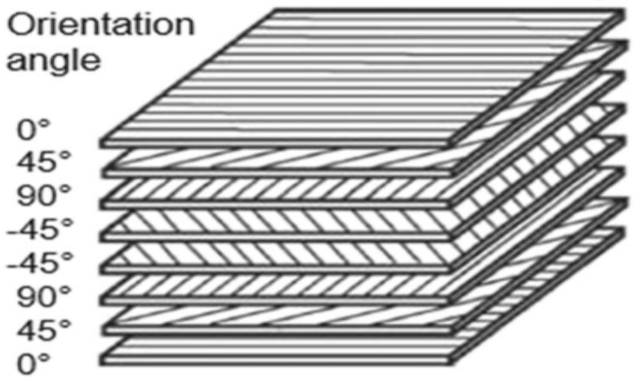

Fig -2: Typical CFRP plate with orientation of layers.

For the calculation of material properties an excel spreadsheet is made which will give the properties of material for different orientations of carbon fibers also for the change in angles and orientations of stiffeners which will be provided in the modeling for analysis.

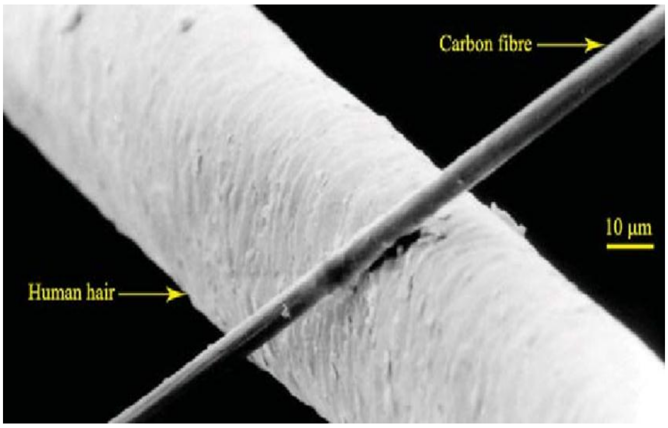

Fig -3: Single Carbon fiber strand compared with human hair (photo credit: Anton)

Table -1: For plate in XY Direction: -

Angle	0	Angle	45	Angle	90	Angle	-45
Exx	290	Exx	25.5	Exx	23	Exx	25.5
Eyy	23	Eyy	25.5	Eyy	290	Eyy	25.5
Ezz	23	Ezz	23	Ezz	23	Ezz	23
Vxy	0.2	vxy	0.419	vxy	0.016	vxy	0.419
Vxz	0.2	vxz	0.231	vxz	0.4	vxz	0.231
Vyz	0.4	vyz	0.231	vyz	0.2	vyz	0.231
Gxy	9	Gxy	20.7	Gxy	9	Gxy	20.7
Gxz	9	Gxz	8.59	Gxz	8.21	Gxz	8.59
Gyz	8.21	Gyz	8.59	Gyz	9	Gyz	8.59

Table -2: For plate in XZ Direction: -

Angle	0	Angle	45	Angle	90	Angle	-45
Exx	290	Exx	25.5	Exx	23	Exx	25.5
Eyy	23	Eyy	23	Eyy	23	Eyy	23
Ezz	23	Ezz	25.5	Ezz	290	Ezz	25.5
Vxy	0.2	vxy	0.231	vxy	0.4	vxy	0.231
Vxz	0.2	vxz	0.419	vxz	0.016	vxz	0.419
Vyz	0.4	vyz	0.208	vyz	0.016	vyz	0.208
Gxy	9	Gxy	8.59	Gxy	8.21	Gxy	8.59
Gxz	9	Gxz	20.7	Gxz	9	Gxz	20.7
Gyz	8.21	Gyz	8.59	Gyz	9	Gyz	8.59

Table -3: For plate in YZ Direction: -

Angle	0	Angle	45	Angle	90	Angle	-45
Exx	23	Exx	23	Exx	23	Exx	23
Eyy	290	Eyy	25.5	Eyy	23	Eyy	25.5
Ezz	23	Ezz	25.5	Ezz	290	Ezz	25.5
Vxy	0.016	vxy	0.208	vxy	0.4	vxy	0.208
Vxz	0.4	vxz	0.208	vxz	0.016	vxz	0.208
Vyz	0.2	vyz	0.419	vyz	0.016	vyz	0.419
Gxy	9	Gxy	8.59	Gxy	8.21	Gxy	8.59
Gxz	8.21	Gxz	8.59	Gxz	9	Gxz	8.59
Gyz	9	Gyz	20.7	Gyz	9	Gyz	20.7

Density of CFRP material is - 1600 Kg/m^3

Table -4: Properties of Aluminium Plate

Density	2713 Kg/m3
Young's Modulus	69.04 GPa
Poison's Ratio	0.33
Bulk Modulus	67.69 GPa
Shear Modulus	25.96 Gpa
Tensile Yield Strength	0.259 GPa
Tensile Ultimate Strength	0.313 GPa

5. Formulation of Plates with and Without Stiffeners

The plate formed on ANSYS FEM software having following specifications.

Plate having size of 1200mm x 1200mm with thickness of 5mm is formed which having eight layers of uni-directional CFRP fibers and with fibers with orientations as per mentioned before. Also same plate is made of the Aluminium material which does not require layers formation as the Aluminium is an isotropic material.

The stiffeners are considered as of 3mm and having eight layers of uni-directional carbon fibers with different orientations same as of plate and for Aluminium plate stiffeners are made for Aluminium plate. The plate is provided as no of stiffeners in X and Z directions are- 0 x 0, 2 x2, 3 x 3, 4 x 4 etc.

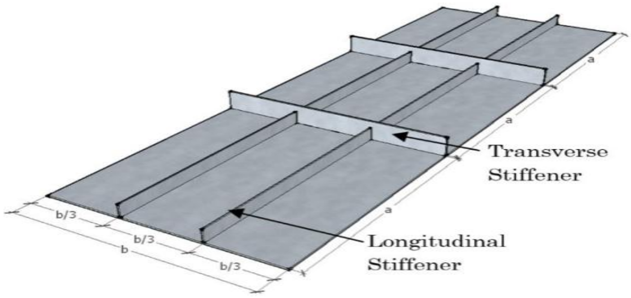

Fig -4: The Stiffened Plate

6. Lamb Waves

Lamb waves in plates have been used in Non-Destructive Testing (NDT) for over the past 50 years. There are many advantages to using these guided waves instead of traditional C-scans to investigate the integrity of a plate-like structure, with time of testing being one of the most attractive. Unfortunately, use of guided waves is also complicated by several factors, most notably their dispersive nature, i.e. that a given mode's velocities are a function of the frequency in a plate of a given thickness. However, despite these dispersive relationships, Lamb waves can be successfully implemented in structural health monitoring [3].

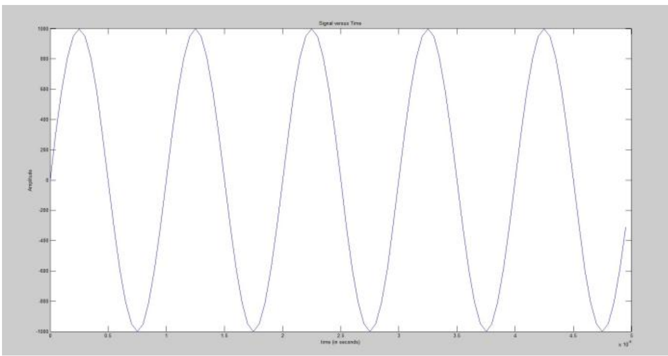

Fig -5: Sine wave for 100 KHz frequency

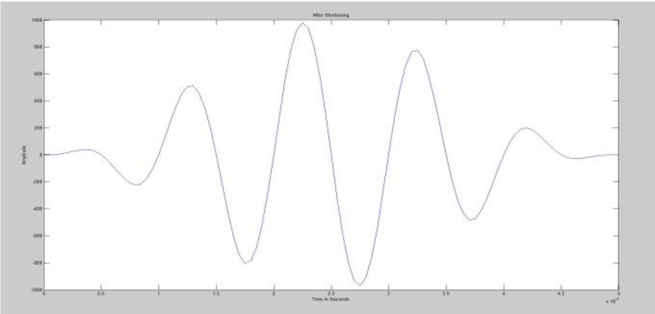

Fig -6: Hanning wave after windowing for five cycles of 100 KHz frequency of sine wave

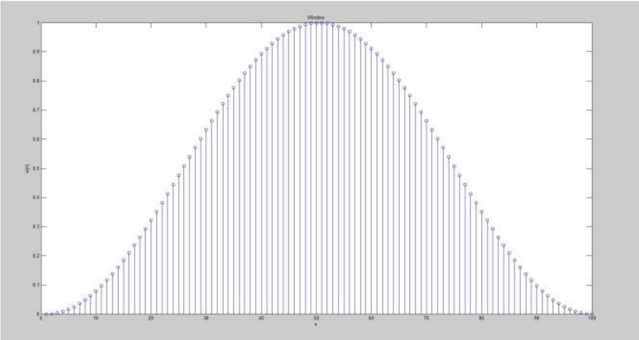

Fig -5: Hanning wave window for five cycles of 100 KHz frequency of sine wave

7. Data collection and analysis

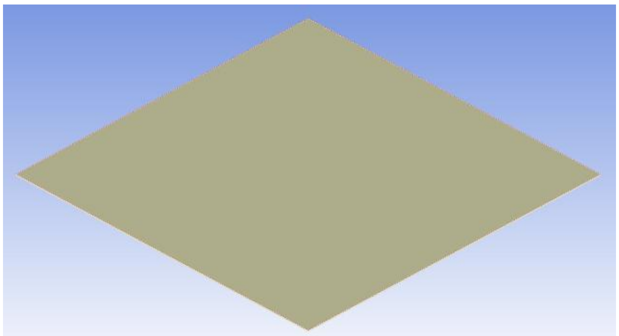

Fig -6: Plain CFRP and Aluminium plate

Plate type : Plain CFRP and Aluminium Plate

Plate dimension : 1200 × 1200 × 5 mm

Plate material : CFRP and Aluminium

Volume of the plate: 7200000 cu-mm

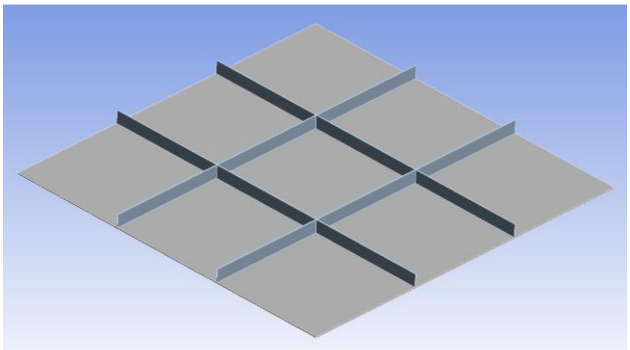

Fig -7: Stiffened CFRP and Aluminium plate having stiffeners spaced 400 mm apart

Plate dimension: 1200 × 1200 × 5 mm

Plate material: CFRP and Aluminium

Volume of the plate: 7918200 cu-mm

Spacing between Stiffeners: 3mm thick 400 mm C-C

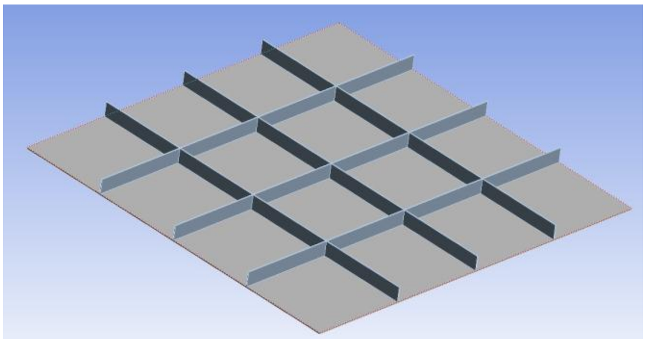

Fig -8: Stiffened CFRP and Aluminium plate having stiffeners spaced 300 mm apart

Plate dimension: 1200 × 1200 × 5 mm

Plate material: CFRP and Aluminium

Volume of the plate: 8275950 cu-mm

Spacing between Stiffeners: 3mm thick 300 mm C-C

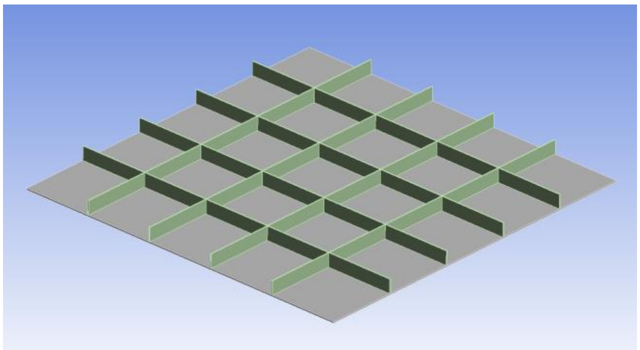

Fig -9: Stiffened CFRP and Aluminium plate having stiffeners spaced 240 mm apart

Plate dimension: 1200 × 1200 × 5 mm

Plate material: CFRP and Aluminium

Volume of the plate: 8632800 cu-mm

Spacing between Stiffeners: 3mm thick 240 mm C-C

8. Results and Discussion

The following results show the comparison of CFRP and Aluminium plates with respect to volume change samples are taken at centre where the load is applied also at 100mm, 200mm, 300mm, 400mm, and 500mm.

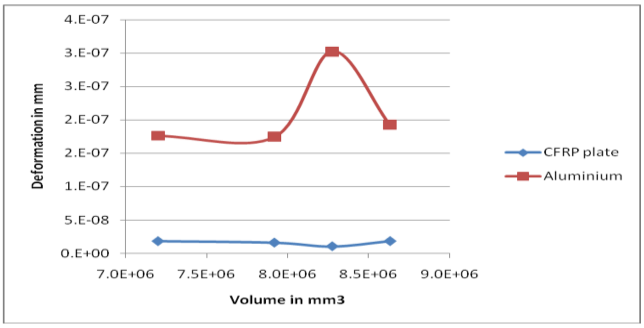

Fig -10: Comparison between CFRP and Aluminium plates at the centre

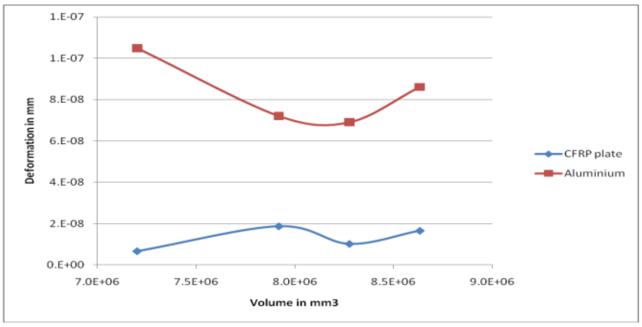

Fig -11: Comparison between CFRP and Aluminium plates at 100 mm from centre

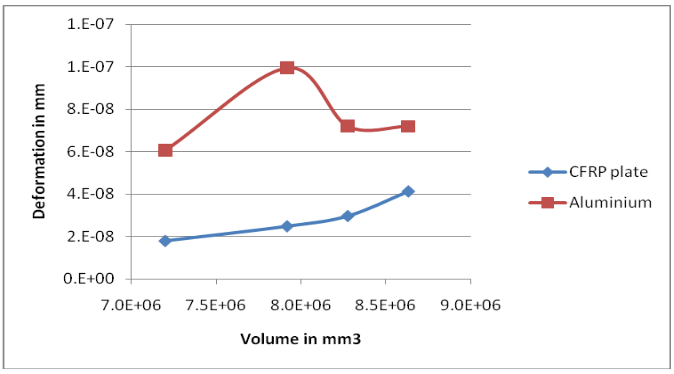

Fig -12: Comparison between CFRP and Aluminium plates at 200 mm from centre

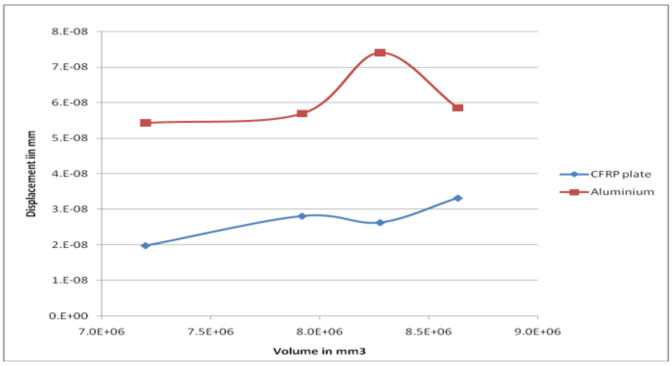

Fig -13: Comparison between CFRP and Aluminium plates at 300 mm from centre

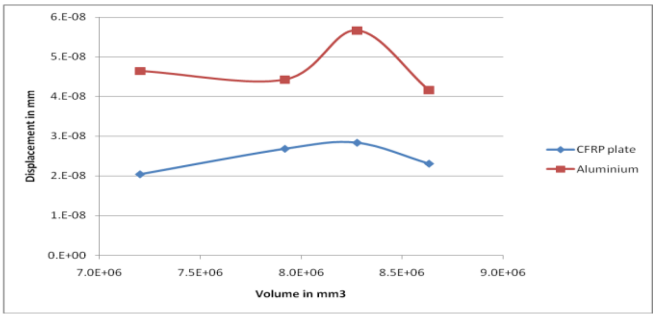

Fig -14: Comparison between CFRP and Aluminium plates at 400 mm from centre

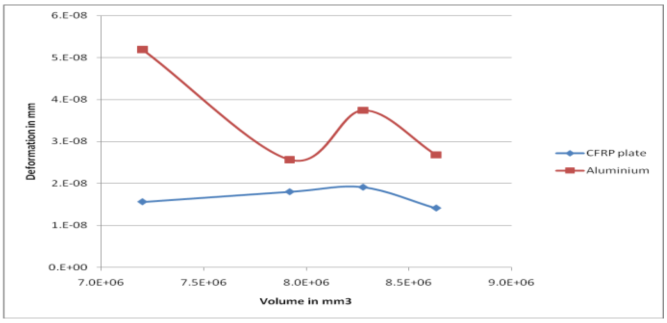

Fig -15: Comparison between CFRP and Aluminium plates at 500 mm from centre

The following results show the comparison of CFRP and Aluminium plates with respect to sampling distance and number of stiffeners.

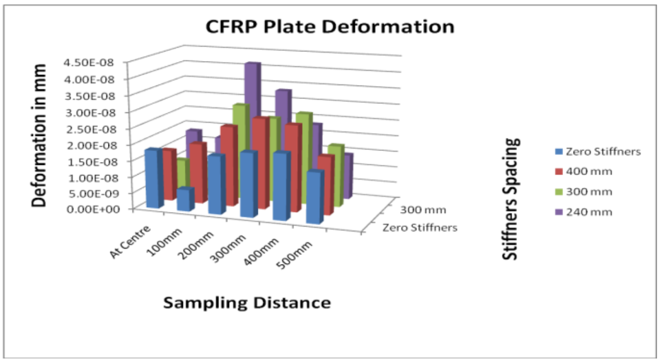

Fig -16: CFRP Plates Deformation

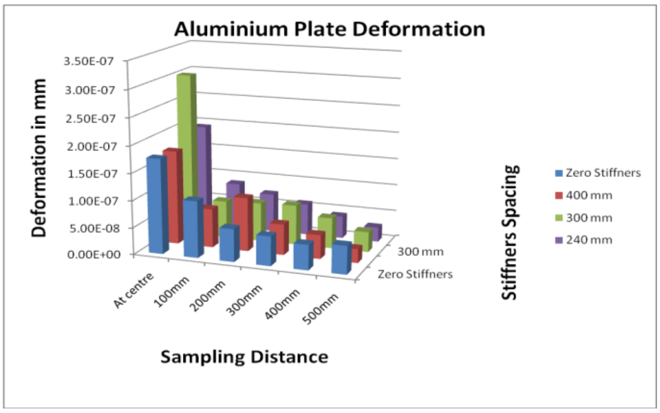

Fig -17: Aluminium Plates Deformation

For better response and satisfactory results the frequency of the signal is changed and the behavior of the plates is observed when the load application point and the Geometry are same. For the result interpretation, 100 mm distance is considered as a base for conclusion calculations.

For better response and satisfactory results following frequency 100 KHz, 150 KHz, 200 KHz, 250 KHz and 300 KHz are used.

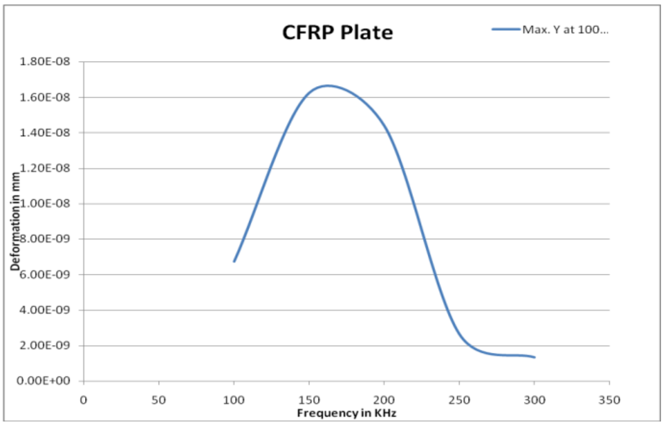

Fig -18: CFRP Plates Deformation with respect to change in frequency

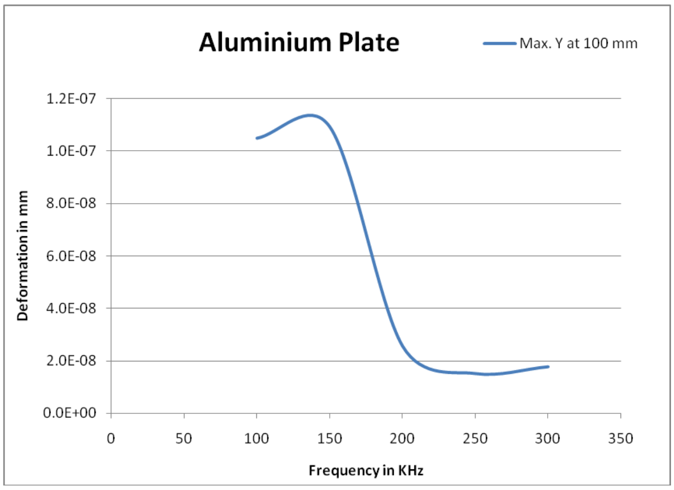

Fig -19: CFRP Plates Deformation with respect to change in frequency

9. CONCLUSIONS

i. In CFRP plate it is observed that load is being transmitted faster in the direction of fibers are laid.

ii. In both CFRP and Aluminium plates Change in deformation reduces with increase in stiffeners and after some point it will increases in case when volume increases.

iii. If compared CFRP plates with Aluminium Plates CFRP plates shows much less deformation than that of Aluminium plate.

iv. The deformation gap between the both plates reduces as the Distance of sampling increases.

v. In CFRP plates as the distance increases from the point of loading the maximum deformation values increases over time up to a certain limit and after that it shows the reduction in deformation.

vi. In Aluminium plates, the maximum deformation reduces as the distance increases from the point of loading.

vii. In CFRP plate when the application of change in frequency is conducted, a huge increase in the deformation is occurred approximately up to 200 KHz frequency and after that, the deformation reduces with the increase of frequency.

viii. Also in Aluminium plate with increase in the frequency deformation increases approximately up to 150 KHz after that reduction in the deformation is observed.

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