ANALYSIS OF HYBRIDIZED COMPOSITE PLATES FOR UNDER GROUND CONSTRUCTION

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***Abstract*— Materials with isotropic behavior are generally used for engineering purposes because they exhibit uniform property but in current scenario materials are used for multipurposes so they required to show variation in property as per requirement. Composite materials shows aelotropic behaviour and their property can be controlled and a single material can show different property in different direction within a controlled manner. As the composite plates are hybridized and their is variation in layup sequence, the dynamic behaviour of plates vary continuously. Variation in the aspect ratio of composite hybridized plate may also results in variation in property. These variations influence the natural frequency , displacement , stiffness and mode shapes of plate which can be investigated by detailed parametric analysis with the help of Ansys Workbench 14.O software .From the observation it can be observed that dynamic behavior of composite plate of Steel +Kevlar is better than other lay up sequences and as thickness increases dynamic resistance also increases.**

Index Terms—***Aelotropic behaviour, Free vibration, Hybridized composite materials, Natural frequency, Parametric analysis, Stiffness .***

I. INTRODUCTION

Composite materials are structural materials which are obtained by combination of two or more different constituents on a macroscopic scale. There are two phases of composite such as reinforcing phase and matrix phase. The materials of reinforcing phase are in the form of fibres, particles or flakes and embedded in the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer. The properties of composite materials are derived from its constituents, geometry and distributions of phases.

CLASSIFICATION OF COMPOSITES

(a) BASED ON MATRIX MATERIAL:

- Metal Matrix Composites (MMC)
- Polymer Matrix Composites (PMC)

(b) BASED ON REINFORCING MATERIAL STRUCTURE:

- Particulate Composites
- Composites with preferred orientation of particles

Most of the work done on laminated composite plates are analytical based on central cut-out, effect of eccentric cut-outs on free vibrational analysis of composite plate not to be studied.Generally plates are taken are composite plates their is no work related to hybridization of composite plates and the effect of cut-outs on dynamic behaviour of plates also not studied properly.

In current study I am going to study the influence of different boundary conditions, different lay up sequence, hybridization effect, different shapes of cut-out and also location of cut-outs when it is concentric and when it is eccentric. Plates are taken to be in space under different boundary condition in order to generate actual working condition. Results are going to be compared with the steel plate of same conditions. Plates taken for study are thin therefore effect of shear and bending both plays important role during study of behaviour of composite plates.It is noted that most of the work done on laminated composite plates are analytical based on central cut-out. Almost all works are related to unidirectional fibre for fabrication of laminated composite.

But now a days materials are used for multipurposes so they required to show variation in property as per requirement therefore laminated composite plates are required to be hybridized. The present work deals with vibration analysis of laminated composite plate with cut-out by considering the effect of cut-out ratio (d/D ratio), position of cut-out as in current cut-outs becomes necessary in order to reduce stress concentration over the plate surface. As both shear and flexure taken in account to study the dynamic behaviour of composite plates which meets the actual field conditions

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II. OBJECTIVE OF PRESENT WORK

The aim of this research work is to study the dynamic behaviour of composite plates under different conditions when plates are subjected to free vibration-

1. Analyse the variation in dynamic behaviour (stiffness, frequency, formation of mode shapes and displacement) of ordinary steel plate, composite plates, hybridized composite plate when they are subjected to free vibration .
2. Determine the influence of aspect ratio over the free vibration behaviour(stiffness, frequency, formation of mode shapes and displacement) of best arrangement obtain from above (point 1) analysis

In current scenario materials are used for multipurposes so they required to show variation in property as per requirement. In order to show uniform behaviour with the variation in required property a material is required to be construct artificially. As the composite plates are hybridized by using different lay-up sequence and their is variation in boundary condition, the dynamic behaviour of composite plates may vary continuously. Variation in the aspect ratio of composite hybridized plate may also results in variation in dynamic behaviour of composite plate.

III. METHOD OF ANALYSIS

Method used- Finite Element Method
Software used- Ansys Workbench 14.O

For the study software used is ANSYS Workbench 14 .O. This software was developed in 1987 by John A. Swanson. Software belongs to a company named Ansys.in . ANSYS is a powerful and integrated structural analysis and testing software. This software mainly used for dynamic analysis of structural members made of composite materials. This software is based on FEM and FEA approach. Free vibration of plates done by using Finite Element Approach.

The finite element method (FEM), is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The analytical solution of these problems generally require the solution to boundary value problems for partial differential equations. The finite element method formulation of the problem results in a system of algebraic equations.

IV. DETAILS OF THE PLATES

Size of plate:-
Plan: Square- 1m x 1m
Thickness: 12mm , 30mm , 60mm
Number of layers : 6
Support condition: all sides fixed

Materials properties: Table -1 shows

Material		Modulus of elasticity (E) GPa	Shear modulus (G) GPa	Poisson's ratio (μ)	Mass density (ρ) Kg/m³
Matri -x	Steel	210	79.3	0.3	7850
Reinf orce- ment	Glass fiber(g)	18.5	2.7	0.14	2590
	Carbon fiber(c)	46.7	2.8	0.2	1800
	Kevlar fiber(a)	19.6	1.2	0.09	1440

Table-1 Material properties

IV. PROBLEM FORMULATION

(A) VARIATION IN LAYERS:

All sides are fixed and thickness of the plates is 12mm having 6 layers of 2mm each in every case-

1. Steel plate* 6 layers
2. (Steel plate+ glass fiber plate)* 3 layers
3. (Steel plate + Kevlar fiber plate)* 3layers
4. (Steel plate + Carbon fiber plate)* 3 layers
5. (Steel + Glass + Steel + Kevlar + Steel + Carbon)

(B)VARIATION IN THICKNESS:

All sides are fixed and best suited section obtained from clause 3.1.A is analysed for different thickness-

1. 12 mm , each layer of 2mm
2. 30mm , each layer of 5mm
3. 60mm , each layer of 10mm

Plates are analysed with help of Ansys workbench software which is based on Finite Element Method. Free vibration of plates done by using Finite Element Approach. Free vibration analysis of plate done for different lay up sequences by using Kevlar fibers, Glass fibers, Carbon fibers . The best arrangement obtained from the above condition is also analysed for different thickness which are 12mm , 30mm, 60mm in order to know the variation in dynamic behaviour with respect to thickness. All analysis is done by providing fix support at all sides. Behaviour of plates is compared on the basis of following parameters-

- Natural frequency
- Mode shapes
- Displacement
- Dynamic stiffness

The main governing parameter for the comparision is dynamic stiffness because dynamic stiffness shows the effect of both frequency as well as mass of the plate.Stiffness can be determined from

$$T=2\pi\sqrt{(M/K)}$$

Where,

K= Stiffness

M= Mass of Structure

Unit of natural time period is in seconds

V. RESULTS AND DISCUSSIONS

(A)INFLUENCE OF LAY UP SEQUENCES:

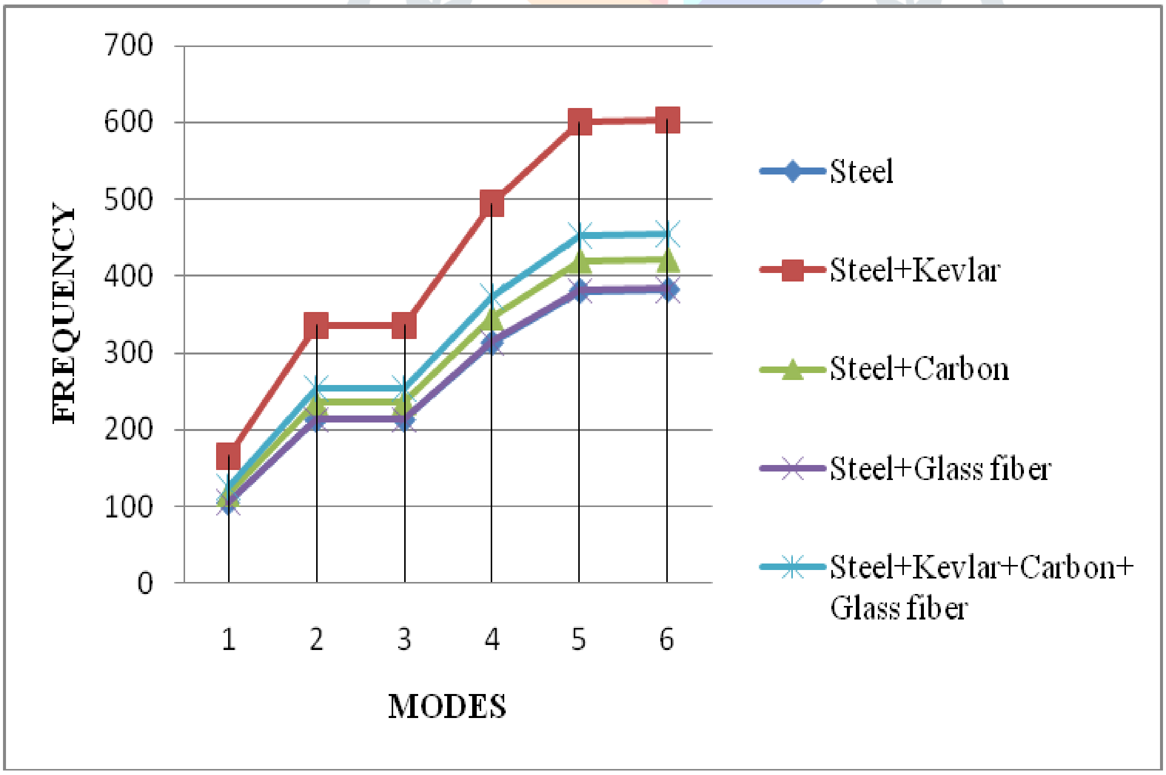
Influence of variation in the lay up sequences over the free vibration behaviour of plate discussed when a common support condition that is CCCC and a common thickness that is 12mm is taken.

COMPARISION OF FREQUENCY (Hz):

MODES / PLATES		1	2	3	4	5	6	Avg. % variation
Steel	Freq.(Hz)	104.33	212.53	212.53	313.02	380.40	382.24	
Steel + Kevlar	Freq. (Hz)	165.19	336.10	336.10	494.43	600.52	603.49	
	% change	58.33	58.14	58.14	57.94	57.86	57.88	58.04
Steel + glass	Freq.(Hz)	104.93	213.40	213.40	313.81	381.07	382.97	
	% change	0.575	0.409	0.409	0.205	0.176	0.190	0.327
Steel + carbon	Freq.(Hz)	115.66	235.29	235.29	346.08	420.31	422.39	
	% change	10.86	10.70	10.70	10.56	10.49	10.50	10.63
Steel + Kevlar + Glass + Carbon	Freq.(Hz)	124.53	253.56	253.56	373.28	453.53	455.74	
	% change	19.36	19.30	19.30	19.25	19.22	19.23	19.27

Table 2- Natural frequency corresponding to different modes for different lay up sequences having all sides clamped

From the Table 2 it can be seen that Steel + Kevlar shows higher frequency in all modes .While Steel plate shows minimum natural frequency in all modes , natural frequency of Steel +Glass plate are nearly equal to that of Steel plate. Natural frequency of mode 2 and mode 3 are equal, these modes are known as degenerate modes. Graph 1 represents the variation in the natural frequency of different composite plates corresponding different modes in the form of lines.



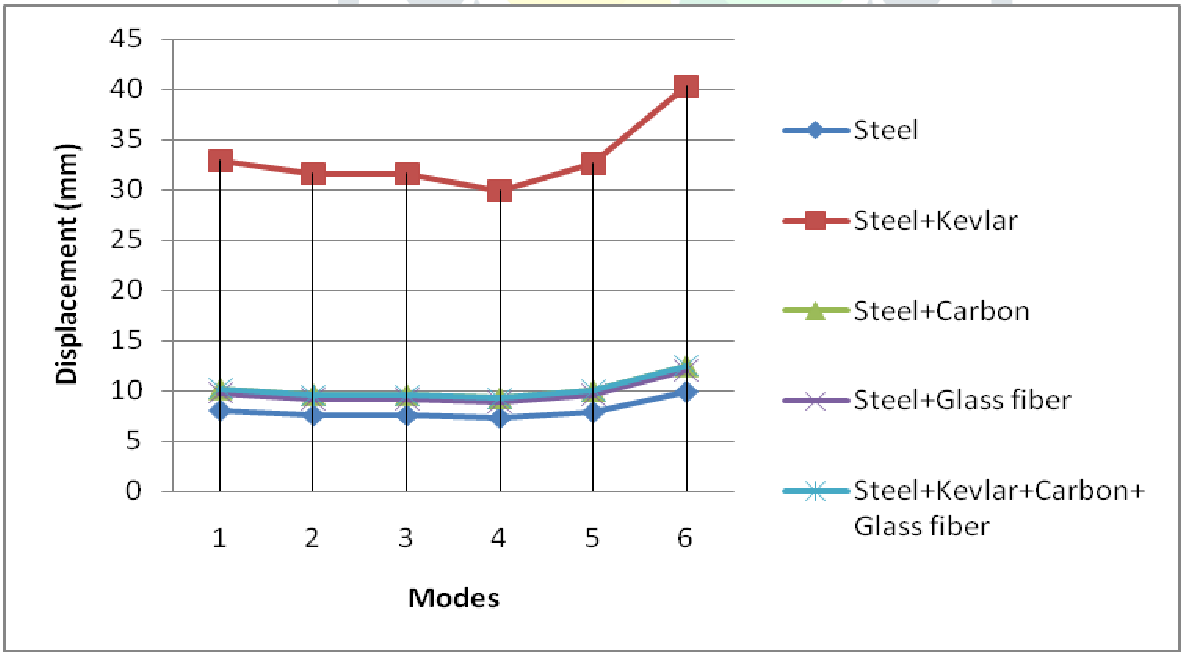
Graph 1- Natural frequency corresponding to different modes for different lay up sequences having all sides clamped

COMPARISION OF DISPLACEMENTS (mm):

PLATES \ MODES		1	2	3	4	5	6	Avg. % change
Steel	Displ.(mm)	8.08	7.59	7.59	7.33	7.91	9.91	
Steel + Kevlar	Displ. (mm)	32.929	31.622	31.622	29.89	32.625	40.338	
	% change	307.53	316.627	316.622	307.77	312.45	307.04	309.26
Steel + glass	Displ. (mm)	9.82	9.23	9.23	8.91	9.62	12.00	
	% change	21.53	21.60	21.60	21.55	21.61	21.08	21.49
Steel + carbon	Displ. (mm)	10.20	9.60	9.60	9.27	10.00	12.50	
	% change	26.23	26.48	26.48	26.46	26.42	26.13	26.37
Steel + Kevlar + Glass + Carbon	Displ. (mm)	10.20	9.50	9.50	9.26	10.00	12.50	
	% change	26.23	25.16	25.16	26.33	21.61	26.13	25.10

Table -3 Maximum displacement corresponding to different modes for various lay up sequence when all sides are clamped

From the Table 3 it can be seen that Steel + Kevlar shows higher displacement in all modes with respect to other plates .While Steel plate shows minimum displacement in all modes , displacement of Steel +Glass plate, Steel + Carbon plate and hybridized composite plate are nearly equal .Higher displacement indicates higher ductility which is very important parameter in case of seismic design. Graph 2 represents the variation in the displacement of different composite plates corresponding different modes in the form of lines when all sides of plates are clamped.



Graph -2 Maximum displacement corresponding to different modes for various lay up sequence when all sides are clamped

COMPARISION OF DYNAMIC STIFFNESS (K):

PLATES \ MODES		1	2	3	4	5	6	Avg. % change
Steel K(KN/mm)		40.47	167.97	167.97	364.37	538.13	543.35	
Steel + Kevlar	K (KN/mm)	60.04	248.57	248.57	537.94	793.56	801.43	
	% change	48.30	47.98	47.98	47.63	47.46	47.49	47.81
Steel + glass	K(KN/mm)	27.22	112.61	112.61	243.52	359.1	362.69	
	% change	32.74	32.95	32.95	33.16	33.26	33.24	33.05(-)
Steel + carbon	K(KN/mm)	30.58	126.54	126.54	273.77	403.81	407.81	
	% change	24.43	24.66	24.66	24.86	24.96	24.94	24.75(-)
Steel + Kevlar + Glass + Carbon	K(KN/mm)	35.97	149.14	149.14	323.22	477.14	481.81	
	% change	11.11	11.21	11.21	11.29	11.33	11.32	11.24(-)

Table 4- Dynamic stiffness corresponding to different modes for various lay up sequence when all sides are clamped

From the Table 4 it can be seen that Steel + Kevlar shows higher stiffness in all modes .While Steel + Glass plate shows minimum natural frequency in all modes , stiffness of mode 2 and mode 3 are equal, these modes are known as degenerate modes. Parameter stiffness indicates the resistance provided by the plates against the dynamic action. As higher the stiffness of the plate, better the behavior of plate with respect dynamic forces.Graph 3 represents the variation in the stiffness of different composite plates corresponding different modes in the form of lines.

Stiffness can be determined from-

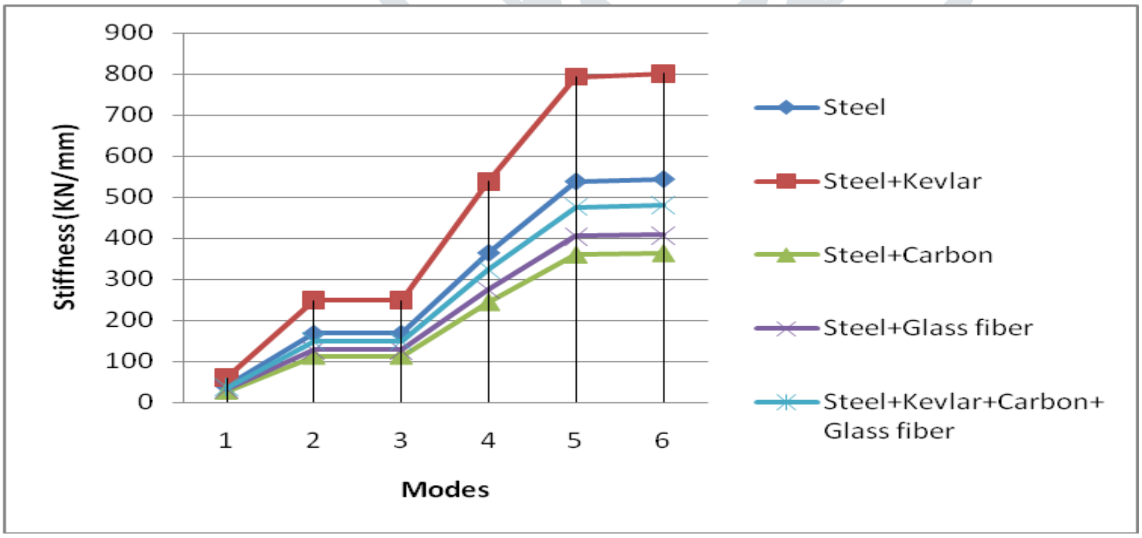
$$T=2\pi\sqrt{(M/K)}$$

Where,

K= Stiffness

M= Mass of Structure

Unit of natural time period is in seconds



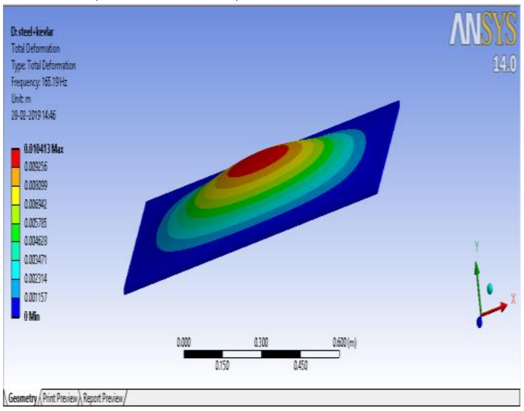
Graph 3- Dynamic stiffness corresponding to different modes for various lay up sequence when all sides are clamped

MODE SHAPES:

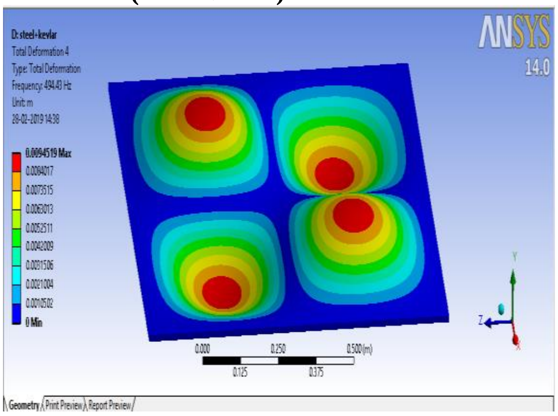
Mode shape is analysis technique for showing the linear response of structures to dynamic loading in a model analysis.Mode is a pictorial representation which represents the shape of plate when it is subjected to resonance. In model analysis we decompose the response of the structure into several vibration modes. A mode is defined by its frequency and shape.. The point at which amplitude changes its sign from positive to negative or vice versa is called mode. Mode 1 shows bending while Mode 2, Mode 3, Mode 4, Mode 5, Mode 6 shows bending as well as torsion.

Mode shapes generated due to free vibration of composite plate made by the composition of steel and Kevlar-

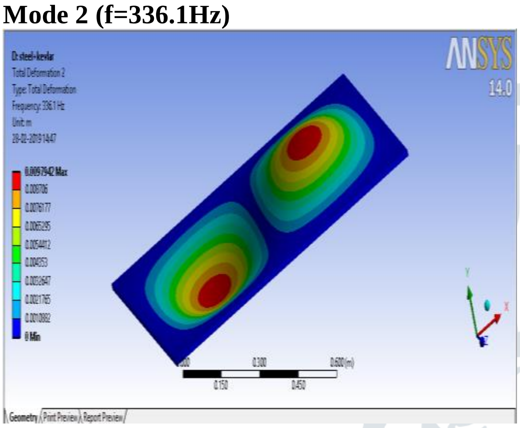
Mode 1(f= 165.19Hz)



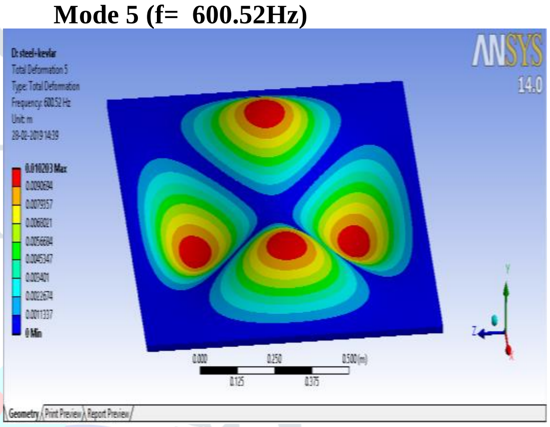
Mode 4(f= 494.43Hz)



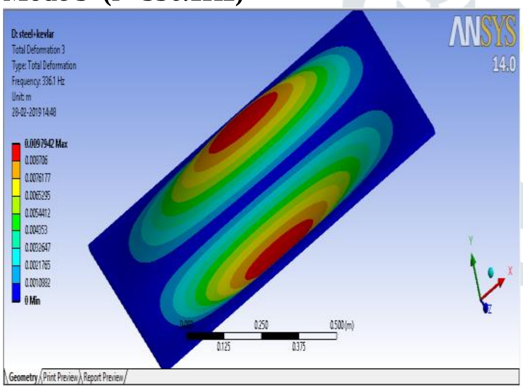
Mode 2 (f=336.1Hz)



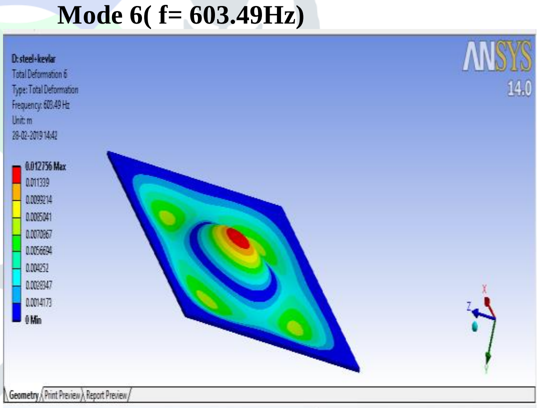
Mode 5 (f= 600.52Hz)



Mode 3 (f= 336.1Hz)



Mode 6(f= 603.49Hz)



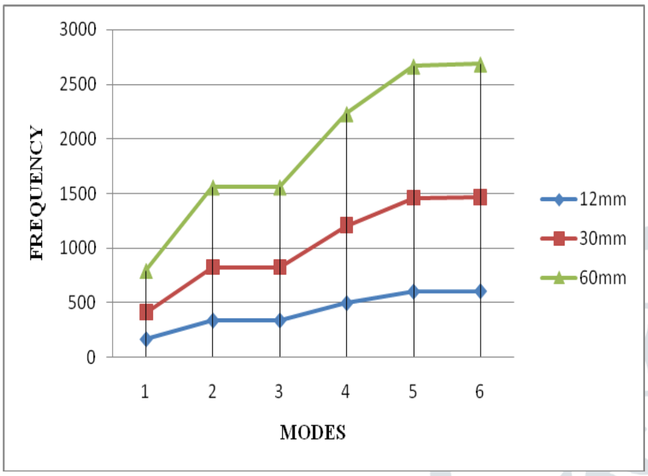
(B) INFLUENCE OF VARIATION IN THICKNESS: Effect of variation in thickness of plate over the free vibration analysis of plate while support condition that is all side clamped keep constant and plate is made of composition of Steel and Kevlar is shown. To show the variation three plates of thickness 12mm, 30mm, 60mm are used.

COMPARISION OF NATURAL FREQUENCY(Hz):

Modes	FREQUENCY(Hz)				
	12mm plate	30mm plate		60mm plate	
		Frequency	% variation	Frequency	% variation
1	165.19	408.66	147.38	790.66	378.63
2	336.1	824.41	145.28	1557.1	363.28

3	336.1	824.41	145.28	1557.1	363.28
4	494.43	1203.4	143.39	2229.6	350.94
5	600.52	1455.7	142.40	2665.8	343.91
6	603.49	1463.8	142.55	2685.4	344.98
Avg %			144.38		357.50

Table5- Frequency corresponding to different modes for different thickness when all sides are clamped



Graph - 4 Frequency corresponding to different modes for different thickness when all sides are clamped

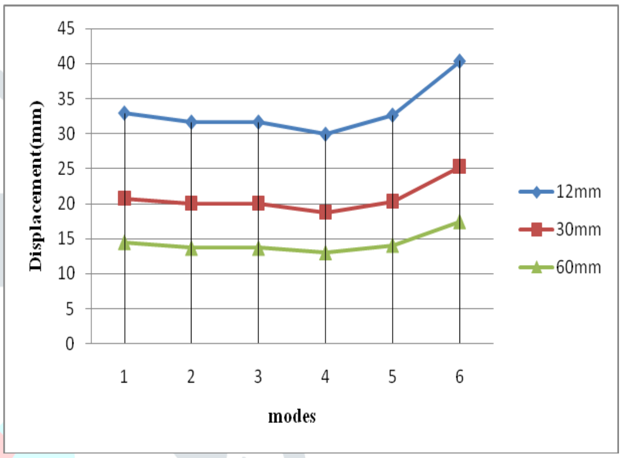
Frequency can be defined as number of oscillations of system per unit time. All the objects of structure have a tendency to vibrate. The rate at which it wants to vibrate is its fundamental time period (natural time period) or un-damped free vibration of a structure. From the Table 5 it can be observed that as the thickness of the plate increases , natural frequency of the system also increases that means system -becomes more resistive.

COMPARISION OF DISPLACEMENTS (mm):

Modes	DISPLACEMENTS (mm)				
	12mm plate	30mm plate		60mm plate	
		displacements	%variation	Displacements	%variation
1	32.929	20.765	36.94	14.549	52.99
2	31.622	20.039	36.62	13.711	56.64
3	31.622	20.039	36.62	13.711	56.64
4	29.89	18.782	37.16	13.062	56.29
5	32.625	20.286	37.82	14.133	56.68
6	40.338	25.296	37.28	17.506	56.6
Avg %			37.12		55.97

Table – 6 Displacement corresponding to different mode for different thickness when all sides are clamped

Displacement or amplitude can be defined as deformation that can be occur when plate subjected to vibration .The displacement is maximum when resonance is occurs. Resonance is a condition when frequency due to external force coincides with the natural frequency of the system. From the Table 6 it can be observed that as thickness increases value of displacement decreases corresponding to different modes of vibration. Displacement of plates corresponding to mode 2 and mode 3 are same as both modes represents same natural frequency.



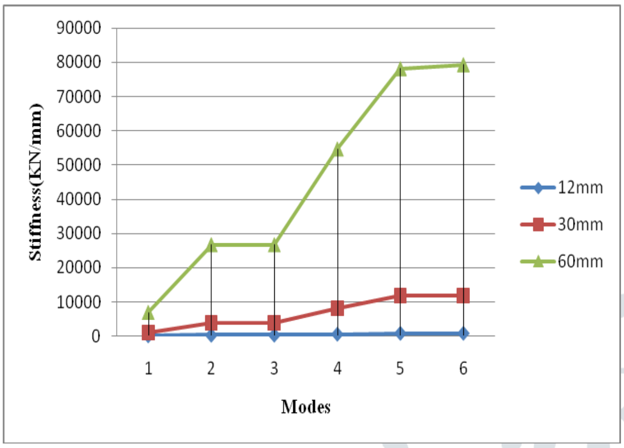
Graph -5 Displacement corresponding to different modes for different thickness when all sides are clamped

COMPARISION OF DYNAMIC STIFFNESS (KN/mm):

Modes	STIFFNESS (KN/mm)				
	12mm plate	30mm plate		60mm plate	
		Stiffness	%variation	Stiffness	%variation
1	60.04	918.73	1430.19	6878.21	11356.0
2	248.57	3738.98	1404.19	26676.5	10632.0
3	248.57	3738.98	1404.19	26676.5	10632.0
4	537.94	7966.8	1380.98	54695.3	1006754
5	793.56	11657.6	1369.02	78190.0	9753.07
6	801.43	11787.7	1370.83	79344.0	9800.31
Avg %			1393.23		10373.4

Table 7- Stiffness corresponding to different mode s for different thickness when all sides are clamped

Stiffness can be simply defined as resistance against deformation. Where deformation may be linear or angular. From the Table 7 in can be observed that as the thickness increases the stiffness of the plate increases that means plate becomes more dynamic resistance as thickness increases. This is because as thickness increases mass of the plate increases and frequency also increases which results in increase in stiffness of plates. Mode 2 and Mode 3 shows same stiffness while stiffness of plates for Mode 5 and Mode 6 are nearly equal.



Graph 6 - Stiffness corresponding to different modes for different thickness when all sides are clamped

CONCLUSIONS:

(A) Free vibration analysis of plates by taking constant thickness that is 12 mm and fixed boundary condition that is CCCC by taking variation in material used in composition layers gives following results-

For frequency

- Frequency of Steel + Kevlar plate is 58.04 % higher than that of Steel plate
- Frequency of Steel + Carbon plate is 10.63% higher than that of Steel plate
- Frequency of Steel + Glass plate is 0.327% higher than that of Steel plate
- Frequency of Steel + Kevlar + Carbon +Glass plate is 19.27% higher than that of Steel plate

For displacement

- Displacement of Steel + Kevlar plate is 309.26% higher than that of Steel plate
- Displacement of Steel + Carbon plate is 26.37% higher than that of Steel plate
- Displacement of Steel + Glass plate is 21.49% higher than that of Steel plate
- Displacement of Steel + Kevlar + Carbon +Glass plate is 25.10% higher than that of Steel plate

For stiffness

- Stiffness of Steel + Kevlar plate is 47.81% higher than that of Steel plate
- Stiffness of Steel + Carbon plate is 24.75 % lesser than that of Steel plate
- Stiffness of Steel + Glass plate is 33.05% lesser than that of Steel plate
- Stiffness of Steel + Kevlar + Carbon +Glass plate is 11.24% lesser than that of Steel plate

From the above data it can be determined that Steel + Kevlar plate shows highest frequency and more stiffness, therefore Steel + Kevlar plate is best plate out of all composite plates.

(B) Free vibration analysis of plates by taking Steel + Kevlar plate and constant boundary condition that is CCCC by taking variation in thickness gives following results-

For frequency

- Frequency of 30mm plate is 144.38% higher than that of 12mm
- Frequency of 60mm plate is 357.50% higher than that of 12mm

For displacement

- Displacement of 30mm plate is 37.12% less than that of 12mm
- Displacement of 60mm plate is 55.92% less than that of 12mm

For stiffness

- Stiffness of 30mm plate is 1393.23% higher than that of 12mm
- Stiffness of 60mm plate is 10373.49% higher than that of 12mm

From the observations it can be determined that as the thickness increases plate becomes more resistive against the dynamic action.

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