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INFLUENCE OF FIBER LAYER HYBRIDIZATION ON FREE VIBRATION OF HYBRID COMPOSITES USING FEM/ANSYS

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ABSTRACT

The present investigation was mainly concern with the free vibration analysis of hybrid composites using validated finite element analysis through the medium of general-purpose program i.e., FEM/ANSYS. Influence of synthetic (glass) fiber volume fraction in a total constant fiber volume and their orders of layup on natural frequencies was the main focus of study. The modal behavior of hybrid composite panels was compared with the modal behavior of NFRP composites. From the present study it was observed that hybridization of synthetic (glass) fibers with natural fibers reinforced in composite improves the overall dynamic behavior in general and free vibration behavior in particular. Number of synthetic fiber layers i.e., synthetic fiber volume and their layup positions influences more on natural frequency. From the present studies it is evident that layup of synthetic fiber layers near to the free surfaces (both sides) of the panel, will have better influence on natural frequency.

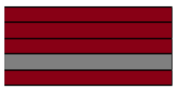
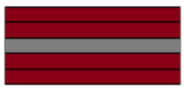
Keywords: Hybrid Composites Free Vibration Fiber Hybridization Layup Order Experimentation And FEM/ ANSYS.

I. INTRODUCTION

Composites reinforced with glass fibers are quite popular advanced structural materials available and used in entire world in many fields of applications due to their diverse features and functional benefits [1-3]. Now a day natural fibers obtained from plants and natural resources for composites are gaining popularity due to some advantages i.e. they are less dense, recyclable and biodegradable. However totally reinforced natural fiber plastic composites are not applicable for particular regions. To make them applicable/to improve the desired properties n it, a little volume fraction of synthetic fibers will be added to natural fibers. The process of mixing two different fibers to a composite is known as hybridization. Use of hybrid composites is gaining popularity and growing demand for aircraft industries. Many researchers around the globe have carried out the extensive research to study the physical properties and dynamic behavior under external load. Taber and Viano [4] have obtained the resonant frequencies for Tirnoshanko beams of varying cross section by using Transfer matrix technique. From the results they suggested that the uniform beam element provides an accurate solution for a wide variety of engineering applications. Calim [5] presented the numerical procedure to analyze the free and forced vibrations of non-uniform composite beams with various boundary conditions such as Clamped-Free, Simply Supported and Clamped-Clamped. Vo and Lee [6] derived the numerical results to study the free vibrations of thin-walled composite beams addressing the effects of fiber angle and boundary conditions on the vibration frequencies and mode shapes of the composites. Teh and Huang [7] have studied the torsion-flexure coupling effect of orthotropic beams. They concluded that vibration behavior is generally dependent on reinforcing fiber orientation angles and mode order. Hence the mode shapes can change suddenly with a small increase in fiber orientation. Krishnaswamy et al [8] attempted a dynamic equation governing the free vibration of laminated composite beams using Hamilton's principle including the transverse shear and rotary inertia effects. Chandrashekhara et al [9] gives the exact solutions for the free vibration of laminated composite beams including shear deformation and rotary inertia effects. Cui Yanbin et al. [10] made the finite element modal analysis to obtain the modal parameters and natural frequency of the turbine blade. Ghaffari et al [11] investigates the influences of de-lamination on the natural frequencies, frequency and voltage response of smart non-uniform thickness laminated composite beams. Abramovich and Livshits [12] made an approach to the problem of the free vibrations of a cross-ply non-symmetric laminated composite beam which include shear deformation, rotary inertia and bending-stretching coupling terms. Nabi and Ganesan [13] develop a generalized beam element for the free vibration analysis of composite beams by considering bi-axial bending, extensional and torsional effects and also including shear deformations. From the above literature review it was observed limited research has carried out on the influence of method of layup orders of synthetic fibers with natural fibers in hybrid fiber reinforcement composites on free vibration. Furthermore, the composite panels used for aircraft design are subjected to variable loads which cause undesirable vibrations. This necessitates the study of vibration behavior of these structures for safe design. Thus, the dynamic studies of these structures are utmost essential for safety of systems. For complete dynamic study, knowledge of free vibration studies is necessary. In context of above fact, the present investigation is generally concerned with free vibration studies of hybrid composites made up of glass and jute fibers reinforced with epoxy resin. Influence of synthetic (glass) fiber volume fraction in a total constant fiber volume and their orders of layup on natural frequencies was the main focus of study. The various models of hybrid composites with different layup orders of synthetic fibers chosen for study are as shown in table 1.

Type-1(HFRC-1) No of GFL=01 No of NFL=04 Layer position Bottom most 1^{st} & Topmost 5^{th}

Table 1: Models of hybrid composites with different layer order (20% fiber volume)

Model	Model-1	Model-2	Model-3
Layer position (From bottom to top)	2^{nd}	3^{rd}	4^{th}
Composite section (20% glass fiber volume)			

Glass fiber Jute fiber

II. METHODOLOGY

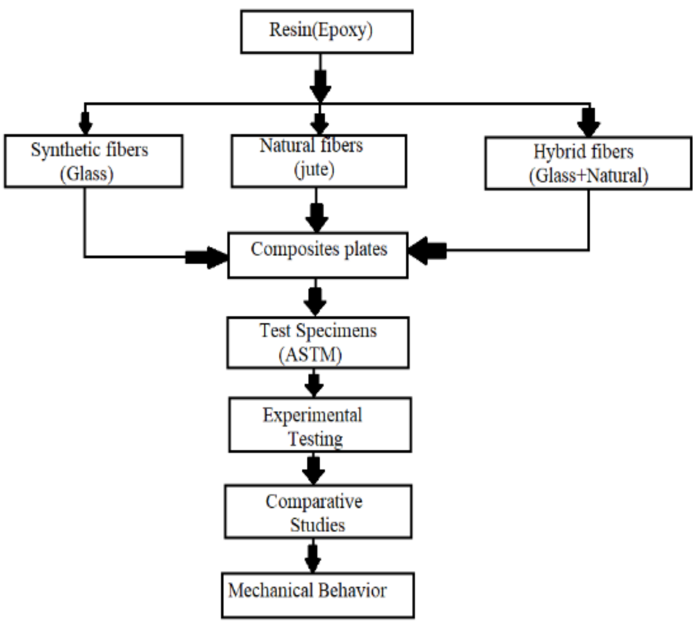


Figure 1: Workflow diagram for present project work

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For safe design and manufacture of hybrid composites complete information regarding static as well as dynamic behavior and their properties are quite essential. Especially in low weight structures like air bus, space craft design become more sensitive. Furthermore, the composite panels used for aircraft design are subjected to variable loads which cause undesirable vibrations. This necessitates the study of vibration behavior of these structures for safe design. Thus, the dynamic studies of these structures are utmost essential for safety of systems. For complete dynamic study, knowledge of free vibration studies is necessary. The presence of combination of synthetic and natural fibers in hybrid composites makes the analysis complex. Hybridization of synthetic fibers with natural fibers to improve the strength of panels leads to anisotropic behavior. Hence for safe design of these structures dynamic analysis is utmost essential.

To carry out the above project work experimental tests as well as numerical analysis were performed precisely with great care. The methodologies included experimental investigations, finite element analysis (FEM/ANSYS) and theoretical calculations of modal analysis. To pursue this task a systematic procedure is followed. The complete workflow diagram is as shown in figure 1.

III. EXPERIMENTAL FREE VIBRATION ANALYSIS OF GFRP COMPOSITES

In this section of study free vibration analysis of glass fiber reinforced plastic (GFRP) composite was carried out experimentally. The vibration test specimens of required dimensions 250x20x 6.2 mm^3 were prepared from fabricated glass fiber reinforced plastic composite panel. For clamping and to make fixed support at one end as cantilever an additional length of 50mm provided to make an overall length as 300mm. The specimen dimensions follow ASTM E756.The fabricated composite panel consists of 5 layers of bi-woven glass fiber cloth of each 0.2 mm thickness and a total thickness of panel as 1.8mm. A photocopy of prepared specimens is shown in figure-2.

Figure 2: Fabricated GFRP composite test specimens

After marking various impact points over the specimen, it is rigidly mounted over the test table as cantilever beam as shown in figure 2. After placing the accelerometer at one marking point and remaining initial set up was completed. An impulse is generated over specimen using impact hammer. The sensor receives the excited signal will be processed at FFT analyzer. The frequency response gets recorded and displayed on the system by means of universal software. Precession in the measurement can be reflected (coherence curve). The first mode frequency as obtained from experimentation is as displayed in figure 3. The technical data and the test results given in table 2.

Figure-2(a): Preparation of actual setup for experimentation

Figure-2(b): Stages of vibration testing of GFRP composites

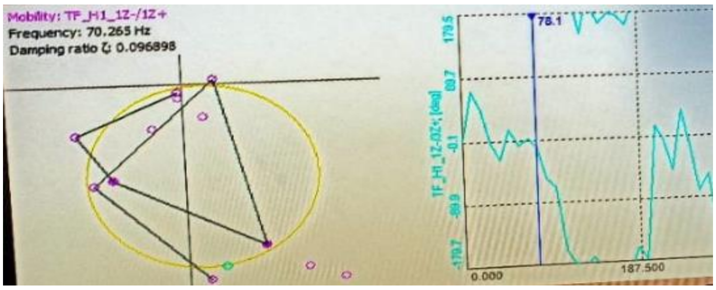

Figure-3: 1st mode frequency domain obtained from experimentation

Table-2: Technical data & test result of GFRP Composite plate

Material	No of fiber layers	Thickness of fiber(t_f)	Span (l)	Width(b)	Thickness of Composite (tc)	1st mode frequency
GFRP Composite	5	0.2 mm	250 mm	20 mm	1.8 mm	70.26 Hz

To correlate the experimental results, finite element analysis was performed for free vibration analysis using validated FEM/ANSYS [15]. For modeling and analysis of component under test, the following technical data as given in table-3 is used. For descritization of composite plate 8-noded shell 281 elements are chosen and 5 layers of section layup were used for analysis.

Table-3: Engineering properties of GFRP composite plate

E_x MPa	E_y MPa	E_z MPa	ν_{xy}	ν_{yz}	ν_{zx}	G_{xy} MPa	G_{yz} MPa	G_{zx} MPa
$44x10^3$	$44x10^3$	$10x10^3$	0.36	0.49	0.49	$3.74x10^3$	$2.37x10^3$	$2.37x10^3$

After modeling and pre-processing, ANSYS program was run successfully, and the first four modal frequencies and mode shapes of the model were extracted from post files of analysis as shown in figure 4. The values of frequencies obtained from post results are as given in table 4.

Table-4: First four frequencies of GFRP composite plate

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***** INDEX OF DATA SETS ON RESULTS FILE *****

 SET   TIME/FREQ    LOAD STEP   SUBSTEP  CUMULATIVE
   1   80.202           1          1          1
   2   307.12           1          2          2
   3   454.41           1          3          3
   4   622.30           1          4          4
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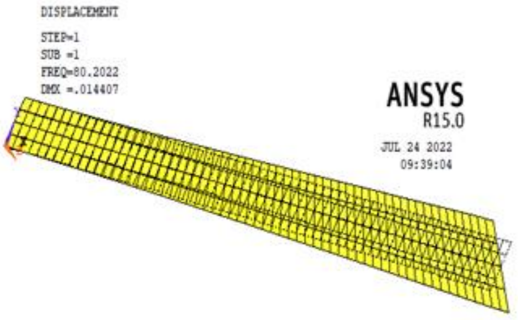

Figure-4(a): 1st mode shape of GFRP composite

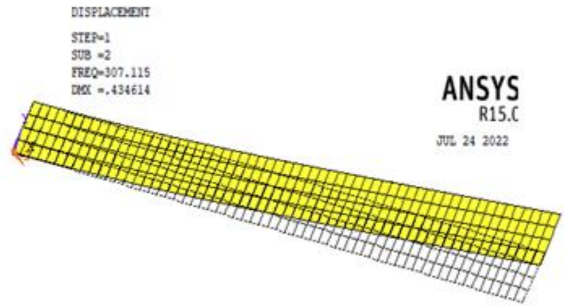

Figure- 4(b): 2nd mode shape of GFRP composite

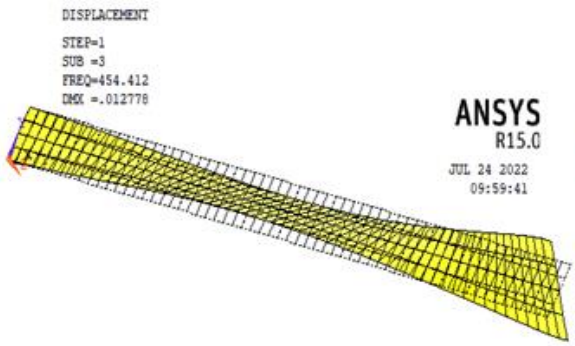

Figure-4.(c): 3rd mode shape of GFRP composite

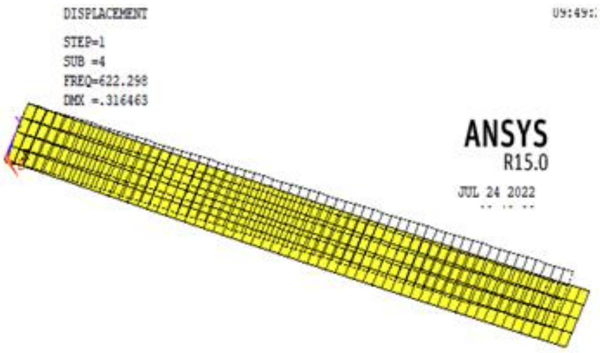

Figure-4(d): 4th mode shape of GFRP composite

A comparison was made between the experimental and FEM/ANSYS solutions for 1st mode frequency as given in table 5.

Table-5: Comparison of Experimental and FEM/ANSYS results

1st mode natural frequency (Hz)		% Error
Experimental (fn)	FEM/ANSYS (f_n)	
70.26	80.202	14.12

Upon comparison it was noted that finite element method can provide solutions close to actual/analytical results by upon pre-processing the modeling data. The validated analysis tool i.e. FEM/ANSYS is extensively used to study the influence of layer hybridization on natural frequency of hybrid composites.

IV. FREE VIBRATION ANALYSIS OF HYBRID COMPOSITIONS

In the previous section, free vibration analysis of glass fiber reinforced plastic (GFRP) composites was carried out using experimental technique. The experimental results were correlated using numerical solutions. The correlation shows that the solution obtained by FEM/ANSYS is close to experimental results. In this section modal analysis of hybrid composites were carried out using validated finite element analysis through the medium of general purpose program i.e. FEM/ANSYS. Major attention was given to study the influence of synthetic fiber layer (20% of total fiber volume) order or layup position on natural frequency of hybrid composite. The various layup orders considered for study is as shown in Table-1. To maintain the uniformity throughout the analysis of above models , some constant analysis data was used as follows.

Type of composite: Hybrid of Glass-jute fiber reinforced plastic composites (HFRP-1)

Total no of fiber layers =05 (GF=01; JF=04)

No of Synthetic layers (Glass fiber) = 01 (20% of total fiber volume)

No of layup orders: 03($H1_2$,$H1_3$,$H1_4$) : subscript 2,3,4 indicate the layup orders

Dimensions of test specimen 300x20x6 mm^3

Span length=250mm

Type of elements: 8 node shell 281

Prior to study of influence of fiber layer hybridization on natural frequency of hybrid composites, for comparison, free vibration analysis of pure natural fiber reinforced composite (NFRC) were studied under same test conditions. Finite element analysis was performed on NFRP composite model of above specification and analysis data. The post processing results of analysis i.e. modal frequencies and mode shapes of NFRP composite panel was obtained as shown in figure-5.

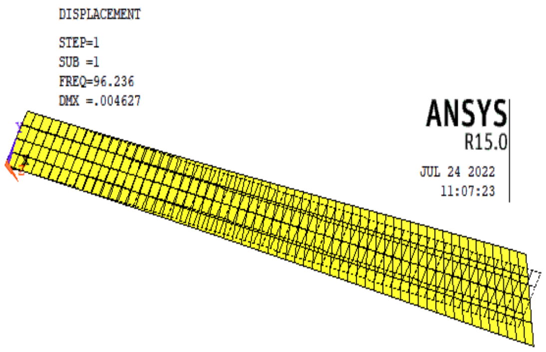

Figure-5(a): 1st mode shape of NFRP composite

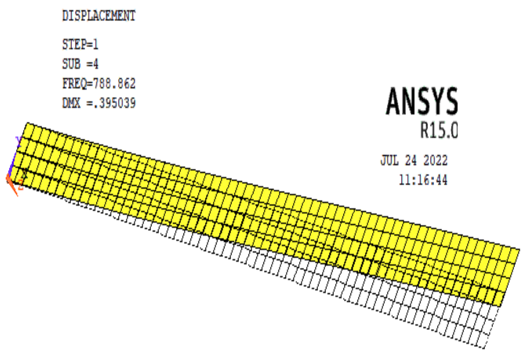

Figure-5(b): 4th mode shape of NFRP composite

Finite element analysis was performed on all hybrid composite models chosen for study and first four natural frequencies were extracted from post files. The outcome of result summary obtained from post processing files of FEM/NSYS is given in table-6.

Table-6: First four natural frequencies of various models of hybrid composites

Table-6(a): Result summary of Model-1

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	110.20	1	1	1
2	656.81	1	2	2
3	658.38	1	3	3
4	847.20	1	4	4

Table-6(b): Result summary of Model-2

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	97.613	1	1	1
2	581.39	1	2	2
3	714.46	1	3	3
4	909.30	1	4	4

Table-6(c): Result summary of Model-3

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	110.20	1	1	1
2	656.81	1	2	2
3	658.38	1	3	3
4	847.20	1	4	4

For comparison study the first mode frequency of the models chosen for study is as given below table-7.

Natural frequency of NFRP composite (1st mode) =96Hz

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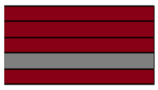
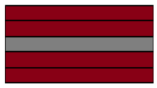
Table-7: Natural frequency of single layer hybridization models

Model (Type)	Model-1 ($H1_2$)	Model-2 ($H1_3$)	Model-3 ($H1_4$)
Layer position	2	3	4
Composite section			
1st mode frequency	110	97	110

V. RESULTS AND DISCUSSIONS

The demand and applicability of composite materials is increasing in all technical industries. Researchers and technocrats around the globe are in search of new and advanced constituents for reinforcements used in composite materials. In opinion of researchers, the performance behavior of composite materials mainly relay on the composition of matrix and reinforcement [15]. For effective design and construction of composites, proper understanding of behavior of all their constituents under operation prior to manufacture is quite essential. This is mainly because, composite construction permits the tailored constituents i.e., reinforced materials, matrix materials, hardeners and method of manufacture dueto which the derived /global properties get modified or can be altered. Making use of this advantage, hybridization of reinforcement is preferred. For structural application hybrid composites are preferred rather than natural fiber composites due to improved properties. However presence of hybrid fibers adds to the complexity of the analysis and design of such structures. At the same time most of the composite structures subjected to undesirable vibration, deflection during their service life. For safety and good service life of these structures dynamic studies are quite essential. Furthermore free vibration analysis is the stepping stage of dynamic analysis. In view of above fact, the present investigation was mainly focused on the study of free vibration behavior of hybrid composites made up of glass-jute fibers and epoxy resin. The validated finite element analysis using Ansys code was effectively used. The main purpose of present investigation was to study the influence of synthetic fibers (Glass fiber) and their layup orders on natural frequency of the hybrid composites. To pursue the goal, at first GFRP composite specimens were tested and the results were correlated with numerical solution using FEM/ANSYS as shown in figure-6.

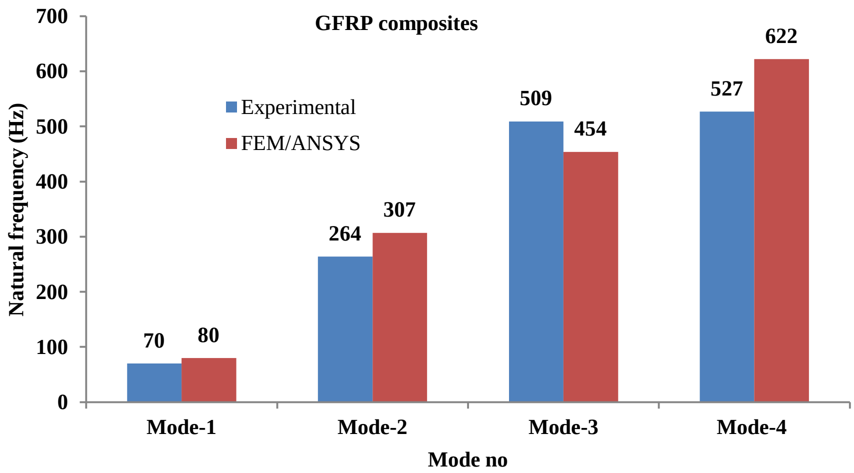


Figure-6: Graph of f_n v/s mode no for GFRP composite

After successful correlation, influence of single layer hybridization (20% of total fiber volume) on natural frequency of hybrid composites studied. Three hybrid models of single layer hybridization i.e. $H1_2$, $H1_3$ and $H1_4$

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in which subscript number indicates the layer order of hybridization considered for investigation. Free vibration analysis was carried out using validated FEM/ANSYS. Natural frequencies were extracted for all the models under study. For comparison 1st mode frequency of all the models were tabulated in table-7. A comparative graph of 1st mode frequency v/s hybrid models was drawn as shown in figure-7 mode number for various layer order hybridization is as shown in figure-8.

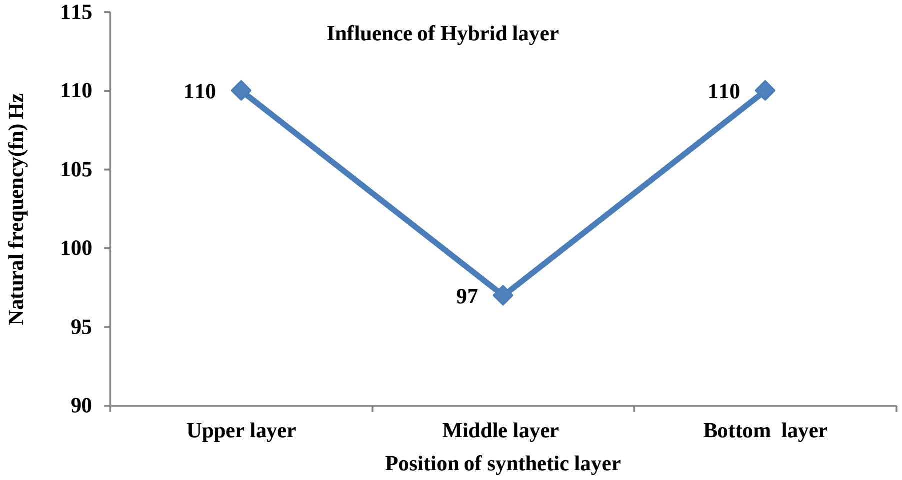

Figure-7: Natural frequency v/s various hybrid models

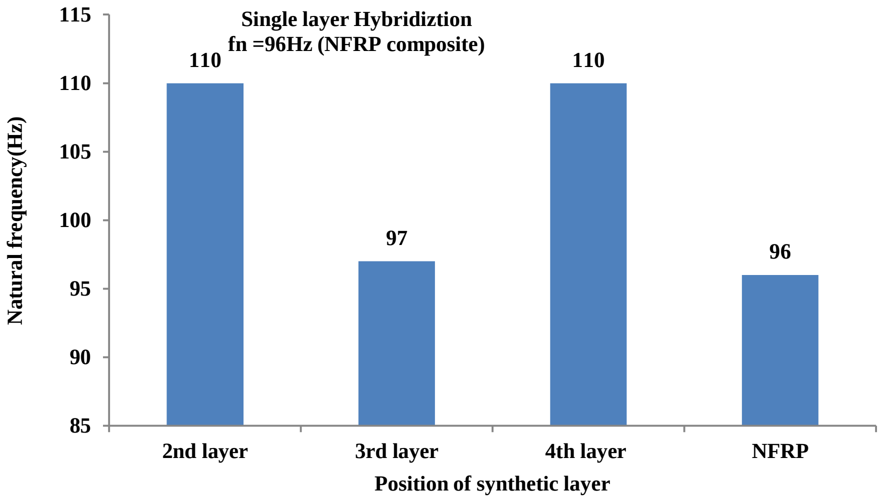

Figure-8: Comparison of fn in NFRP& HFRP composites

The behavior of hybrid panels was compared with the behavior of NFRP composites as given in figure-8. From the present investigation it was noted that natural frequency of model 1&3 where the synthetic fibers are away from neutral axis are higher than model-2 where the synthetic fiber is at neutral position. This indicates that layup of synthetic fiber near extreme regions i.e. away from neutral fiber improves the structural rigidity.

From the present study it is evident that hybridization of glass (synthetic) fibers with natural fibers reinforced composite improves the overall mechanical behavior in general and free vibration behavior in particular. Number of synthetic fiber layers and their positions/layup influences more on natural frequency. From the present study it is evident that layup of synthetic fiber layers away from neutral axis may have better influence than at the middle r neutral axis.

VI. CONCLUSION

Free vibration analysis of hybrid composites were carried out using validated FEM/ANSYS. From the present investigation it is obvious that hybridization of reinforcement with little volume fraction of synthetic fibers in natural fibers for composite construction produces tremendous improvements in dynamic behavior in general and free vibration behavior in particular. Number of synthetic fiber layers i.e. volume fraction of synthetic fibers and their layup positions also influences more on natural frequency of the structure. Layup of synthetic fiber layers away from neutral axis will have better influence on natural frequency.

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