

# VIBRATION ANALYSIS OF WOVEN HYBRID CARBON-KEVLAR COMPOSITE LAMINATES

*G Ram Vishal<sup>1</sup>, Subha S<sup>1</sup>, Rahul B<sup>2</sup>*

<sup>1</sup>School of Aeronautical Sciences, Hindustan Institute of Technology and Science, Chennai

<sup>2</sup>Department of Aeronautical Engineering, Nitte Meenakshi Institute of Technology, Bangalore

## **Abstract**

*Composite materials have revolutionized the field of engineering and design, providing the ability to combine two or more materials with different properties to create new materials with enhanced characteristics. The intricate process of weaving together carbon fiber and Kevlar fiber to create a 3D composite fabric is not only fascinating but also results in a beautiful, intricate pattern. Hand weaving is an art that requires precision and skill, and when combined with the use of carbon fiber and Kevlar fiber, it results in a stunningly intricate and durable fabric. The fibers are woven together at a binding angle of 45 degrees, creating a strong and flexible structure that can withstand immense stress and strain. In this work, the fabricated specimens were prepared in various architectures as a combination of carbon and Kevlar fibers. The composite was analyzed for vibrations, and the findings were contrasted with theoretical and numerical predictions. The superior stiffness and mechanical properties of carbon fibers were found to result in generally higher natural frequencies compared to Kevlar fibers.*

**Keywords:** 3D woven composites, Vibration analysis, Carbon fiber, Kevlar fiber, Modal analysis

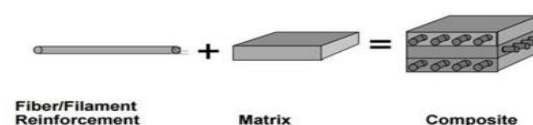
**\*Author for Correspondence** E-mail: ramvishal32@gmail.com,

## **1. INTRODUCTION**

Composite materials result from combining two or more materials with distinct properties that cannot be dissolved or homogenized. These materials come together to form a new substance with unique and improved characteristics not found in the individual components. Alternatively, the composite material may take the form of a matrix-phase/reinforcing-phase structure, where two or more components unite on a macroscopic scale but remain insoluble in each other. The amalgamation of these diverse materials creates a synergistic effect, enhancing the overall performance of the composite material. This enhancement may include increased strength, stiffness, durability, and resistance to various environmental factors such as high temperatures and moisture [1]. In summary, composite materials have become crucial in industries like aerospace, automotive, construction, and sports equipment, revolutionizing the approach to material selection for engineers and designers, opening up new possibilities for innovation and progress in the field.

Composites comprise a reinforcing phase, such as fibers, particles, or flakes, embedded in a continuous matrix phase [16]. In contrast to impure metals, composites display macroscopic heterogeneity, resulting in distinct and improved properties [10]. The reinforcing phase, usually stronger and less ductile, is paired with a weaker but more ductile matrix phase. Adhesion is enhanced, and protection against environmental effects is provided through the use of coupling agents and coatings. Decreasing fiber cross-sectional area increases strength but decreases ductility, while properties like fiber length, orientation, and material influence the stiffness and strength of the composite.

COMPOSITE=REINFORCING PHASE+MATRIX PHASE.



**Fig:1.** Composition of composite

Composites encompass various examples such as woods and bones, along with artificially created materials like concrete, plywood, and cements. Composites are characterized by a reinforcing phase, such as fibers, particles, or flakes, embedded within a continuous matrix phase. In contrast to impure metals, composites display macroscopic heterogeneity, resulting in distinctive and enhanced properties. The reinforcing phase, generally possessing greater strength and less ductility, is balanced by a matrix phase that is weaker but more ductile. Utilizing coupling agents and coatings enhances adhesion and provides protection against environmental effects. Adjusting the fiber cross-sectional area can increase strength while reducing ductility, and the properties of fibers, such as length, orientation, and material composition, impact the stiffness and strength of the composite. Examples of composites range from natural substances like woods and bones to human-made materials like concrete, plywood, and cements [13].

## 2. MATERIALS AND FABRICATION

In this study, an attempt was made to secure the 3D woven composite at an angle, deviating from the conventional Trellis frame test that applies force uniformly in all directions to assess the composite strength [15]. The objective is to bind the layers of weft and warp at a 45-degree angle to investigate the resulting alterations in its mechanical characteristics [23]. Carbon and Kevlar are employed as tows in their entirety. Four variations of 3D woven composites are crafted, each designated as follows:

- (X, Y, Z) : (Carbon, Carbon, Carbon) - Carbon serves as the weft, warp, and binder [8].
- (X, Y, Z) : (Carbon, Carbon, Kevlar) - Carbon functions as the weft and warp, while Kevlar is utilized as the binder.
- (X, Y, Z) : (Kevlar, Kevlar, Kevlar) - Kevlar is employed as the weft, warp, and binder.
- (X, Y, Z) : (Kevlar, Kevlar, Carbon) - Kevlar is utilized as the weft and warp, with Carbon serving as the binder [9].

The fabrication involves the use of Carbon 3K fibers and Kevlar@49 fibers to create hybrid composites, incorporating their respective properties as outlined in Table 1. Two hybrid 3D woven plates are to be produced in this process.

**Table-1 Fiber properties**

Fiber	Carbon	Kevlar
Tensile strength	3800MPa	3620MPa
Tensile Modulus	240GPa	112GPa
Density	1.78g/cm <sup>3</sup>	1.45g/cm <sup>3</sup>
Strain	1.6%	2.4%



**Fig:2.** Carbon- Carbon- Kevlar



**Fig:3.** Kevlar- Kevlar- Carbon

## 3. FABRICATION

Fabric is a textile created through the interweaving or interlocking of multiple yarns. Similarly, a composite fabric is produced by intricately weaving a specified number of yarns to form a fabric structure [2]. Various fabric weaves exist, each possessing distinct mechanical and formability

characteristics, some of which are illustrated in the accompanying figures. In our current investigation, the selected fabric comprises a [0/90] plain weave, with layers stacked on top of each other and secured through stitching with a binder fabric. Prior to the weaving process, a wooden frame measuring 40\*40 cm<sup>2</sup> was constructed. The construction involved the following steps:

- Cutting and joining 40 cm wooden pieces.
- Drilling holes with a diameter of 0.2 mm on the top face at intervals of 10 mm.
- Trimming bicycle spokes to the required length and affixing them in the drilled holes.
- Strengthening the joints using a mixture of Fevicol and wood powder.



*Fig:4. Weaving Frame*

#### **(a) Fabric Weaving**

The fabric weaving procedure, as delineated in [6], involves the following steps:

- Placement of the weft yarn onto the frame.
- Alternating up and down weaving of the warp yarn between the weft yarns.
- Repetition of the above process to weave a total of 5 fabrics.
- Introduction of the binder yarn at a 45-degree angle in the final fabric.
- Application of masking tape around the borders to prevent fiber pulling, followed by the removal of the frame.

#### **(b) Types of fabrics:**

We have hand-woven four different types of fabrics using different fibers [3]. Different types of fabrics based on weft-warp-binder, are as:

- Carbon-Carbon-Carbon
- Carbon-Carbon-Kevlar
- Kevlar- Kevlar-Kevlar
- Kevlar- Kevlar-Carbon
- Carbon-Carbon
- Kevlar-Kevlar

#### **(c) Matrix**

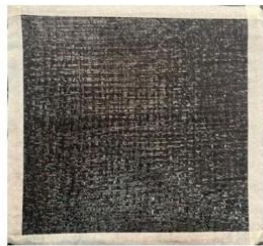
In this study Araldite LY 556 resin and HY 951 hardener were used [4]. Their property of resin as follows: A resin to hardener ration of 10:1 by weight was taken and their weight fraction consider shown in Table 2. The liquids were first poured on a container and mixed together. Then the mixture was applied on the fabric uniformly.

#### **(d) Vacuum Bagging**

Post-preparation, the fabric underwent transformation into a laminate through the vacuum bagging process. Despite the inherently low permeability of 3D woven weaves, effective wetting was ensured by applying the matrix on both sides of the fabric [5]. The choice of vacuum bagging was driven by its cost-effectiveness, and the following sequential steps were executed:

- The mold was covered with a Mylar sheet, and release wax was applied.
- The Mylar sheet was layered with peel ply, followed by the stacking of the 3D woven fabric.

- A mixture of resin and hardener was poured onto the fabric, ensuring even spreading. A Resin-Hardener ratio of 10:1 was maintained.
- On top of the resin-wetted fabric, peel ply was added, followed by the placement of a breather fabric.
- A vacuum bag film of appropriate size was cut from the roll.
- Sealant tape was applied around the vacuum bag film, with a one-way valve attached to one face of the bag.
- The mold was positioned on the vacuum bag film and sealed.
- A pipe was connected to the vacuum pump.
- A vacuum pressure of 25 inches of Hg was sustained.
- The vacuum pump was activated and left to operate for 6 hours, after which it was disconnected and the setup was left undisturbed for 48 hours.



**Fig:5.** Carbon-Carbon-Carbon Fabric



**Fig:6.** Carbon-Carbon-Kevlar Fabric



**Fig:7.** Kevlar-Kevlar-Kevlar Fabric



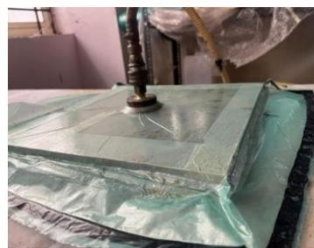
**Fig:8.** Kevlar-Kevlar-Carbon Fabric



**Fig:9.** Carbon-Carbon Fabric



**Fig:10.** Kevlar-Kevlar Fabric



**Fig:11.** Vacuum Bagging

Following were the compositions of resin, hardener and fabric used to fabricate two specimens:

**Table-2: Resin, Hardener and Fabric used to fabricate**

S. No	Specimen	Fabric weight, Gm	Resin weight, gm	Hardener weight, gm

1	Carbon-Carbon-Carbon	62	62	6.2
2	Carbon-Carbon-Kevlar	60	60	6
3	Kevlar-Kevlar-Carbon	58	58	5.8
4	Kevlar-Kevlar- Kevlar	55	55	5.5

#### 4. EXPERIMENTAL WORK

The evaluation of composite materials, including Kevlar and carbon, involves a vital stage known as vibration testing, which plays a key role in assessing their performance and durability. The primary objective of this vibration testing is to discern the natural frequencies, modes of vibration, and damping characteristics exhibited by each composite configuration when subjected to diverse loading conditions [18]. By exposing each configuration to a spectrum of frequencies and amplitudes of mechanical vibrations, essential data on the dynamic properties of the material are collected. This process enables the identification of any potential structural weaknesses or defects [17]. Through meticulous analysis of the results obtained from the vibration tests, this study aims to optimize the design and enhance the performance of each composite configuration. The ultimate goal is to ensure that these configurations adhere to the required standards for safety and reliability within their designated applications.

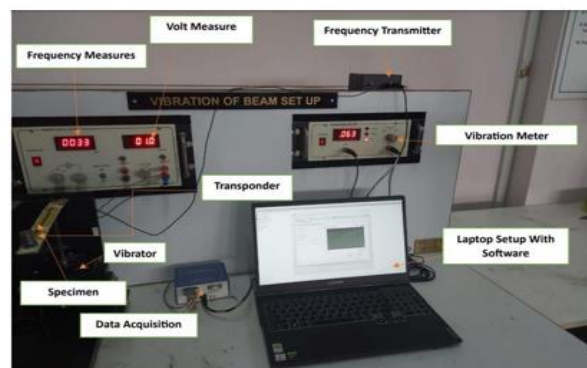
**Table-3 Dimension of specimen**

S. No	Notation	Meaning	Thickness in cm
1	W	Width of specimen	2.5
2	LO	Length overall	26
3	G	Gauge Length	24
4	T	Thickness	0.02 – 0.05

##### (a) Vibration Testing Procedure:

The test procedure for the vibration of a cantilever beam in a beam setup testing beam [12] typically involves the following steps:

- Prepare the cantilever beam and instrumentation.
- Apply controlled excitation to the beam at a specific frequency.
- Collect data on the response of the beam.
- Analyse the data to determine natural frequencies, damping coefficients, and mode shapes.
- Interpret the results and draw conclusions about the behavior of the beam.



**Fig:12. Setup for Vibration Movement**

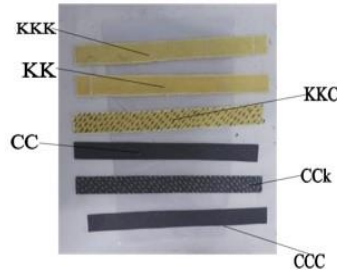


Fig:13. Test Specimens

**5. THEORITICAL ANALYSIS:**

Theoretical analysis in this context is centered on comprehending the vibration attributes of hybrid carbon-Kevlar composite laminates with stitching. This process encompasses the formulation of analytical models and the execution of numerical simulations aimed at forecasting the dynamic response of the laminates [22]. The analysis entails the determination of mode shapes, natural frequencies, and damping characteristics. Parametric studies are additionally carried out to explore the impact of variables like stitching pattern and laminate layup on the vibration response. This theoretical analysis serves as a cornerstone for interpreting experimental outcomes and significantly contributes to the comprehensive understanding and optimization of these composite laminates.

$$\text{Moment of Inertia } I = \frac{wt^3}{12}$$

w = Width of the specimen and t = Thickness of the specimen

$$\text{Young's Modulus } E = \frac{\sigma}{\epsilon}$$

σ = Tensile strength and ε = Tensile strains

$$\text{Area of the Specimen } A = wt$$

$$\text{First natural frequency } \omega_{n1} = (1.875)^2 \sqrt{\frac{EI}{ql^4}}$$

$$\text{Second natural frequency } \omega_{n2} = (4.694)^2 \sqrt{\frac{EI}{ql^4}}$$

$$\text{Third natural frequency } \omega_{n3} = (7.889)^2 \sqrt{\frac{EI}{ql^4}}$$

**6. EXPERIMENTAL RESULTS**

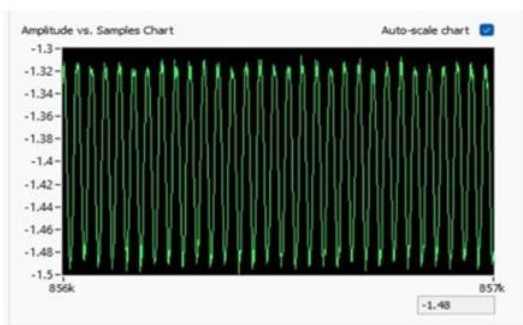
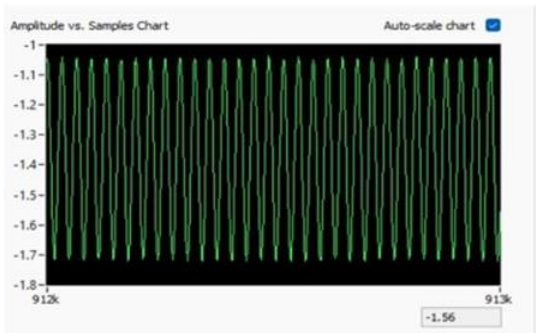


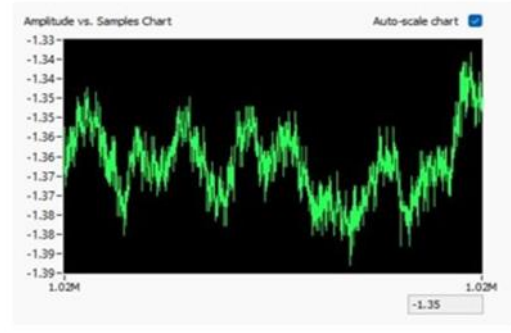
Fig:14. 1<sup>st</sup> mode Acceleration of C-C



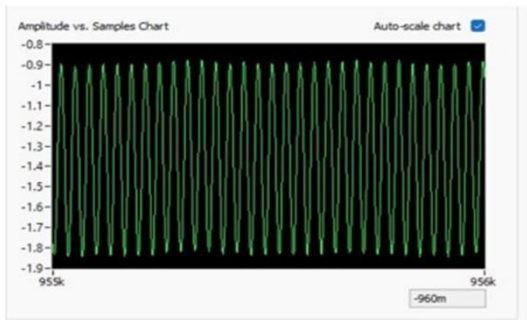
Fig:15. 2<sup>nd</sup> mode Acceleration of C-C



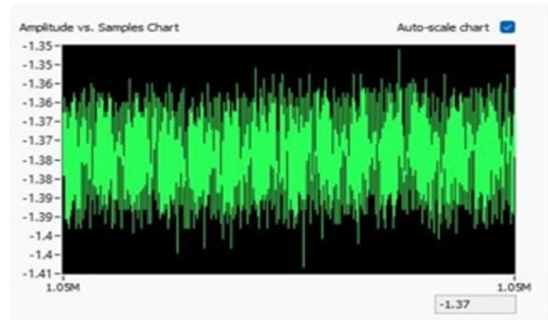
**Fig:16.** 1<sup>st</sup> mode Velocity of C-C



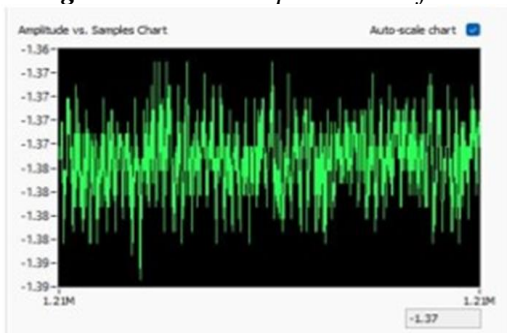
**Fig:17.** 2<sup>nd</sup> mode Velocity of C-C



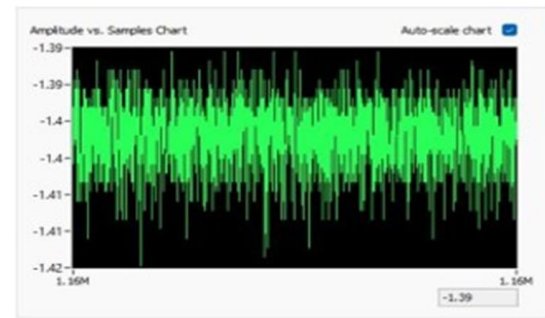
**Fig:18.** 1<sup>st</sup> mode Displacement of C-C



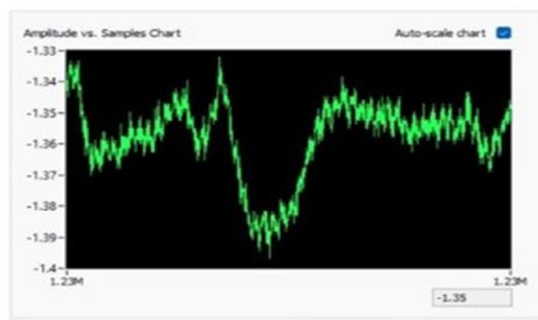
**Fig:19.** 2<sup>nd</sup> mode Displacement of C-C



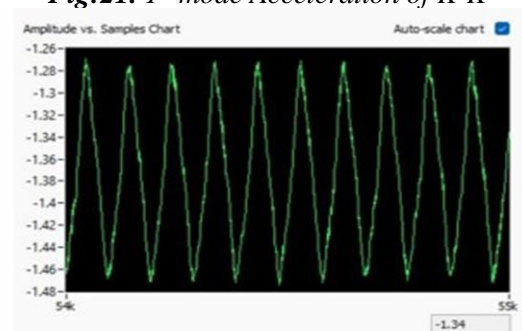
**Fig:20.** 3<sup>rd</sup> mode Acceleration of C-C



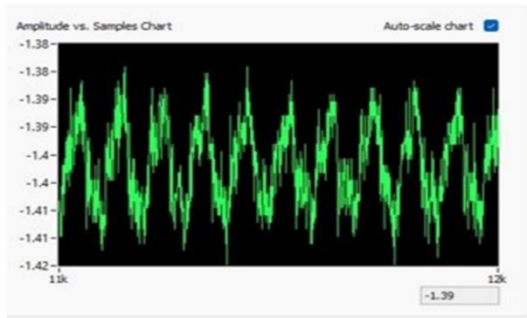
**Fig:21.** 1<sup>st</sup> mode Acceleration of K-K



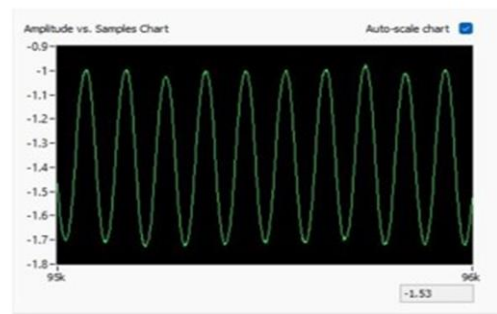
**Fig:22.** 3<sup>rd</sup> mode Velocity of C-C



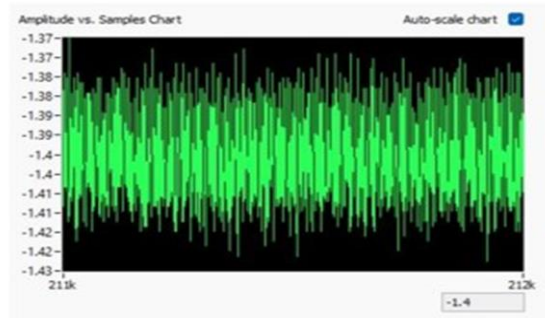
**Fig:23.** 1<sup>st</sup> mode Velocity of K-K



**Fig:24.** 3<sup>rd</sup> mode Displacement of C-C



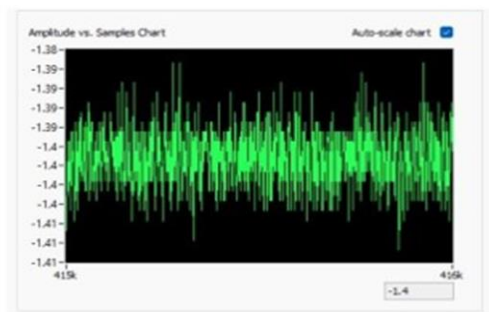
**Fig:25.** 1<sup>st</sup> mode Acceleration of K-K



**Fig:26.** 2<sup>nd</sup> mode Acceleration of K-K



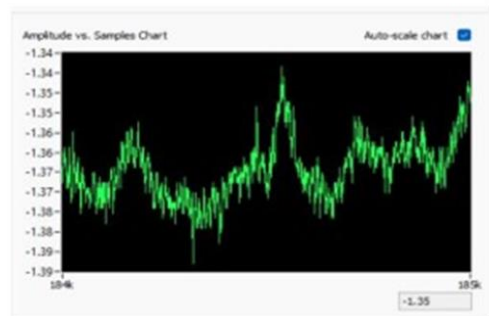
**Fig:27.** 3<sup>rd</sup> mode Acceleration of K-K



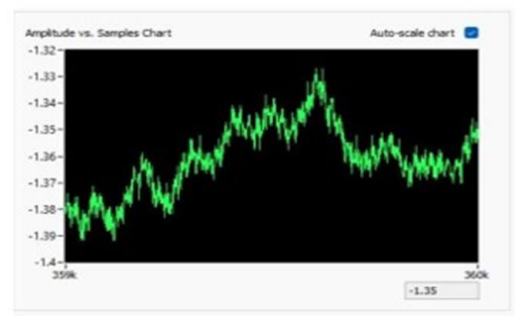
**Fig:28.** 2<sup>nd</sup> mode Velocity of K-K



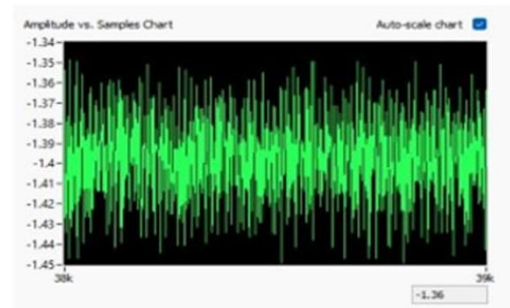
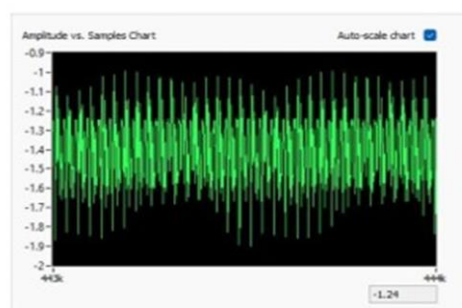
**Fig:29.** 3<sup>rd</sup> mode Velocity of K-K



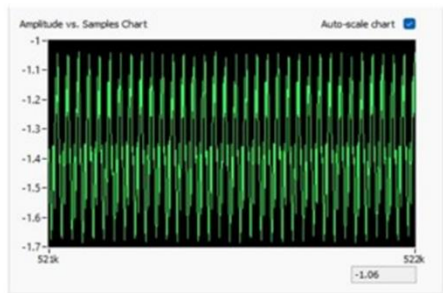
**Fig:30.** 2<sup>nd</sup> mode Displacement of K-K



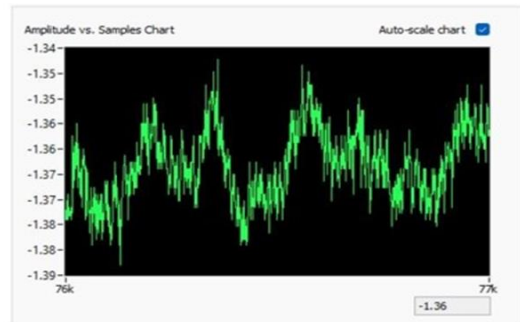
**Fig:31.** 3<sup>rd</sup> mode Displacement of K-K



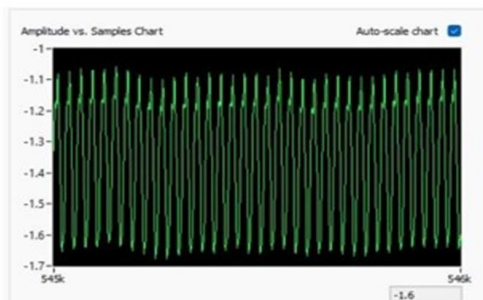
**Fig:32.** 1<sup>st</sup> mode Acceleration of C-C-C



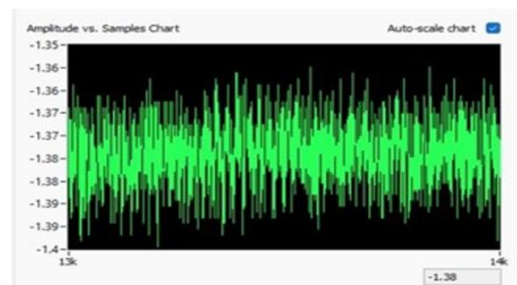
**Fig:33.** 2<sup>nd</sup> mode Acceleration of C-C-C



**Fig:34.** 1<sup>st</sup> mode Velocity of C-C-C



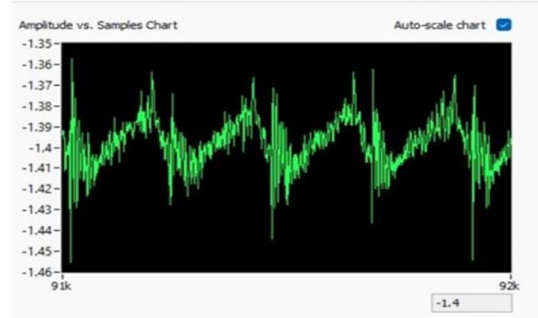
**Fig:35.** 2<sup>nd</sup> mode Velocity of C-C-C



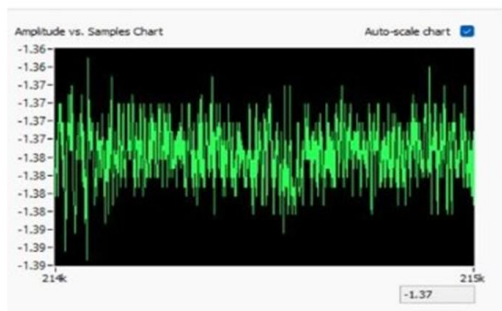
**Fig:36.** 1<sup>st</sup> mode Displacement of C-C-C



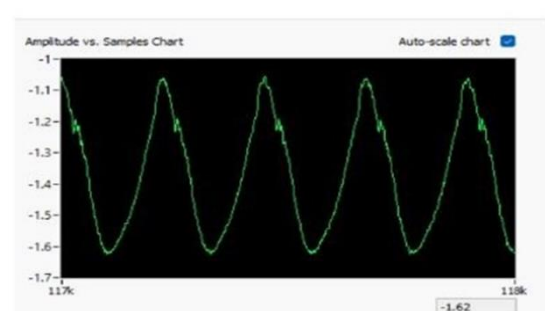
**Fig:37.** 2<sup>nd</sup> mode Displacement of C-C-C



**Fig:38.** 3<sup>rd</sup> mode Acceleration of C-C-C

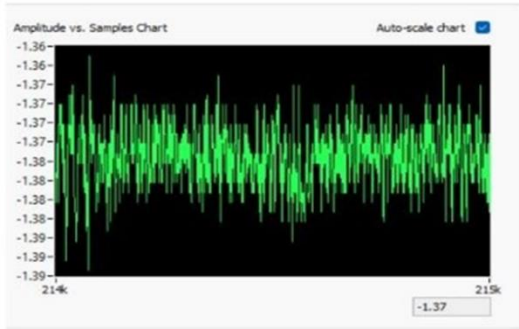


**Fig:39.** 1<sup>st</sup> mode Acceleration of K-K-K

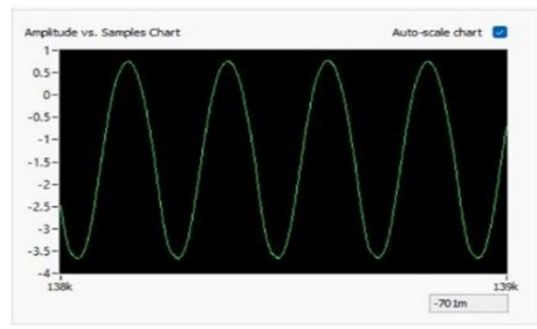


**Fig:40.** 3<sup>rd</sup> mode Velocity of C-C-C

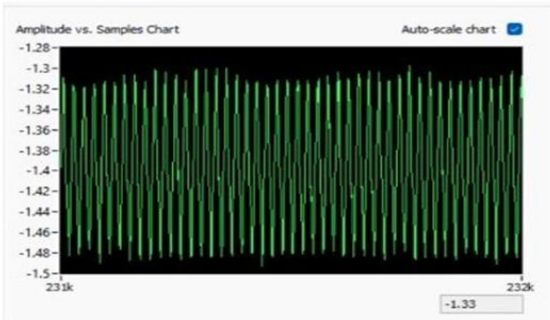
**Fig:41.** 1<sup>st</sup> mode Velocity of K-K-K



**Fig:42.** 3<sup>rd</sup> mode Displacement of C-C-C



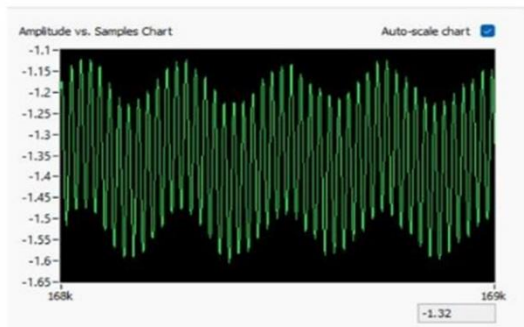
**Fig:42.** 1<sup>st</sup> mode Displacement of K-K-K



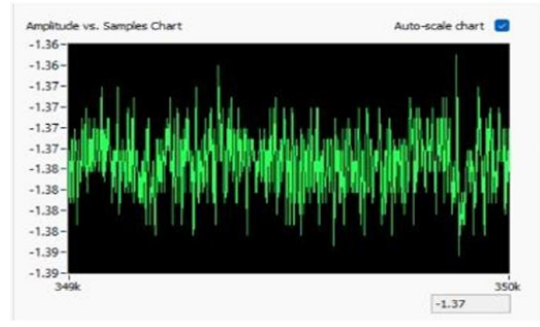
**Fig:43.** 2<sup>nd</sup> mode Acceleration of K-K-K



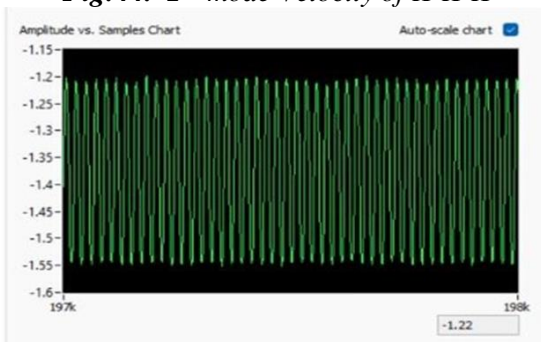
**Fig:44.** 3<sup>rd</sup> mode Acceleration of K-K-K



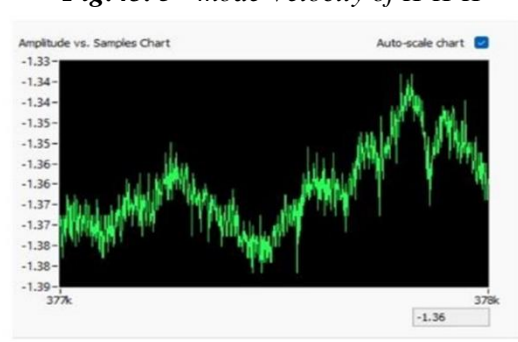
**Fig:44.** 2<sup>nd</sup> mode Velocity of K-K-K



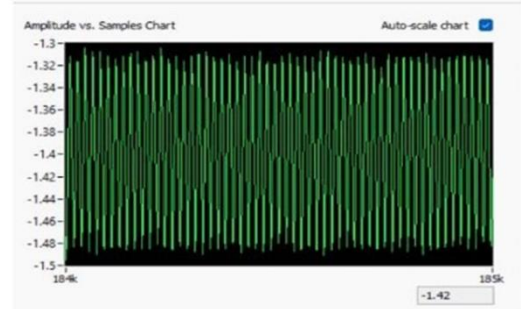
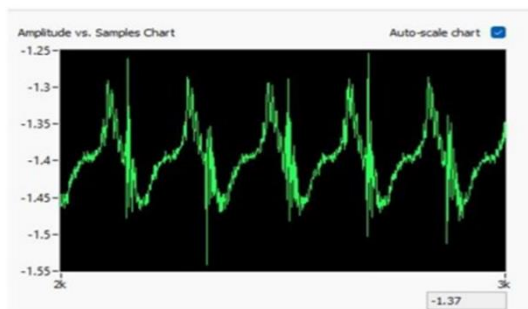
**Fig:45.** 3<sup>rd</sup> mode Velocity of K-K-K



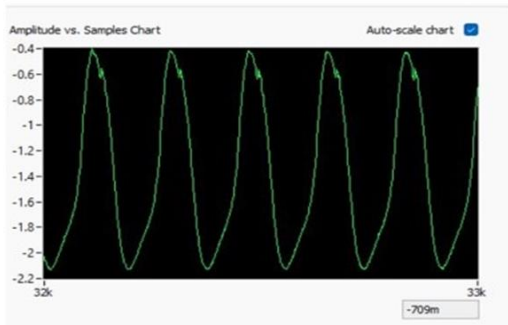
**Fig:46.** 2<sup>nd</sup> mode Displacement of K-K-K



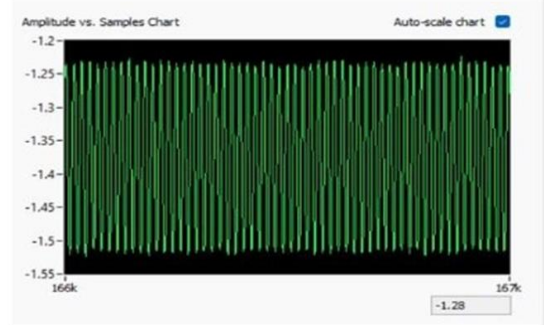
**Fig:47.** 3<sup>rd</sup> mode Displacement of K-K-K



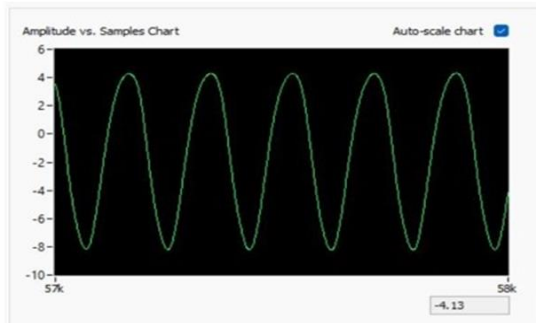
**Fig:48.** 1<sup>st</sup> mode Acceleration of C-C-K



**Fig:49.** 2<sup>nd</sup> mode Acceleration of C-C-K



**Fig:50.** 1<sup>st</sup> mode Velocity of C-C-K

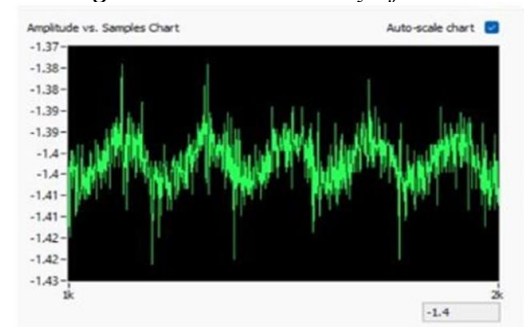


**Fig:51.** 2<sup>nd</sup> mode Displacement of C-C-K



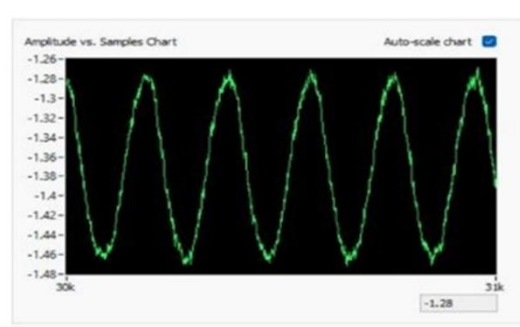
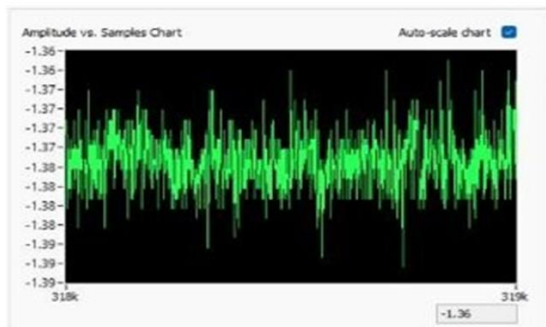
**Fig:52.** 1<sup>st</sup> mode Displacement of C-C-K

**Fig:53.** 2<sup>nd</sup> mode Velocity of C-C-K



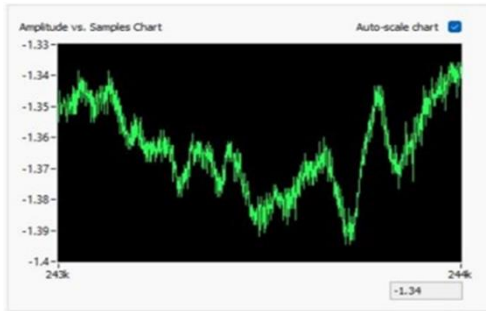
**Fig:54.** 3<sup>rd</sup> mode Acceleration of C-C-K

**Fig:55.** 1<sup>st</sup> mode Acceleration of K-K-C

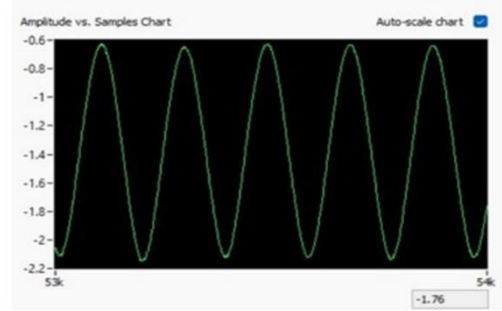


**Fig:56.** 3<sup>rd</sup> mode Velocity of C-C-K

**Fig:57.** 1<sup>st</sup> mode Velocity of K-K-C



**Fig:58.** 3<sup>rd</sup> mode Displacement of C-C-K



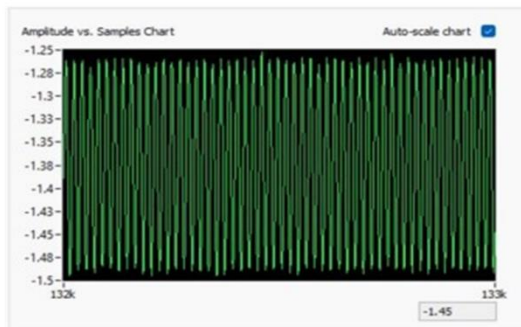
**Fig:59.** 1<sup>st</sup> mode Displacement of K-K-C



**Fig:60.** 2<sup>nd</sup> mode Acceleration of K-K-C



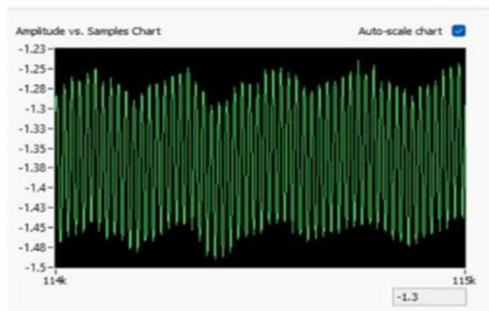
**Fig:61.** 3<sup>rd</sup> mode Displacement of K-K-C



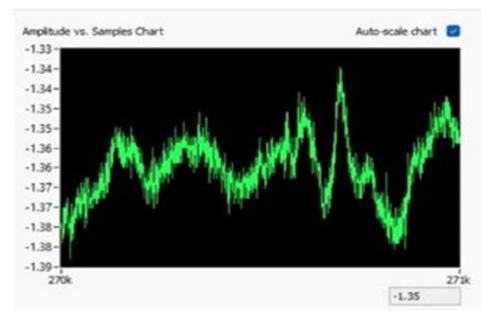
**Fig:62.** 2<sup>nd</sup> mode Velocity of K-K-C



**Fig:63.** 3<sup>rd</sup> mode Velocity of K-K-C



**Fig:64.** 2<sup>nd</sup> mode Displacement of K-K-C



**Fig:65.** 3<sup>rd</sup> mode Acceleration of K-K-C

## 7. NUMERICAL MODELLING

Procedures for conducting a vibration analysis on a cantilever beam using ANSYS Workbench are as follows:

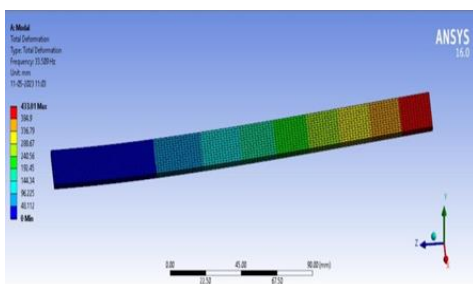
- Geometry creation: Develop the 3D geometry of the cantilever beam in ANSYS Design Modeler with dimensions of Length: 24 cm, Width: 2.5 cm, and Thickness: 0.2 cm.

- Material properties: Assign material properties, such as carbon and Kevlar, to the cantilever beam.
- Mesh generation: Employ ANSYS Meshing to generate a finite element mesh for the cantilever beam [11].
- Boundary conditions: Define the necessary boundary conditions for the cantilever beam.
- Analysis setup: Establish a modal analysis within ANSYS Workbench, specifying the analysis type, selecting the appropriate solver, and defining the number of vibration modes to be solved.
- Solution: Execute the analysis to obtain mode shapes and natural frequencies of the cantilever beam.

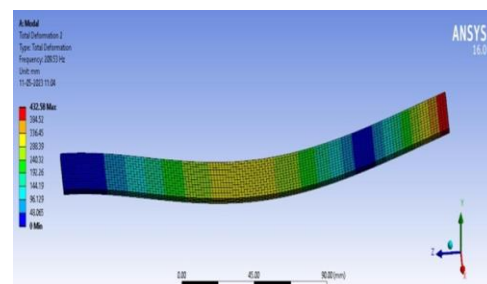
**(a) Carbon material properties cantilever beam**

Mode 1 in a carbon fiber structure denotes the vibration mode associated with the lowest natural frequency. Its mode shape often entails a uniform bending or flexing of the structure in a specific direction. Grasping the characteristics of Mode 1 is instrumental in pinpointing potential vulnerabilities or regions with elevated stress levels, thereby guiding the design and optimization processes of the structure [20]. Carbon fiber composites, characterized by distinctive material properties, may exhibit susceptibility to damage under cyclic loading or impact occurrences.

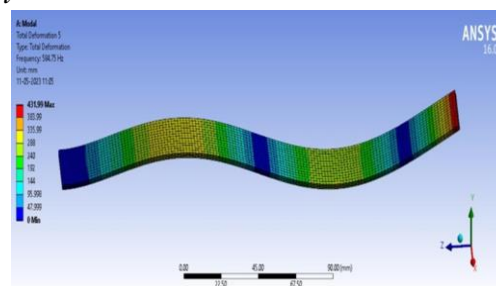
On the other hand, Mode 2 for a carbon fiber structure represents the second vibration mode corresponding to the second lowest natural frequency. The mode shape of Mode 2 is typically more intricate than that of Mode 1, involving a combination of bending and twisting of the structure [7]. A comprehensive understanding of Mode 2's behavior can offer additional insights into the dynamic characteristics of the structure. This knowledge is valuable for design optimization and the identification of potential failure points. The unique material properties of carbon fiber composites can influence the behavior of Mode 2, and analyzing multiple vibration modes contributes to a more thorough comprehension of the structure's dynamic response.



**Fig:66.** Mode – 1 mode shape of carbon beam



**Fig:67.** Mode – 2 mode shape of carbon beam



**Fig:68.** Mode – 3 mode shape of carbon beam

**(b) Kevlar material properties cantilever beam**

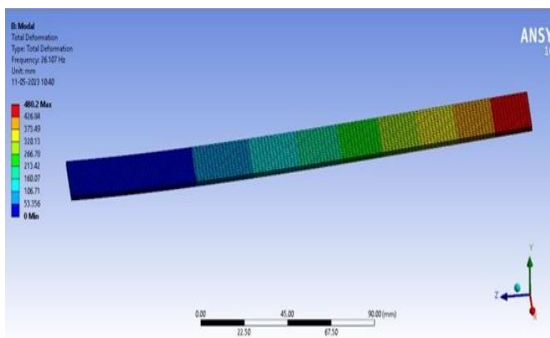
Mode 1 in a Kevlar structure denotes the initial vibration mode, characterized by a mode shape encompassing a combination of bending and axial deformation. Delving into the behavior of Mode 1 offers valuable insights into the dynamic characteristics of the structure, particularly regarding its responsiveness to external loads or vibrations within the frequency range of Mode 1. The analysis of various vibration modes contributes to a more thorough understanding of the dynamic response of a Kevlar structure, facilitating the optimization of its design and the identification of potential failure points.

Similarly, Mode 2 in a Kevlar structure represents the second vibration mode, featuring a more intricate mode shape involving a combination of bending and twisting. Understanding the dynamics of Mode 2 provides additional insights into the behavior of the structure, especially concerning its susceptibility to external loads or vibrations within the frequency range of Mode 2. A comprehensive analysis of multiple vibration modes enhances the understanding of the dynamic behavior of a Kevlar structure, aiding in design optimization and the identification of potential failure points.

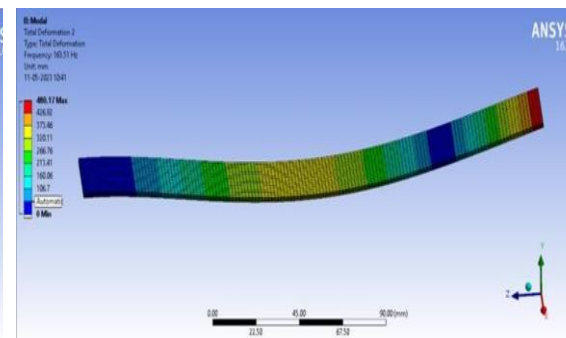
Moreover, Mode 3 in a Kevlar structure signifies the third vibration mode, characterized by a complex mode shape involving a combination of bending and twisting [19]. Insight into the behavior of Mode 3 further enhances the understanding of the structure's dynamics, particularly its responsiveness to external loads or vibrations within the frequency range of Mode 3. Analyzing various vibration modes contributes to a comprehensive understanding of the dynamic behavior of a Kevlar structure, facilitating design optimization and the identification of potential failure points.

**Table-4 Numerical natural frequencies of carbon and Kevlar beams**

S. No	Mode	Natural Frequency in HZ	
		Carbon	Kevlar
1	Mode-1	33.509	24.83
2	Mode-2	209.53	138.61
3	Mode-3	285.48	343.25
4	Mode-4	404.57	416.84
5	Mode-5	584.75	426.83
6	Mode-6	877.41	897.9



**Fig:69. Mode – 1 mode shape of kevlar beam**



**Fig:70. Mode – 2 mode shape of kevlar beam**

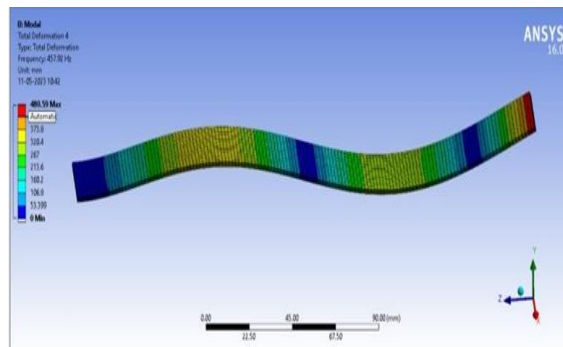


Fig:71. Mode – 3 mode shape of kevlar beam

This study centered on the vibrational analysis of composite laminates incorporating stitched hybrid carbon-Kevlar materials. The selection of carbon and Kevlar fibers was based on their outstanding mechanical attributes, including high strength-to-weight ratio, stiffness, heat resistance, impact resistance, electrical insulation, thermal stability, and fatigue resistance. The primary goal was to explore the vibrational features exhibited by the composite laminates and subsequently compare the theoretical predictions with the experimental findings.

**Table-5 Response comparison of various 3D woven composites**

Material		C-C			K-K			C-C-C		
Density (kg/m)	Suffer (s)	1780			1450			1780		
	Filler (F)	1780			1450			1780		
	Binder (B_	-			-			1780		
Mode		1	2	3	1	2	3	1	2	3
Acceleration (m <sup>2</sup> /s)		2	0.9	0.2	0.1	0.03	0.01	0.9	0.8	0.3
Velocity (m/s)		0.73	0.05	0.01	0.09	0.03	0.01	0.62	0.03	0.01
Displacement (mm)		0.104	0.001	0.001	0.036	0.001	0.001	0.065	0.001	0.001
Frequency (Hz)	Theoretical	33.41	209.39	591.4	25.9	162.5	459.1	33.4	209.3	591.4
	Experimental	31	201	576	21	162	455	33	210	556
	Numerical	33.5	209.5	584.7	26.1	163.5	457.9	33	210	556

Material		K-K-K			C-C-K			K-K-C		
Density (kg/m)	Suffer (s)	1450			1780			1450		
	Filler (F)	1450			1780			1550		
	Binder (B_	1450			1450			1780		
Mode		1	2	3	1	2	3	1	2	3
Acceleration (m <sup>2</sup> /s)		0.2	1.8	0.1	0.6	2	0.2	0.1	1.4	0.1
Velocity (m/s)		0.15	0.45	0.001	0.54	0.41	0.01	0.04	0.31	0.1
Displacement (mm)		0.082	0.046	0.001	0.601	0.032	0.001	0.4	0.025	0.001
Frequency (Hz)	Theoretical	25.9	162.5	459.1	33.4	209.3	591.4	25.9	162.5	459.1
	Experimental	26	163	455	6	56	672	26	163	453
	Numerical	-	-	-	-	-	-	-	-	-

The experimental assessment encompassed 2D fiber laminates (C-C and K-K) and 3D fiber laminates (C-C-C, K-K-K, C-C-K, and K-K-C), representing diverse fiber types and configurations. Modal analysis was executed to ascertain the natural frequencies of the

composite beams, and the outcomes were juxtaposed with theoretical calculations and ANSYS simulations.

Upon scrutiny of the presented data, it was discerned that carbon fibers consistently manifested higher natural frequencies when juxtaposed with Kevlar fibers. This discrepancy can be ascribed to the superior stiffness and mechanical characteristics inherent in carbon fibers. The comparison between theoretical predictions and experimental findings demonstrated minimal discrepancies, affirming the validity of the theoretical models.

## CONCLUSIONS

Incorporating a binder material into the 3D fiber configurations introduced an additional variable influencing the vibration behavior of the laminates. The suffer (S), filler (F), and binder (B) values delineated specific characteristics of the composite laminates under investigation. The results demonstrated variations in natural frequencies and other vibrational parameters across different modes and configurations, thereby illustrating the significant impact of these factors on the overall performance of the laminates.

The study outcomes contribute to an advanced understanding of the vibrational properties inherent in composite laminates amalgamating carbon and Kevlar through stitching. Furthermore, the findings validate the practical utility of theoretical models in predicting natural frequencies, providing valuable insights into how fiber type, arrangement, and binder material collectively influence vibration characteristics. This knowledge proves instrumental in the strategic design and optimization of composite structures in applications where vibration plays a pivotal role.

This work marks a substantial expansion of knowledge in the domain of composite materials and their vibration behavior. This advancement lays the groundwork for further innovations in lightweight and high-performance structural designs.

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