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Modal Analysis of Aluminium and Natural Rubber Sandwich Composite Beam

Investigation and Validation of Natural Frequencies with Various Cross- Sections

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Abstract : Composite materials are extensively utilized in a wide array of applications nowadays. They are composed of two or more distinct materials that are typically securely bonded at the interface. In a context where design optimization involves reducing the factor of safety while aiming for increased component reliability over time, composite materials are indispensable. When one material is sandwiched between two or more similar materials with varying mechanical and material properties, it constitutes a type of composite known as Sandwich composites, which are among the most commonly employed. Numerous natural and synthetic materials exhibit this characteristic, including GFRP (Glass Fiber Reinforced Plastic), reinforced rubber, filled polymers, Nylon, polycrystalline aggregates (metals), aligned and chopped fiber composites, and others.For the current study, a beam consisting of Natural Rubber sandwiched between aluminum plates is under consideration. The impact of material dimensions on parameters such as natural frequencies and structural vibration modes has been thoroughly investigated and validated. Various tests have been conducted by altering the thickness of the aluminum and the Natural Rubber. Computational modal analysis of the composite beam is performed using AnSys software for the ongoing project, and the natural frequencies are verified through Impact Hammer tests using an FFT analyzer.

IndexTerms **- Composite Material, Modal analysis, Aluminium and FFT Analyzer, Natural Rubber Composite, Impact Hammer Test.**

I. INTRODUCTION

The study focuses on analyzing the vibration behavior of composite materials to assess their response when exposed to vibrations. Specifically, a composite material comprising Aluminum and Natural Rubber is selected for modal analysis. The Finite Element Method is employed to obtain computational results, which are then validated using experimental data. Prior to delving into the specifics of the research, it's imperative to grasp the fundamentals of vibrations and associated terminology.

A. Objective and Scope:-

1. The aim is to utilize the Finite Element Method (FEM) to determine the natural frequencies of beams composed of varying thicknesses of sandwiched materials (Composite) comprising aluminum and Natural Rubber.
2. Validation of the obtained results will be conducted through experimentation, where the composite beam is treated as a cantilever, ensuring alignment with real-world conditions.

B. Goal:-

In designs with narrow margins, where structures are engineered to minimize material or weight, vibrations in structures have become a growing concern. Often, solutions exhibit unfavorable modal characteristics due to additional constraints on the system, like geometry or weight limitations. Composites are frequently employed in various applications that encounter high-frequency vibrations. Therefore, it is crucial to assess the natural frequency behavior of systems under different dimensional parameter variations to ensure their performance.

C. Methodology:-

Modal analysis will be conducted using AnSys to identify and record six distinct natural frequencies of the specimen, composed of a composite material sandwiched between Aluminum and Natural Rubber, treated as a cantilever beam. Subsequently, the obtained results will be validated through Impact Hammer testing employing an FFT analyzer.

II. REVIEW OF LITERATURE

Ratnaparkhi and Sarnobat emphasize the importance of vibration analysis in structural design due to the detrimental effects of resonant vibrations on structural integrity. They conduct extensive experimental investigations on woven fiber Glass/Epoxy composite plates in free-free boundary conditions, employing modal analysis techniques to obtain natural frequencies. Experimental results are validated against Finite Element Analysis (FEA) using Ansys. The study examines various parameters' effects, including aspect ratio and fiber orientation, providing valuable insights for design applications.

He et al. present an efficient Finite Element Method (FEM) for computing modal damping of laminated composites, integrating a complex stiffness matrix with frequency-dependent viscoelastic properties into the ABAQUS software. They validate the method through cantilever percussion free-decay testing and analyze modal damping and frequency response for laminated composites. The results demonstrate the model's accuracy and efficiency in determining modal damping.

Cavallo et al. explore the impact of composite materials and non-structural masses on the dynamic behavior of space structure components and entire space vehicles. They utilize a refined one-dimensional model, employing the Carrera Unified Formulation, which enables a variable kinematic displacement field over the beam cross-section. The study includes static and free vibration analysis of both compact and thin-walled structural configurations, considering the effects of composite materials and non-structural masses such as fuel. Results are validated using analytical solutions or refined three-dimensional Finite Element Models, demonstrating the model's capability to provide a quasi-three-dimensional solution with low computational cost.

Rodrigues et al. propose a computational homogenization approach for determining effective elastic properties of heterogeneous materials, utilizing Finite Element Method and meshless methods such as the Radial Point Interpolation Method. Their study involves modeling Representative Volume Elements (RVEs) and determining effective elastic properties for different fiber volume fractions, highlighting the effectiveness of the Natural Neighbor Radial Point Interpolation Method in achieving accurate solutions.

Mehdi et al. investigate the dynamic behavior of composite beams with and without cracks, conducting computational modal analysis using ANSYS and experimental modal analysis using FFT analyzer. The study evaluates the influence of cracks on natural frequencies, revealing insights into the behavior of composite materials under dynamic loading conditions.

Ramesh and Reddy focus on suppressing vibrations in high-technology structures using passive damping materials integrated into advanced composite materials. They conduct structural analysis on shafts with and without damping materials, comparing the results for different materials and conducting modal analysis to determine mode shapes. The study aims to design lightweight, vibration-resistant structural components.

Chavan and Joshi discuss the significance of vibration analysis and composite materials in structural design, particularly in aerospace, automotive, and manufacturing industries. They conduct experimental investigations on woven E-fiber Glass/Epoxy composite plates, analyzing free vibration behavior under fix-free boundary conditions. The study examines various geometric parameters' effects, providing valuable insights for design applications and demonstrating good agreement between experimental and analytical results.

Abdul Khader Shahadaf conducts numerical studies on the free vibration response of composite beams using Finite Element Analysis (FEA), investigating various parameters' effects on natural frequencies. The study examines the influence of factors such as fiber orientation, crack location, and support conditions on structural dynamics, providing insights for optimizing composite beam designs.

Mahale and Mate explore the influence of composite materials on structural characteristics such as natural frequencies and modes of vibration. They conduct computational modal analysis of composite beams using ANSYS, validating results through experimental testing. The study provides insights into the dynamic behavior of composite structures and demonstrates good agreement between experimental and analytical results.

Shrigandhi and Deshmukh investigate sandwich panel structures for aerospace applications, conducting free vibration analysis using Finite Element Analysis (FEA) and analytical methods. The study explores the effects of sandwich design parameters on global bending and vibration responses, highlighting the accuracy of FEA results compared to experimental and analytical values.

III. PROPOSED SYSTEM APPROACH

Understanding the importance of modal analysis is crucial as it enables us to obtain the natural frequencies (Modal analysis) of beams made from various sandwiched materials, which is the objective of this study.

A. Introduction to Modal Analysis

Modal analysis serves as a fundamental tool for understanding the dynamic properties of structures when subjected to vibrational excitation. By leveraging the overall mass and stiffness of a structure, modal analysis identifies the various periods at which it will naturally resonate. This information is critical in machine vibration, as resonance between a structure and a component's frequency can lead to structural damage. In structural mechanics, the primary objective of modal analysis is to determine the natural mode shapes and frequencies of an object or structure during free vibration. The Finite Element Method (FEM) is commonly employed for this purpose due to its capability to handle complex geometries and provide accurate results. Detailed modal analysis involves identifying the fundamental vibration mode shapes and their corresponding frequencies. While this process may be straightforward for simple components of a basic system, it becomes highly intricate for complex mechanical devices or structures subjected to periodic wind loading. Accurate determination of natural frequencies and mode shapes is crucial and often requires advanced techniques such as Finite Element Analysis. Today, modal analysis is a standard procedure for identifying the modes of vibration of machines or structures. It involves determining the dynamic characteristics of a system, including natural frequency, damping factors, and mode shapes, to generate a mathematical model for its dynamic behavior. In essence, modal analysis enables the study of the inherent characteristics of structures, providing insights into structural noise and vibration applications.

A mode shape represents a specific pattern of vibration exhibited by a mechanical system at a particular frequency. Each mode shape is associated with a distinct frequency, and the mode shape's curvature describes the vibration's behavior over time. The mode shape is influenced by the shape of the surface and its boundary conditions. Modal analysis is closely linked to structural response, as the structure's response varies at each natural frequency. These deformation patterns, known as mode shapes, play a crucial role in understanding the dynamic behavior of structures. In summary, modal analysis is the study of the natural characteristics of structures, enabling the design of various structures, including automotive and aircraft components, by providing insights into natural frequencies and mode shapes.

IV. RESEARCH WORK

A. *Specimen Details*

A specimen refers to a small, representative quantity of something that is intended to mirror and symbolize a larger quantity or group of similar items.

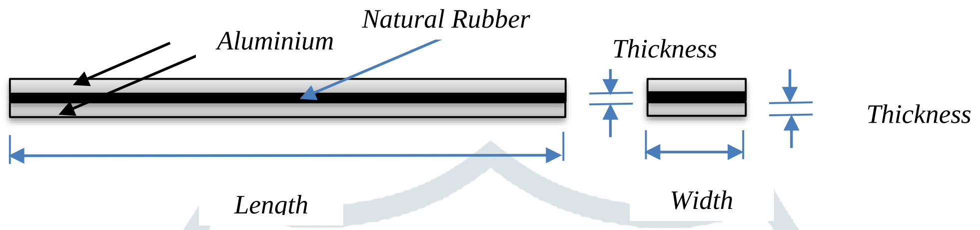

Fig: 1. Specimen

Table.1 Dimension of the specimen (Natural Rubber)

Sr. No.	Specimen Name	Dimensions of Natural Rubber		
		Length (l)	Width (w)	Thickness (t)
1	AL2.5NR1	300	30	1
2	AL1.5NR1	300	30	1
3	AL1NR1	300	30	1
4	AL2.5NR1.5	300	30	1.5
5	AL1.5NR1.5	300	30	1.5
6	AL1NR1.5	300	30	1.5
7	AL2.5NR2.5	300	30	2.5
8	AL1.5NR2.5	300	30	2.5
9	AL1NR2.5	300	30	2.5

Table.2 Dimension of the specimen (Aluminium)

Sr. No.	Specimen Name	Dimensions of Aluminium		
		Length (l)	Width (w)	Thickness (t)
1	AL2.5NR1	300	30	2.5
2	AL1.5NR1	300	30	1.5
3	AL1NR1	300	30	1
4	AL2.5NR1.5	300	30	2.5
5	AL1.5NR1.5	300	30	1.5
6	AL1NR1.5	300	30	1
7	AL2.5NR2.5	300	30	2.5
8	AL1.5NR2.5	300	30	1.5
9	AL1NR2.5	300	30	1

Note:
All dimensions are in millimeters (mm).
'AL' denotes Aluminum.
'NR' denotes Natural Rubber.
a. The specimen under study is a sandwich-type composite material consisting of three layers of different materials. b. The upper and lower layers are made of Aluminum with a thickness of 3mm. c. Natural rubber is sandwiched between the Aluminum layers with a thickness of 3mm. d. All layers are bonded together using Araldite Adhesive Bond. Fig. 1 shows a specimen
Specimen Designations:
Specimen AL2.5NR1: Natural Rubber with a thickness of 1mm sandwiched between Aluminum layers each with a thickness of 2.5mm.

Specimen AL1.5NR1: Natural Rubber with a thickness of 1mm sandwiched between Aluminum layers each with a thickness of 1.5mm.
Specimen AL1NR1: Natural Rubber with a thickness of 1mm sandwiched between Aluminum layers with a thickness of 1mm.
Specimen AL2.5NR1.5: Natural Rubber with a thickness of 1.5mm sandwiched between Aluminum layers each with a thickness of 2.5mm.
Specimen AL1.5NR1.5: Natural Rubber with a thickness of 1.5mm sandwiched between Aluminum layers each with a thickness of 1.5mm.
Specimen AL1NR1.5: Natural Rubber with a thickness of 1.5mm sandwiched between Aluminum layers with a thickness of 1mm.
Specimen AL2.5NR2.5: Natural Rubber with a thickness of 2.5mm sandwiched between Aluminum layers each with a thickness of 2.5mm.
Specimen AL1.5NR2.5: Natural Rubber with a thickness of 2.5mm sandwiched between Aluminum layers each with a thickness of 1.5mm.
Specimen AL1NR42.5: Natural Rubber with a thickness of 2.5mm sandwiched between Aluminum layers with a thickness of 1mm.

B. Meshing and Boundary Conditions

The sandwich beam is meshed using solid elements, with hex elements chosen for meshing to ensure optimal mesh quality and connectivity, meeting meshing standards. Subsequently, the material properties are detailed in Table 3.

Table 3. Material Properties

Sr.No	Type of Material	Young's Modulus(GPa)	Shear Modulus(GPa)	Density(Kg/m3)	Poisson's Ratio
1	Aluminium	71	27.3	2700	0.33
2	Natural Rubber	0.00154	0.005	950	0.45

V. EXPERIMENTATION

A. Vibration of composite beam

Designing a structure necessitates careful consideration of deflecting and overstressing to avoid resonances. Dynamic loading on a structure can range from recurring cyclic loading, like an unbalanced motor turning at a specified RPM, to intense, nonrecurring shock or impact loading, such as a bird striking an aircraft component during flight. Between these extremes lie an infinite spectrum of dynamic loads, from harmonic oscillations to impacts, each associated with its own mode shapes. Mathematically, continuous structures harbor an infinity of natural frequencies and mode shapes.

Dynamic loading, whether shock loads like a bird strike or cyclic loads like motor vibrations, can lead to resonance if the structure's frequency of oscillation aligns with its natural frequency. Such resonance can cause rapid amplitude growth, potentially leading to overstressing and structural failure. Additionally, large oscillations can induce fatigue damage, necessitating limitations on amplitude.

To ensure structural integrity, time-dependent loading must be compared to natural frequencies, with a significant disparity between the two frequencies.

B. Modal Testing

In modal testing, Frequency Response Function (FRF) measurements are typically conducted under controlled conditions. The test structure is stimulated artificially using either an impact hammer or one or more shakers driven by broadband signals. Subsequently, a multi-channel Fast Fourier Transform (FFT) analyzer is employed to measure FRFs between input and output Degree of Freedom (DOF) pairs on the test structure

C.Exciting modes with impact testing

The advent of computing FRF measurements in an FFT analyzer facilitated the development of impact testing in the late 1970s, subsequently becoming the predominant method for modal testing today. Impact testing offers a rapid, convenient, and cost-effective means of identifying the modes of machines and structures.

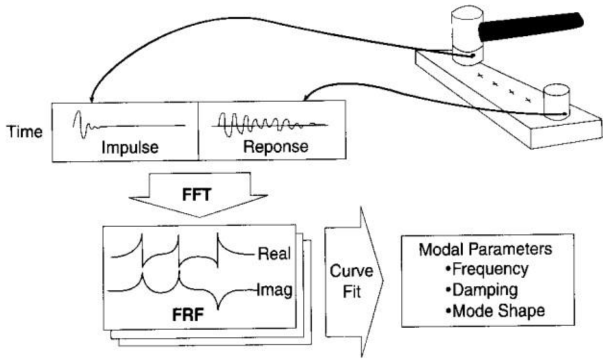

Fig: 2. Impact Testing

Figure 2 illustrates the schematic representation of the impact testing procedure. To conduct an impact test, the following equipment is necessary:

An impact hammer equipped with a load cell at its head to gauge the input force.

An accelerometer to measure the response acceleration at a fixed point and direction.

A 2 or 4 channel FFT analyzer for computing FRFs.

Post-processing modal software designed to identify modal parameters and visualize mode shapes in animation.

During the impact test, the specimen undergoes an impact from the hammer, while the accelerometer records the resulting response, as depicted in Figure 2. Impact testing can be applied to a diverse array of structures and machines. The size of the hammer must be tailored to provide the appropriate impact force, corresponding to the size of the structure; small hammers for smaller structures and large hammers for larger ones.

D. Modal Frequency as Peak Frequency

The frequency of a resonance peak in the Frequency Response Function (FRF) is used as an estimate of the modal frequency. This peak frequency, which depends on the frequency resolution of the measurements, is not exactly equal to the modal frequency but serves as a close approximation, particularly for lightly damped structures. The resonance peak should be consistent across nearly all FRF measurements, except for those corresponding to nodal lines (zero magnitude) of the mode shape.Figure 2 depicts the vibrating beam subjected to hammer testing. After the hammer impact, the response of the vibrations for different modes is illustrated schematically in the figure. The vibration behavior of the specimen for mode 1, mode 2, and mode 3 is shown in Figure 3. Eight different measurement points, referred to as the imaginary parts of the FRP, are depicted in the figures, and the deflection of the specimen is observed at these points, taking damping into account.The points where the mode shapes intersect the horizontal axis are called nodes, which are points of no motion. If one of the test points coincides with a node for a particular mode, the peak for that mode will not appear in the transfer function. Therefore, when estimating natural frequencies and damping ratios, a transfer function should be chosen in which all the modes are present.The points where the displacement is the largest are called antinodes. Once the modal parameters and mode shapes are determined, the dynamic characteristics of the system can be fully defined. This information can then be used to enhance the system or correct an existing issue. Either way, modal analysis provides designers with a powerful tool for the dynamic analysis and design of mechanical systems.

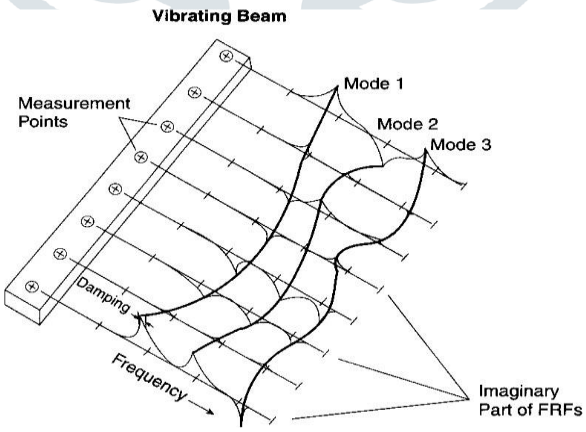

Fig. 3.Curve Fitting FRF Measurements.

The testing of the sandwich beam is conducted by clamping one end to function as a cantilever beam. The hammering test is performed as previously described. In the testing setup, the specimen is held as a cantilever beam. The details of the specimen are provided in the following sections.

VI. Experimental results and discussion

The results after testing are presented in Table 4 below. These results were obtained through multiple consecutive readings at the same point on the specimen. The table lists the various values recorded by the FFT analyzer. The value closest to the FEM results is considered for validation.

Table: 4 Comparison of the result FEM and Experimental Testing

Modes	AL2.5NR1			AL1.5NR1			AL1NR1		
	FEM results (Hz)	Exp. results (Hz)	% devi-ation	FEM results (Hz)	Exp. results (Hz)	% devi-ation	FEM results (Hz)	Exp. results (Hz)	% devi-ation
Mode 1	239	248	3.77	210	208	-0.95	176	179	1.70
Mode 2	410	417	1.71	358	351	-1.96	303	310	2.31
Mode 3	595	601	1.01	426	432	1.41	399	389	-2.51
Mode 4	623	628	0.80	588	581	-1.19	467	465	-0.43
Mode 5	644	649	0.78	612	614	0.33	501	505	0.80
Mode 6	656	650	0.91	627	634	1.12	521	528	1.34

Modes	AL2.5NR1.5			AL1.5NR1.5			AL1NR1.5		
	FEM results (Hz)	Exp. results (Hz)	% devi-ation	FEM results (Hz)	Exp. results (Hz)	% devi-ation	FEM results (Hz)	Exp. results (Hz)	% devi-ation
Mode 1	276	269	-2.54	240	251	4.58	208	218	4.81
Mode 2	455	448	-1.54	412	418	1.46	351	337	-3.99
Mode 3	635	643	1.26	596	603	1.17	431	403	-6.50
Mode 4	669	671	0.30	619	611	-1.29	596	571	-4.19
Mode 5	691	697	0.87	649	642	-1.08	603	651	7.96
Mode 6	706	701	-0.71	652	651	-0.15	638	688	7.84

Modes	AL2.5NR2.5			AL1.5NR2.5			AL1NR2.5		
	FEM results (Hz)	Exp. results (Hz)	% devi-ation	FEM results (Hz)	Exp. results (Hz)	% devi-ation	FEM results (Hz)	Exp. results (Hz)	% devi-ation
Mode 1	328	332	1.22	271	278	2.58	255	241	-5.49
Mode 2	499	505	1.20	462	444	-3.90	421	411	-2.38
Mode 3	635	649	2.20	647	641	-0.93	593	607	2.36
Mode 4	720	731	1.53	685	670	-2.19	637	606	-4.87
Mode 5	748	728	-2.67	692	664	-4.05	651	623	-4.30
Mode 6	759	741	-2.37	707	671	-5.09	667	649	-2.70

As discussed above, the results achieved are very close, showing minimal deviation from each other. However, considering other readings results in higher deviations, which can be attributed to several factors:
Specimen Bonding: The specimen is bonded with Araldite, whereas the FEM assumes rigid bonding. The damping properties of the Araldite bond are not considered in the impact test.
Specimen Holding: The specimen is held in a vice to approximate a cantilever, but this setup differs from the perfect cantilever assumed in the FEM, leading to deviations.
Material Properties: Differences in material properties, such as isotropy and homogeneity, contribute to the deviations in results.
Dimensional and Geometric Tolerances: Variations in dimensional and geometric tolerances also affect the results.
Despite these factors, the deviations between the impact test readings and FEM results are not significant. As seen in Table 4, the deviation percentages varies from ±0.15% to ±7.96%.

VII. FUTURE SCOPE

The experimentation on the modal analysis of the aluminum and natural rubber composite offers significant opportunities for future research. Varying the structure and dimensions of the composite can provide better options for specific applications of other composites.

Thickness Variation: Increasing the thickness of the natural rubber while decreasing that of the aluminum can enhance vibration damping and increase resilience. This adjustment will also reduce the overall weight of the material, which is often desirable in various applications.
Honeycomb Structures: Using natural rubber with a triangular or hexagonal honeycomb structure can further reduce the composite's weight.
Binding Materials: The specimen can be tested with different binding materials besides Araldite to optimize for specific structural analysis requirements.

The proposed specimen presents a promising alternative for composite materials and has the potential for widespread application.

VIII. Conclusion

A CAD model of the composite beam was developed, and FEA analysis was conducted to evaluate its vibration response. The composite beam was analyzed for design safety, and its natural frequency was determined. The results were interpreted, compared, and a comparative study was performed. The composite beam was fabricated and tested using an FFT analyzer, and the results from FEA and experimentation were compared and validated, showing acceptable deviations.

The FEM analysis conducted using HyperMesh provided reliable results, with minimal deviations observed after impact testing. The binding material effectively bonded the different components with negligible variation in composite properties, which is desirable. The observed frequencies were lower, which is advantageous for many composite applications. The highest frequency observed was 759 Hz, which is suitable for applications such as aircraft and aerospace.

REFERENCES

[1] Steven Leuridan, Quentin Goossens, Leonard Pastrav,Jorg Roosen, Michiel Mulier, Kathleen Denis, Wim Desmet, Jos Vander Sloten, "*Determination of Replicate CompositeBone Material Properties using Modal Analysis*", *Journal of the Mechanical Behavior of Biomedical Materials*, S1751- 6161(16)30372-1, 2016.

[2] Prashant R. Mahale, Prof.Dr.D.M.Mate ," *Modal AnalysisOf Aluminium & Natural Rubber Sandwiched Beam*", International Journal of Science & Technology, ISSN : 2250- 141, Vol. 6 Issue 4, October 2016.

[3]T. Cavallo, E. Zappino ⇑, E. Carrera, "*Free-vibration analysis of space vehicle structures made by composite materials*" ,Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy, vol.183 , pp. 53–62, 2017.

[4] Ramaz V. Charkviani, Alexander A. Pavlov, Svetlana A. Pavlova, "*Interlaminar Strength and Stiffness of Layered Composite Materials*", 6th Russian-German Conference on Electric Propulsion and Their Application, vol.185, pp.168 – 172, 2017.

[5] Sharayu U. Ratnaparkhi, 1 S.S. Sarnobat, "*Vibration Analysis of Composite Plate*", International Journal of ModernEngineering Research(IJMER), Vol.3, Issue.1, Jan-Feb. pp-377-380, 2013.

[6] Haim Abramovich, "*Introduction to compositematerials*",Technion, I.I.T., Haifa, Israel

[7] S. S. Chavan, 2M. M. Joshi, "*Study On Vibration Analysis Of Composite Plate*",vol-1,ISSUE-4, pp. 2394-6210, 2015Akash chaudhary Raghuvanshia*, Akhilendra Singha, Mohit Kumara, Abhishek Pandeya,

[8] Raghvendra Kumar Misra," *Effects on four layer composite material by changing their orders*", Proceedings 4 , pp.7189–7193, 2017.

[9] Abhay Chaturvedi(1), Gopal Sanyal(2), ShashankChaturvedi (1) and A.S.PATIL, "*Compressive Properties and Imaging Analysis of A new Metal Foam-Natural Rubber Hybrid Structure*", Journal of Metals, Materials and Minerals, Vol.26 No.2 pp.27-30, 2016.

[10] Husain Mehdi1, Rajan Upadhyay2, Rohan Mehra2, Adit Singhal, "*Modal Analysis of Composite Beam Reinforced by Aluminium-Synthetic Fibers with and without Multiple Cracks Using ANSYS*", International Journal of Mechanical Engineering (IJME) Volume -4 Issue 2, pp: 2277-7059,2014.

[11] Swapnil Sanjay Chavan, "*Study on Vibration Analysis of Composite Plate*", International Conference on Multidisciplinary Research & Practice, Volume 1, Issue 8,ISSN 2321-2705.

[12] Hardik Patel, 2 Prof. N. I. Jamadar, "*Modal Analysis of Composite Structure*", International Journal Of Advancement In Engineering Technology, Management And Applied Sciences, Vol-3, Issue-1, pp-2349-3224, 2016.

[13] Gyadari Ramesh, "*Structural and Modal Analysis of Composite Material Shaft with Damping Material*", International Journal for Innovative Research in Science & Technology, Volume 2, Issue 06, ISSN : 2349-6010, November 2015.

[14] P Karthigeyana, M Senthil Rajab, R Hariharan c, R Karthikeyand, S Prakash, "*Performance evaluation of composite material for aircraft industries*", 5th International Conference of Materials Processing and Characterization , Vol- 4, pp-3263–3269, 2017.

[15] G.D.Shrigandhi†* and Pradip Deshmukh, "*Modal Analysis of Composite Sandwich Panel*", International Journal of Current Engineering and Technology,E-ISSN 2277 – 4106, P-ISSN 2347 – 5161, 2016.

[16] Lei Jong, "*Improved natural rubber composites reinforcedwith a complex filler network of biobased nanoparticles and ionomer",* Materials Chemistry and Physics ,vol.203, pp 156- 165, 2018.