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ASSESSMENT OF FIRE RESISTANCE CHARACTERISTICS AND THEORETICAL MODELING AND NUMERICAL INVESTIGATION OF EFFECT OF LOAD ON CANTILEVER AND RIGIDLY FIXED NATURAL FIBER REINFORCED GREEN COMPOSITE

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Abstract

The current study is ambitious to develop a hybrid composite specimen for evaluating fire resistance characteristics and performing model analysis for validating theoretical and numerical frequencies under cantilever and rigidly fixed support conditions. The composite test specimens are developed using hemp and banana fibers by applying the traditional hand layup fabrication technique. The focus on the use of various natural fibers is very rapid in both domestic and industrial applications. Natural fibers are handy in availability and are possesses extremely good mechanical, chemical and thermal properties. This work is focused on developing the composite specimen according to ASTM –D2863-87, for evaluating fire resistance characteristics. This work also includes theoretical and numerical validation of natural frequency under cantilever and rigidly fixed conditions. The finite Element Analysis (FEM) tool is used to validate the theoretical frequency. Through the statistical analysis, it is concluded that the developed composite specimen showcases good fire resisting property up to a temperature of 175^{o}c with a good fire propagation time of 6minutes. It also exhibits excellent bonding strength up to a temperature of 95^{o}c. It was found that the natural frequency calculated numerically using Roark's formula closely satisfied with the values of theoretically obtained frequency from the Finite Element Method (FEM). The maximum natural frequency developed under cantilever support is 421.04Hz and 626.82Hz for fixed support conditions.

Keywords: Fire resistance Property; Hemp fiber; Banana fiber; Natural fiber composite; Natural frequency; ANSYS.

1. Introduction

There are many environmental problems are exist nowadays due to the use of different metal matrix composites and synthetic fibers. Keeping some of the factors into account like pollution, global warming, and depletion of fossil fuels, many researchers are working on the development of a new category of composites using natural fibers [1, 5]. Various natural fibers like jute, bamboo, hemp banana, etc., find their applications in the structural, automotive, and industrial background. Numbers of tests were happened to identify the mechanical characteristics and their suitability as reinforcement material[2]. Better strength, good stiffness along low cost makes the natural fiber composites are more popular to use in packaging, sports, musical goods [3, 4]. Some regular complaints about the use of natural fibers are poor adaptability, low-temperature resisting capacity, and more moisture absorption property. Fire resisting property analysis is the most important factor to protect lives from the risk associated with the fire [5]. In many industrial applications, flammability is a critical factor to avoid heavy losses. Flammability is a property of a material by virtue of it reacting with the fire. Flammability involves various factors like flame spread, heat release, and products retained after combustion. There are many fire retardants like ammonium polyphosphate, boric acid with magnesium hydroxide that is used to improve the fire resistance capacity. In a few cases, fire retardant gel will be coated over the outer surface of the composite at the finishing stage [6]. If the steel is replaced with the natural fiber composite materials saves around 60 to 80% of its total weight. Natural fibers are organic products that will not cause any allergenic symptoms to the human skin [7]. Plants that produced natural fibers are of two major categories, the first category of plants is grown particularly for fiber content, whereas the second category of plants are producing fiber as a by-product after some usage. Flame retardants are mixed with different product materials during processing. The role of flame retardants is to maintain chemical structure and to maintain the properties equally throughout the product surface. The function of flame retardants is to impede combustion [8]. Analyzing the quality of natural fibers and their developed composites is a difficult process. Modern Modeling and computational techniques prove them as beneficial to analyze the properties of natural fiber composites. Modeling techniques are helps to find out the better combination of constituents in order to balance the strength and over the cost of the resulting material. Modeling involves the analysis and understanding of the relationship between various elements of material processing. Different modern modeling techniques available are FEM, artificial neural network (ANN) [9]. The ambition of this survey is to provide a brief analysis of fire resistance characteristics of developed hybrid natural fiber composite and the model analysis to validate the theoretically obtained natural frequency using FEM with the numerically obtained natural frequency from Roark’s formula.

2. Materials and Methods

*Hemp fiber:*Hemp fiber reinforced polymer composites are commonly used in aerospace applications. Thermoset polymer composites and natural fiber composites are tough in nature as well as have high solvent resistance capacity. In this form of composites, fibers can carry up to 80% of the load. The interfacial bonding between the matrix and reinforcement depends on external force acting and chemical bonding [10]. The tensile strength of composite developed from Hemp with polyester resin can be improved constantly by increasing the quantity of fiber and maintaining the volume fraction by 11%. The shocks absorbed (impact energy) by this composite will also increase by increasing the amount of fiber [11]. The mechanical properties of natural fibers can enhance by using hybridizing method [12]. Table1 shows the physical properties of hemp fiber.

Table1. Physical and Mechanical Properties of Hemp Fiber[13]

Properties	Range
Length 'mm'	8.3-14
Diameter 'µm'	17-23
Length/diameter	549
Specific Gravity	1500
Tensile strength 'MPa'	310-750
Flexural Strain	2-4

Banana fiber: Banana is the one most widely available natural fiber in the world. Banana fiber has four forms of cells, those are phloem, xylem, parenchyma, and sclerenchyma [14]. Plenty of investigations happened on banana and banana reinforced composites in order to identify the different mechanical properties like flexural strength, tensile strength, etc. Banana fiber is having excellent specific strength as compared to that of e-glass fiber. Table2 shows the mechanical properties of banana fiber. It has less weight and low density than synthetic fibers. This is also good in fire resistance and low moisture absorption capacity. Composites prepared from banana fiber and its polymers are widely used in the production of decorative items, paper bags, etc. [15].

Table2. Mechanical Properties of Banana Fiber[15]

Properties	Value
Tensile strength 'MPa'	529-914
Young's Modulus 'GPa'	27-32
Failure Strain	1-3
Density 'Kg/m^3'	750-950

Polyester Resin: It is one of the reasonable and cheapest forms of matrix material available in the market. Polyester matrix material helps to maintain the proper bonding between the reinforcement and preserve the shape of the composite laminate properly. One more function of matrix material is to transfer the load evenly over the entire structure of the composite laminate. The matrix phase avoids the de-bonding between the layers of reinforcement due to various environmental aspects like abrasion, corrosion. This phase will also contribute more to the improvement of the mechanical properties of the composite structure. Polyester resin is used only in a few applications like structural materials and marine industries [16]. A comparison made between the commonly used polyester and epoxy resin is shown in table3.

Table3. Comparison between Polyester resin and epoxy resin[17]

Resin type	Cost/kg Rs	Strength (MPa)	Strength/Cost (MPa/Rs)	Modulus	Modulus/Cost (GPa/Rs)
Epoxy	400	35-100	0.0875-0.25	3-6	0.0075-0.015
Polyester	75	40-90	0.533-1.2	2.5-3.5	0.033-0.046
Polyester to Epoxy ratio	0.187	1.142-0.9	1.142-0.9	0.83-0.58	4.438-3.107

The value of tensile strength decides many mechanical properties, with this concern, in the case of hemp fiber; the tensile strength id depends on the diameter of the fiber, tensile strength decreases with an increase in the diameter of the fiber. The interface bonding between the fiber and matrix decides the surface energy of the laminate [18]. Banana fiber is the most commonly available low-cost natural fiber and it can be grown in most places in India. Banana has many useful advantages like less maintenance cost, fire retardant, water-resistant, less abrasive, and biodegradable. Chemical composition of banana fiber includes lignin 5-10%, cellulose 60-65%, hemicelluloses 5-19% and amount of pectin is 2-3% [19]. In this work, composite laminate is prepared using the layers of hemp and banana along with polyester resin using a simple and economical hand layup fabrication technique.

2.1Method of Fabrication

In order to develop the high-performance natural fiber composite laminate, in this research hemp and banana natural fibers are used along with the polyester resin as matrix material using hand layup fabrication technique. One of the aims of this investigation is to develop low-cost high-performance natural fiber composite material; hence the hand layup method helps to reduce the overall cost as well as time consumption [20].

Figure1. Hand Layup Process

Figure2. Mixing of Polyester resin with Catalyst and accelerator

Figure1 shows the clear image of placing alternative fibers of hemp and banana over the flat laminate mold and all the fibers are bonded together using polyester resin. Figure2 represents adding of MEKP catalyst and cobalt naphthenate as accelerators along with the polyester resin. The ratio of adding polyester resin, accelerator, and catalyst is 1:0.02:0.026.

Initially mold surface has to be cleaned properly using a cleaning agent in order to remove the particles present over the surface; later releasing agent should be applied for the purpose of easy removal of the laminate after the curing process[22]. A cylindrical roller is used to apply the pressure over the laminates for proper bonding and in order to remove the air bubbles present between the layers.

MEKP (Methyl Ethyl Ketone Peroxide): degree and rate of the curing process will be controlled by adding the proper amount of MEKP, this will also act as an initiator for the polymerization process.

Cobalt Nepthanate: This will also be called an accelerator for happening the curing of the process without the application of heat. Cobalt naphthenate takes place during the curing process at room temperature.

Role of Matrix

Polyester resin 1% Catalyst 0.02% Accelerator 0.026%

2.2 Variables Used for Composite Preparation

- ✓ Reinforcement and Matrix ratio : 50:50
- ✓ Orientation of Fibers : Unidirectional
- ✓ Curing Temperature : Room Temperature
- ✓ Fabrication Method : Hand Layup Process
- ✓ Thickness : 3mm
- ✓ Mixture of Resin, catalyst and accelerator : 1:0.02:0.026

3. RESULTS AND DISCUSSION

The hemp and banana fiber reinforced by polyester resin were subjected to a flammability test to evaluate some fire characteristics. Modal analysis is used to measure the dynamic behavior in terms of natural frequency and mode shapes [20].

3.1 Fire Resistance Property

Studying the thermal behavior of any natural composite is essential in order to identify its suitable implicational areas. Whenever we used to suggest natural fiber composites in automobile and aerospace applications it is required to analyze the thermal properties. Fire property analysis is one among the thermal properties of natural fibers, and that can be taken place in this investigation. Figure3 shows the equipment setup of fire testing and figure4 shows the testing specimen after fully burnt.

Figure3. Fire testing Equipment

This property defines the ability of the composite structure maintain the structural properties under the action of fire.

Specimen 1

Table4. Weight of the specimen1 before and after the test

Sl No	Weight of Material before test	After test
1	30.51g	7.1g

Figur4.Specimen after fire testing

Before conducting the fire test, it is necessary to note down the initial weight of the specimen and it is also important to collect the weight of the specimen after the fire test. From the table4 it is clear that the weight of the original specimen is 30.51grams and this weight is reduced to 7.1grams after being treated with the fire.

Table5. Performance characteristics of specimen1 during fire test

Temperature	Time	Fumes	Bubble Formation	Chipping	Fully Burnt
42°c	0’	WHITE	NO	NO	-
50°c	1’38”	WHITE	YES	NO	-
60°c	2’14”	WHITE	YES	NO	-
97°c	3’37”	WHITE	YES	YES	-
175°c	6.1’	WHITE	NO	NO	YES

Once the specimen is started to burn at the temperature of 42°c no fumes will appear and there is no effect on the surface of the specimen. Continuing this process, after 1minute 38seconds temperature reached to 50°c, at this stage bubbles are started to form on the surface but this temperature range does not affect the bonding strength. But at the temperature of 97°c after 3 minutes 37 seconds, bubbles formed over the surface will expand and this leads to the de-bonding of adjacent fiber layers and it is called "Chipping". These values are shown in the table5.

Specimen 2

Table6. Weight of the specimen2 before and after the test

Sl No	Weight of Material before test	After test
1	30.58g	7.13g

The second specimen which is taken to perform a fire test with the same composition and dimensions weighs around 30.58grams initially and after finishing the fire test it weighs 7.13grams which is as shown in the table6.

Table7. Performance characteristics of specimen2 during fire test

Temperature	Time	Fumes	Bubble Formation	Chipping	Fully Burnt
35°c	0'	WHITE	NO	NO	-
60°c	2'17"	WHITE	YES	NO	-
80°c	2'48"	WHITE	YES	NO	-
99°c	3'16"	WHITE	YES	YES	-
152°c	4'33"	WHITE	NO	NO	YES

This specimen takes 2minutes 48seconds to reach the temperature of 80°c at this stage the bubbles are started to form on the surface of the specimen. Chip formation will appear at 99°c over a time of 3minutes 16 seconds. This specimen will completely burn around a temperature range of 152°c over a time period of 4minutes 33seconds. This is represented through the table7. Pictorial representations of all these values of two specimens are illustrated in figure5.

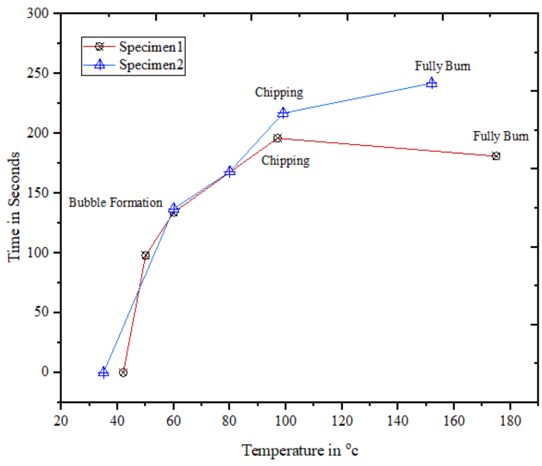

Figure5. Fire test comparison of specimen1 and specimen2

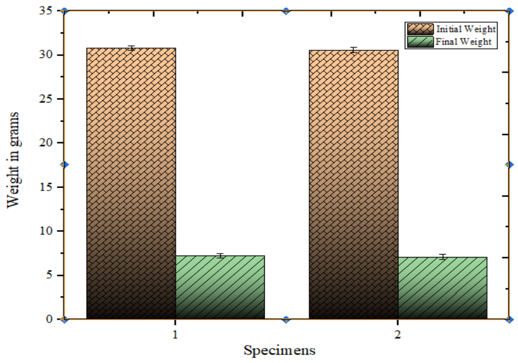

Figure6. Error graph analysis of fire testing specimens

The initial weight and final weight of both the specimens used for the fire test is mentioned through graphical representation from figure6 including error analysis. This composite will not release harmful gases, unlike synthetic fiber composites. Results show that there is not much variation in temperature resisting capacity and time taken for complete combustion.

3.2 Modal Analysis

The dynamic behavior of composite is studied using the Finite Element Analysis method. Roark's formula is used to calculate the natural frequency numerically. Roark's table for referring natural frequency different modes with respect to the support condition is as shown from the table8. The specification used for the development of composite beam for model analysis is shown in table9.

Table8. Roark's Table [21]

TABLE 36 Natural frequencies of vibration for continuous members

NOTATION: f = natural frequency (cycles per second); K_n = constant where n refers to the mode of vibration; g = gravitational acceleration (units consistent with length dimensions); E = modulus of elasticity; I = area moment of inertia; $D = Et^3/12(1-\nu^2)$

Case no. and description		Natural frequencies	Mode	K_n	Nodal positions/l	
1. Uniform beam; both ends simply supported	1a. Center load W, beam weight negligible	$f_1 = \frac{6.93}{2\pi}\sqrt{\frac{EIg}{Wl^3}}$				
	1b. Uniform load w per unit length including beam weight	$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$	1	9.87	0.0 1.00	
			2	39.5	0.0 0.50 1.00	
			3	88.8	0.0 0.33 0.67 1.00	
			4	158	0.0 0.25 0.50 0.75 1.00	
			5	247	0.0 0.20 0.40 0.60 0.80 1.00	Ref. 22
	1c. Uniform load w per unit length plus a center load W	$f_1 = \frac{6.93}{2\pi}\sqrt{\frac{EIg}{Wl^3 + 0.486wl^4}}$ approximately				
2. Uniform beam; both ends fixed	2a. Center load W, beam weight negligible	$f_1 = \frac{13.86}{2\pi}\sqrt{\frac{EIg}{Wl^3}}$				
	2b. Uniform load w per unit length including beam weight	$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$	1	22.4	0.0 1.00	
			2	61.7	0.0 0.50 1.00	
			3	121	0.0 0.36 0.64 1.00	
			4	200	0.0 0.28 0.50 0.72 1.00	
			5	299	0.0 0.23 0.41 0.59 0.77 1.00	(Ref. 22)
	2c. Uniform load w per unit length plus a center load W	$f_1 = \frac{13.86}{2\pi}\sqrt{\frac{EIg}{Wl^3 + 0.383wl^4}}$ approximately				
3. Uniform beam; left end fixed, right end free (cantilever)	3a. Right end load W, beam weight negligible	$f_1 = \frac{1.732}{2\pi}\sqrt{\frac{EIg}{Wl^3}}$				
	3b. Uniform load w per unit length including beam weight	$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$	1	3.52	0.0	
			2	22.0	0.0 0.783	
			3	61.7	0.0 0.504 0.868	
			4	121	0.0 0.358 0.644 0.905	
			5	200	0.0 0.279 0.500 0.723 0.926	(Ref. 22)

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Table9. Specifications of composite beam

L = 1000mm	Length of beam
b = 50mm	Width of the beam
h = 5mm	Thickness of the beam
E = 905.5728MPa	Young's modulus of the Composite Laminate
ρ=1012Kg/m^3	Density of the Composite Laminate

3.2.1 Theoretical Frequency of Cantilever and Fixed support Condition

ANSYS is the tool used for the dynamic analysis of the developed composite specimens. This study is performed for an external load of 2000N. For cantilever support, the point load is applied at the free end, whereas in the case of the rigidly fixed beam, the central point load is applied. Roark's table provides the formula required to find the natural frequency for different end supports.

Roark's formula for cantilever support is given as,

fn= (Kn/2π)*sqrt((E*I*g)/(W*L4)) Hz --------------------------------(1)

E= Young's modulus

I= Moment of inertia

W= Weight per unit length

L= Length

Kn= Constant of Vibration

Cantilever Support

From the Roark's table, fn=2.47Kn (Cantilever beam& Rigidly Fixed Support)

Where, (From the Roark's table)

Kn for mode 1 is 3.52 *Hence,* f1= 11.926 Hz

Kn for mode 2 is 22.0 f2= 76.021 Hz {Natural Frequencies}

Kn for mode 3 is 61.7 f3= H215.02 Hz

Kn for mode 4 is 121 f4= 3421.04 Hz

Rigidly Fixed Support

From the Roark's table

Where,

Kn for mode 1 is 22.4 *Hence,* f1= 77.82 HZ

Kn for mode 2 is 61.7 f2= 216.233 HZ

Kn for mode 3 is 121 f3= 420.49 HZ {Natural Frequencies}

Kn for mode 4 is 200 f4= 626.82 HZ

Table10. *Theoretical and numerical frequency of cantilever support and rigidly fixed support specimens*

	Cantilever Support			**Fixed Support**		
	Theoretical Frequency "Hz"	Numerical Frequency "Hz"	Error %	Theoretical Frequency "Hz"	Numerical Frequency "Hz"	Error %
Mode 1	12.281	11.962	0.31	78.037	77.82	0.21
Mode 2	76.783	76.021	0.76	215.35	216.23	0.88
Mode 3	214.92	215.02	0.1	421.21	420.49	0.72
Mode 4	420.26	421.04	0.78	626.28	626.82	0.54

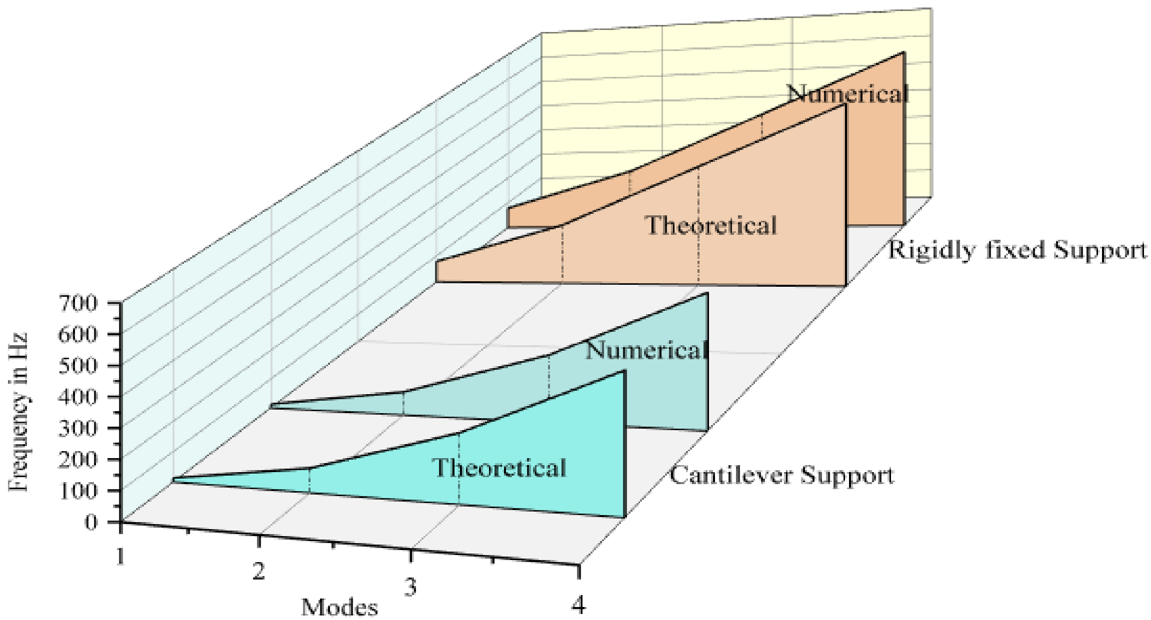

Figure7. *Color mapped Line series comparison of theoretical and numerical frequency*

Mode Shapes

Cantilever support (Load applied at the free end)

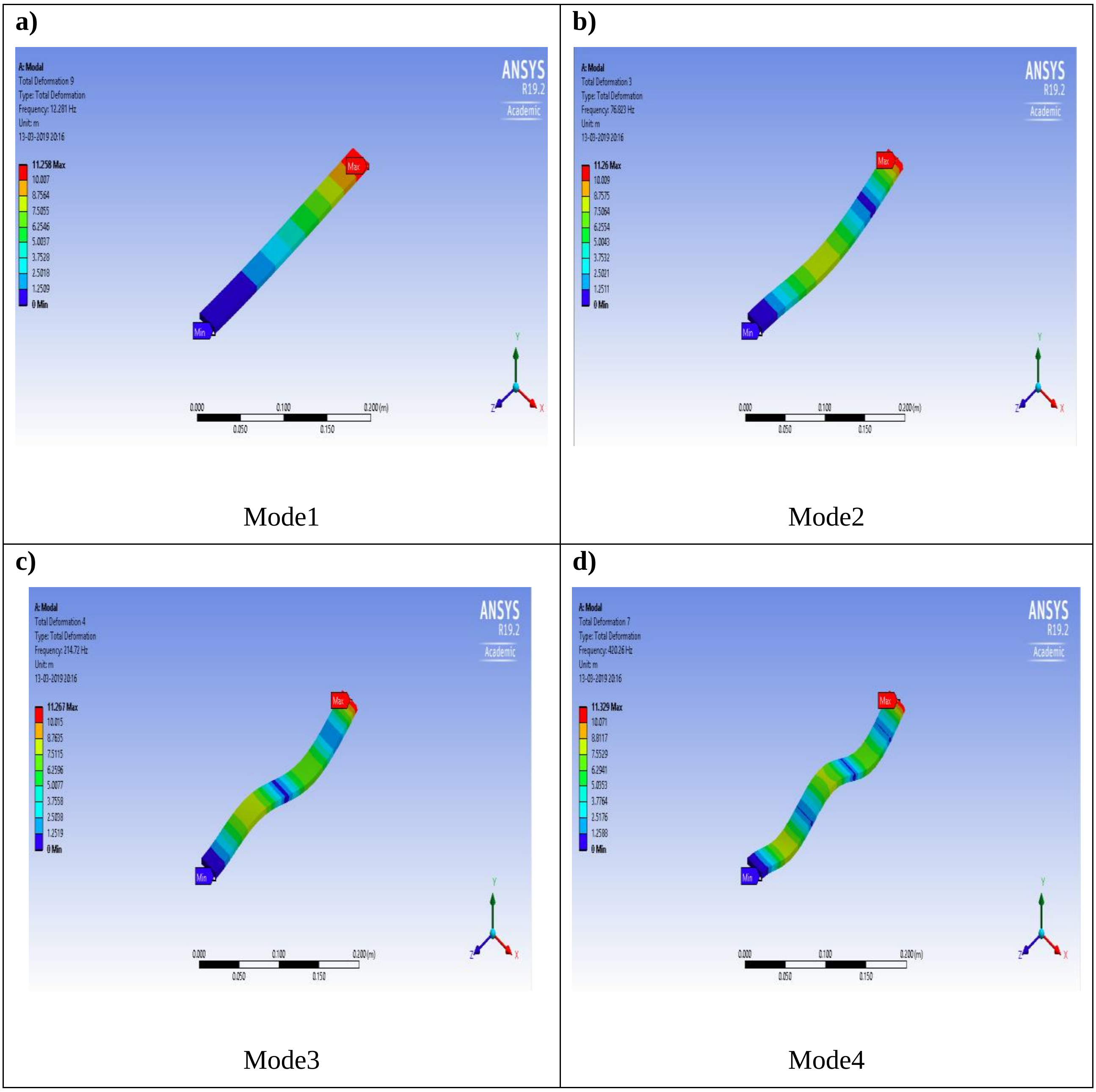

***Figure8**. Mode shapes of cantilever support specimen*

Rigidly Fixed Beam (Central Load)

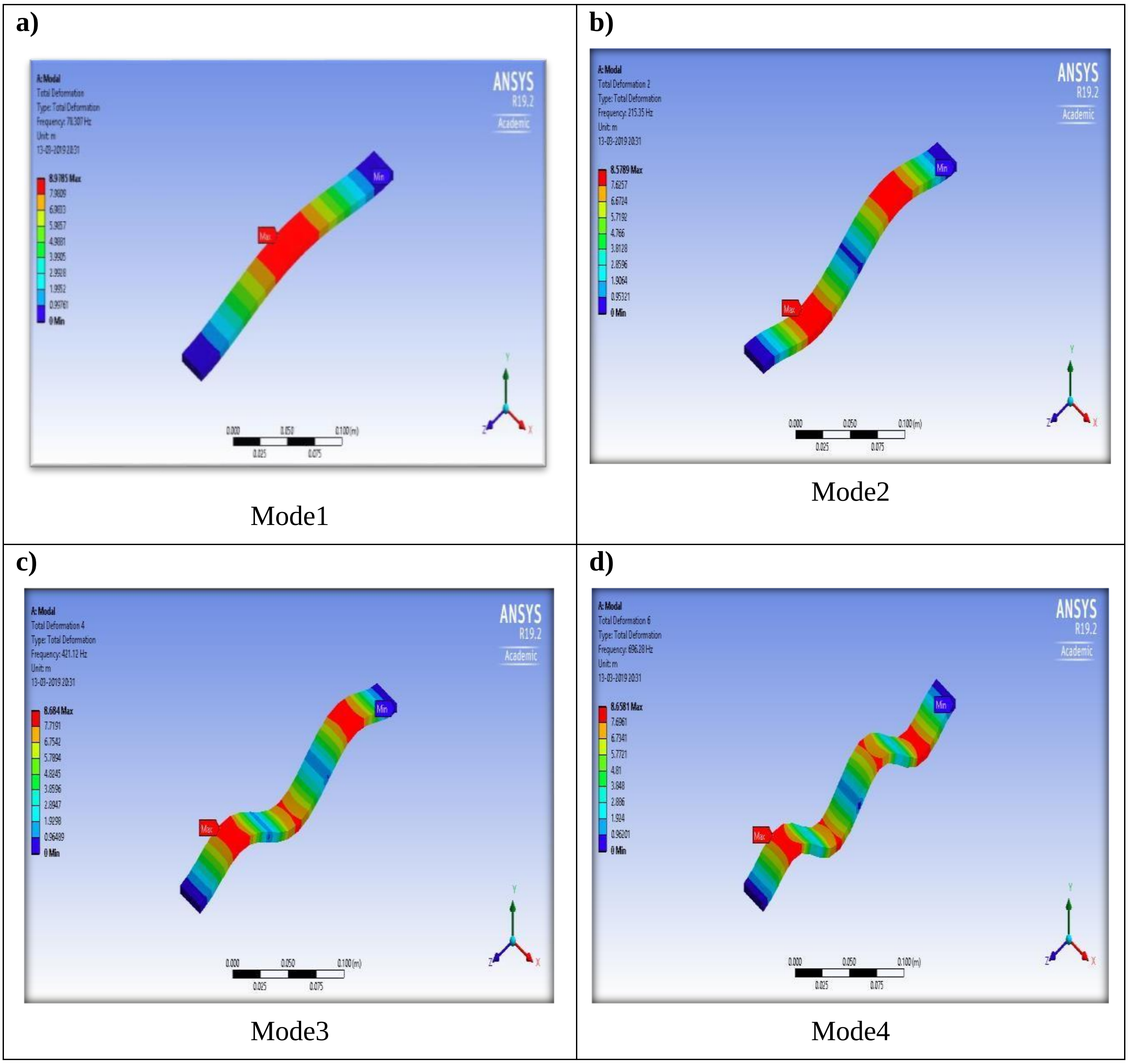

Figure9. *Mode shapes of rigidly fixed support specimen*

The dynamic behavior of prepared composite laminate is determined in terms of natural frequency. The theoretically obtained natural frequency using ANSYS is represented in figure8 and figure9. A clear comparison between numerical and theoretical frequencies is shown in table10. Color mapped Line series comparison of theoretical and numerically obtained natural frequency is drawn between 54 different modes along X-axis and frequency along Y-axis. The maximum error of frequency in cantilever support is at mode4 with 0.78%, similarly the lease error obtained at mode3. For the fixed condition beam at mode2, the maximum error of 0.88 % appears. Red color indicates the place where maximum disturbance occurs undergoes more displacement. Some of the factors influence the performance of the composite specimen like improper arrangement of setup, environmental errors, operator skills, uneven application of load, etc.

CONCLUSION

A lot of environmental issues are arising since the decade due to the rapid use of synthetic and chemical composed materials. Many researchers are trying to find better alternatives to replace them in order to avoid environmental, fire retardance, strength, durability, and cost. The aim of this study is to develop a composite material using hemp and banana reinforcement with a polyester resin matrix to study its fire characteristics and theoretical and numerical validation of natural frequency using ANSYS. We have successfully completed the investigation and the obtained results are described clearly. Analysis of Fire resistance characteristics is one of the major criteria for any natural fiber composites to propose to use in automobile and aerospace applications. The prepared NFRC resists a temperature of 175^{o}c over a period of 6minutes. The De-lamination between the layers of fiber happened around 99^{o}c. The fire properties can further increase by using suitable fire retardants like ammonium polyphosphate, boric acid with magnesium hydroxide, etc. These results proved that the prepared NFRC has good fire resisting capacity, which is suitable to use in some aerospace and automobile parts. The dynamic behavior data obtained from Roark's formula is validated using ANSYS. The maximum error imposed by the cantilever support is 0.78%, which is an impressive and acceptable range. In the case of rigidly fixed support, the error is ranged between 0.21 to 0.88%. These values show that there is not much difference between the theoretical frequency and numerical frequency. Hence the aim of validation is successfully completed.

References

1. D.R. Rajkumar, K. Santhyand K.P. Padmanaban'Influence of Mechanical Properties on Modal Analysis of Natural Fiber Reinforced Laminated Composite Trapezoidal Plates', Journal of Natural Fibers, 18(2021), 2139–2155, doi.org/10.1080/15440478.2020.1724230.
2. B. NagarajaGanesh, B. Rekha and K. Yoganandam 'Assessment of thermal insulation and flame retardancy of cellulose fibers reinforced polymer composites for automobile interiors', Journal Of Natural Fibers, 5(2021), https://doi.org/10.1080/15440478.2021.2009395.
3. Muhammad Yasir Khalid, 'Natural fiber reinforced composites: Sustainable materials for emerging applications',Results in Engineering, 11(2021), https://doi.org/10.1016/j.rineng.2021.100263.
4. Gholampour, A,T. Ozbakkaloglu 'A review of natural fiber composites: Properties, modification and processing techniques, characterization, applications', Journal of Materials Science, 55 (3), 829–92. doi:10.1007/ s10853-019-03990-y,2020.
5. Raquel Ortega, 'Study and fire test of banana fibre reinforced composites with flame retardance properties', De Gruyter, 18(2020), 275-286, doi.org/10.1515/chem-2020-0025.
6. G. Mathubala, M. Nandhini 'Flammability and thermal studies of jute fibre reinforced polymer composites', Malaya Journal of Matematik, S(2020),856-858,

https://doi.org/10.26637/MJM0S20/0193.

7. Husain Mehdi, Arshad Mehmood 'Theoretical Modelling and Experimental Investigation on Mechanical Properties of Natural Fiber Reinforced By Epoxy Resin Matrices', Journal of Materials Science & Surface Engineering, 6(2019), 867-871.
8. S. A. Chukwunwike, 'Flammability properties of flame retarded natural fibre reinforced polymer composites: an overview', Journal of Materials and Environmental Sciences, 10(2019), 647-656.
9. Timothy K. Mulenga, Albert U. Udeand ChinnasamyVivekanandhan'Techniques for Modelling and Optimizing the Mechanical Properties of Natural Fiber Composites: A Review', Journal of fibers, 9(2021), 6-9, https://doi.org/10.3390/fib9010006.
10. Deferne J-L, Pate DW 'Hemp seed oil: A source of valuable fatty acids', Journal of the International Hemp Association, 3(1996), 1-7.
11. Lilholt, H., Lawther, J.M. 'Natural organic fibres", Elsevier Comprehensive composite materials, 1(2000), 303-325.
12. D. Shanmugam, M. Thiruchitrambalam'Static and dynamic mechanical properties of alkali treated unidirectional continuous Palmyra Palm Leaf Stalk Fiber/jute fiber reinforced hybrid polyester composites', Materials and Design,50(2013),533-542, http://dx.doi.org/10.1016/j.matdes.2013.03.048.
13. Mohammad Jawaid,'Impact Properties of Natural Fiber Hybrid Reinforced Epoxy Composites', Advanced Materials Research, 264-265(2011), 688-693,doi:10.4028/www.scientific.net/AMR.264-265.688.
14. S. P. Jani'Machinablity of Hybrid Natural Fibre Composite with and Without Filler as Reinforcement', Materials and Manufacturing Processes, 1532-2475(2014), 1393-1399,http://www.tandfonline.com/loi/lmmp20.
15. P. Yang, S. Kokot'Thermal analysis of different cellulosic fabrics', Journal of Applied Polymer Science,. 8(1996), 1137–1146.
16. Soderstrom J 'Optimisation of two-step steam pretreatment of softwood for bio ethanol production', Ph.D. thesis, Department of Chemical Engineering, Lund University, 2004.
17. RunCang Sun, 'Fractionation and characterization of polysaccharides from abaca fibre', 37(4) (1998), 351-359,DOI: 10.1016/S0144-8617(98)00046-0.
18. Bledzki AK, Sperber VE and Faruk O 'Natural and wood fibre reinforcement in polymers',Rapra Review Reports, 13(2002).
19. Small E,Marcus D 'Hemp: A new crop with new uses for North America. In Trends in New Crops and New Uses', ASHS Press: Alexandria, VA(2002),84–326.
20. Mohammed Y. Abdella, 'A Novel and Highly Effective Natural Vibration Modal Analysis to Predict Nominal Strength of Open Hole Glass Fiber Reinforced Polymer Composites Structure', Polymers, MDPI journal, 13(8)(2021), 1251,https://doi.org/10.3390/polym13081251.

21. Warren C.Young, Richard G.Budynas'Roark's formula forstress and strain', (Mc.Graw hill publication), seventh edition, 2002, ISBN: 0-07-072542-X.
22. Y V RaviS, 'Damage resistance evaluation of E-glass and hybrid hemp-banana natural fiber composite helmet using drop weight impact test', Materials Today Proceedings,1-6 (2021), https://doi.org/10.1016/j.matpr.2021.09.213 2214-7853/© 2021.