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Design and Material Optimization of 1.5MW Horizontal Axis Wind Turbine Blades with Natural Fiber Reinforced composites using Finite Element Method

C. M. Meenakshi [1]
Sathyabama University, Chennai, Tamil Nadu, India.
Dr. A. Krishnamoorthy[2]
Sathyabama University, Chennai, Tamil Nadu, India.

ABSTRACT

Global warming as well as increasing environmental awareness,also depletion of fossil fuelsdiverts the attention of both developing and developed countries towards non-conventionalenergy sources like wind a pollution free source of energy. India is the fifth largest wind power producer in the world, many researches are going in India regarding wind energy power production system. This is one such work aiming at weight reduction of wind turbine blades by using hybrid composites, where 1.5MW wind turbineblades areconsidered which is highly used in the region of Visakapattanam at an average cut-out windspeed range of 14 to 21m/s. The blades are designed and analyzed with different Natural Fiber Reinforced composite materials their weight, static and dynamic performances are compared. From the results obtained it identified that natural fiber reinforced blades weigh less than the glass fiber blades with competitive performance. Modeling and analysis of wind turbine blade have been done using UNIGRAFIC-NX (NX-CAD &NX-NASTRAN) software.

KEY WORDS: Global Warming, Composite Wind Turbine Blade, Weight Reduction.

1. INTRODUCTION

Among the Indian states Tamilnadu and Andhra Pradesh are having the highest wind potential of 5,300MW.Lots of researchis on-goingparticularly to enhance the performance of the wind turbines used in this region. The 1.5MW wind turbines consider here is one of the highest number installed turbines in the above mentioned two states, Almost 700 turbines are running throughout erected by Regen Power Tech and many other leading players of this field.

The wind energy is converted into power through the turbine blades, in that way blades play a major role in the wind turbines. The efficiency of the wind turbine blades mainly depends on three factors the material of the blade, shape of the blade and the angle of the blade[1]. A. Jagadeesh [2] has confirmed that continuous research and development is important to improve the utilization of wind energy. Sanjay Kumar Kar, Atul Sharma [3] is saying that India needs more investments in wind power research and development in wind component manufacturing industry. Pertaining to this many researches are undergoing in wind energy technology to improve its utilization. Jinshui Yang [4] found that the major failure mechanisms that caused the collapse of the blade are the structure stress-concentration in the blade. Erick Y Gomez [5] has designed and manufactured a low capacity composite wind turbine blade using CAD/CAM techniques. Povl Brondsted [6] discusses the possibility of composite as a material for wind turbine blade and also its manufacturing techniques. Darshil U. Shah, Peter [7] has proven that the natural fibers can also be used in wind turbine blade he found out that the flax/ epoxy small wind turbine blade weight 10% less than that of glass / Epoxy blade.

The material used for blade construction must have high stiffness, low density and long fatigue life. Composites are such materials made from two or more constituent materials with different physical or chemical properties. When combined, produce a material with characteristics different from the individual parent material resulting in anadvanced material with enhanced properties.

Even though the wind turbine blade manufacturing industry is already highly dominated by composite materials most of them is using glass fiber as reinforcement which is causing problem in disposal after the end of life of the blade.The natural fiber can act as a good substitute for glass fiber in structural applications. The prominent advantages of using natural fiber are its less weight and biodegradability which is a very important factor in the heavy structures like wind turbine blades. Asia is the largest producer of natural fibers, definitely NFRP can be a better replacement for GFRP in wind turbine blade manufacturing, which will increase the usability of wind turbinesin Asia, particularly in India where the annual power demand is very high.

2. MODELLING OF WIND TURBINE BLADE

The structural design of the blade is mainly decided by the aerodynamic profile selected. Even though the main objective of this paper is not to study the aerodynamic performance and it is only above mass optimization, the design process catches up with the real time blade profile of NREL'S S809 airfoil with 13 sectionswhich is one of the proven airfoilcurvesthat extract as much energy from the wind.The geometrical model of the blade is generated based on cross section profiles using the NX-CAD, NX-NASTRAN. General specifications of the blade are referred from A. Gangele and S. Ahmed [8]shown in Table:1

Table 1: Specification of the Wind Turbine Blade.

Specification of the wind turbine blade	
Length	41051mm
Maximum chord length	5013mm
Station of maximum chord	R3810mm
Root chord length	3297mm
Minimum chord length	1449mm
Hub length	218mm
Hub diameter	512mm
Hub to blade neck length	512mm
Twist angle	16.40
Swept area	5210m^2
Airfoil cross-section types	S809

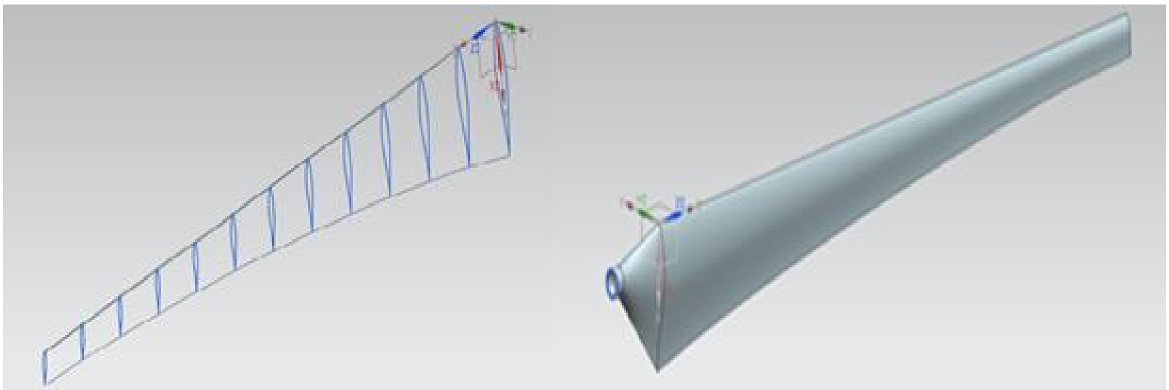

Fig 1: Turbine Blade 3D model with airfoil section and solid model in NASTRAN

3. MATERIAL SELECTION

Wind turbine blade manufacturing industry is dominated bythermoset plastics due to being low operating temperature and availability, among the thermosets, polyester is preferred for medium to large blade and with more extra-large blade development now it is epoxy as the matrix due to its high fatigue strength. By that way we can say almost in all the large wind turbine blade the material used is glass fiber reinforced polymers, which has been proven for its stiffness and fatigue life. The drawback with this material is its synthetic fiber which is causing environmental issues in disposal. Apart from that, another factor to be considered is the weight of the blade which the concern of interest in this work.Today's researcher have proven that the natural fiber can be a very good replacement of glass fiber in structural applications pertaining to their lower density and biodegradability. Nottingham innovative manufacturing, researchcenter, UK is developing small turbine blades with natural fibers like flax, hemp, jute, sisal along with Polyester and Epoxy Resin [9].In this work two such natural fiber reinforced composite material has been taken for analysis one is sisal epoxy and other is flax epoxy and their performance is compared to the glass fiber epoxy.The properties of the materials are given in Table 2.

Table 2: Material properties of composites

Property	Glass Fiber Epoxy	Jute Fiber Epoxy	Sisal Fiber Epoxy
Young's modulus in longitudinal direction	60.52 Gpa	37.54 Gpa	34.06 Gpa
Young's modulus in transverse direction	10.37 Gpa	9.12 Gpa	9.039 Gpa
Poisson's ration in longitudinal direction	0.239	0.3284	0.2846
Poisson's ration in transverse direction	0.0390	0.0798	0.0791
Density	2110 Kg/m3	1300 kg/m3	1500kg/m3

4. FINITE ELEMENT PROCESSING

Finite element method of analysis is one of the most powerful methods of analysis, especially in the case of heavy structure applications like wind turbine blade which is complicated to solve theoretical and time and money consuming experiments. The major advantage of analyzing with FEA is its ability to analyzea variety of problems in one model. Xiao Chen [10] is recommending using solid elements for analysis in finite element models of the turbine blade.The finite element model created has 73935 elements and 148292 nodes.

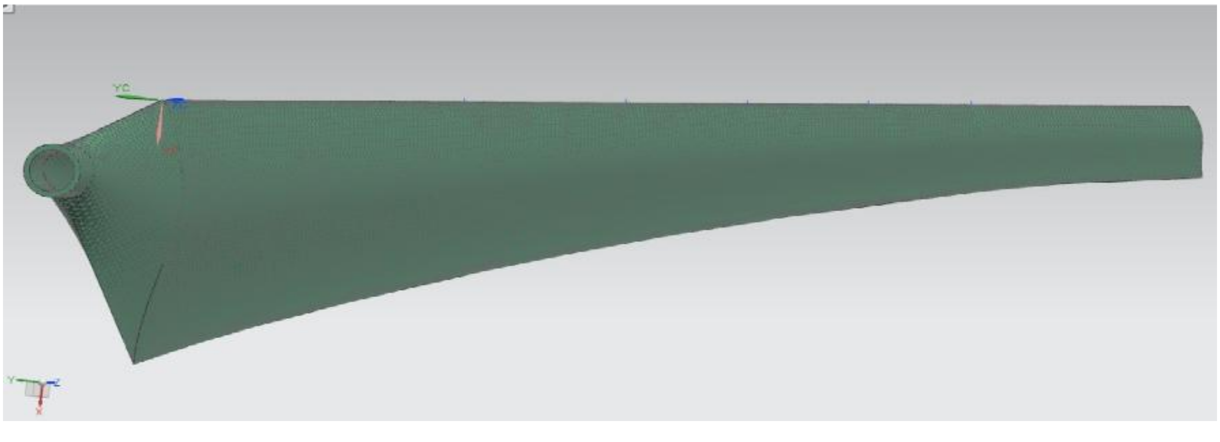

Fig 2: Finite Element Model of the blade

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4.1 FREE VIBRATION ANALYSIS

The free vibration analysis is carried out to find the natural frequency of vibration of the structure when the blade exposed to the wind speed. The free vibration analysis is carried out by the Eigenvalue method of modal analysis using Lanczos equation and first ten modes are extracted and compared for the considered three different composites.

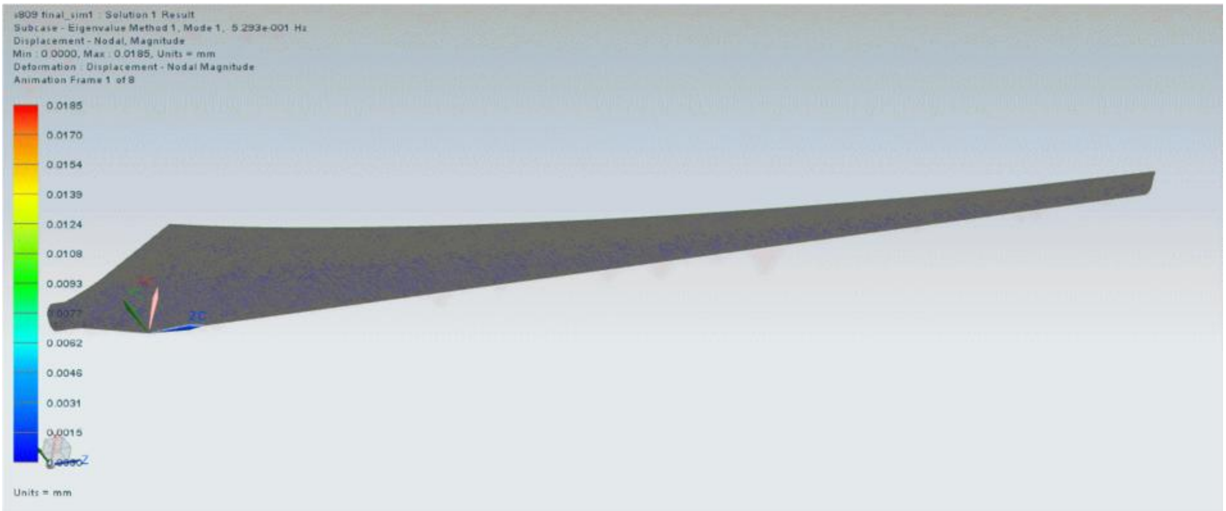

Fig 3: Free Vibration Analysis

4.2 DISPLACEMENT AND STRESS ANALYSIS

The major force of the wind turbine blade is the wind force, for the analysis purpose the blade was considered as a cantilever beam fixed at the rotor end and the wind load at a survival wind speed of 50m/s was applied.For simplicity, the load is reduced to several point loads on the blade from the pressure side towards the suction side, which is understood from [2] and [7].

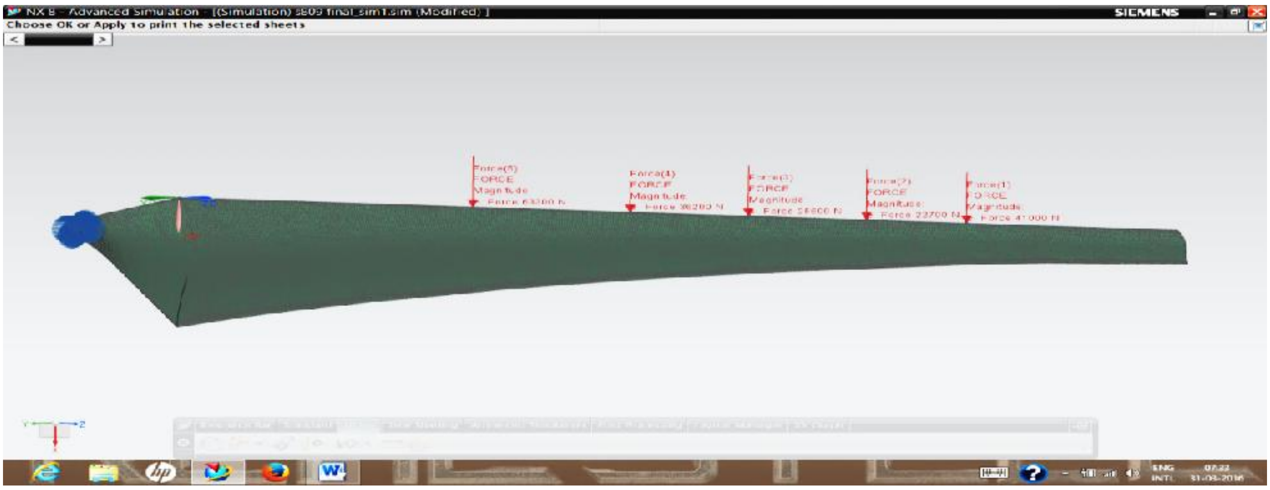

Fig 4: Blade with loads and constrain

5. RESULT AND DISCUSSION

5.1 FREE VIBRATION ANALYSIS

The free vibration analysis is carried out to find the corresponding natural frequencies for different material. The result of the free vibration analysis are given in Table 3 and the comparison of the displacement value for the three different materials are shown in fig 5 from the figure it is understood that the range of magnitude of displacement of Eglass Epoxy blade is less compare to the natural fiber blades, but we can understood that the numerical variation in the magnitude of displacement for the three materials not very much high for all the three material the displacement for the given 10 modes are in the range of 1.5 to 2.8 mm. The frequency of vibration is shown in Table 4 and compared for the three materials are in Fig 5 which is showing the frequency of vibration of all the materials are almost same for the first 5 modes and even after that Eglass and Jute blade is showing same values but the sisal blade frequency is little bit lesser compare to the other two blades.

Table 3: Modal Analysis

Mode Number	Displacement in mm		
	E glass Epoxy	Jute Epoxy	Sisal Epoxy
1	1.562e-002	1.991e-002	1.853e-002
2	1.222e-002	1.560e-002	1.451e-002
3	1.711e-002	2.180e-002	2.029e-002
4	1.765e-002	2.249e-002	2.094e-002
5	1.804e-002	2.296e-002	2.139e-002
6	1.744e-002	2.222e-002	2.069e-002
7	1.835e-002	2.364e-002	2.192e-002
8	1.563e-002	2.045e-002	1.879e-002
9	1.801e-002	2.299e-002	2.139e-002
10	2.162e-002	2.805e-002	2.595e-002

Table 4: Frequency of Vibration

Si.No	Mode Number	Frequency Hz		
		EGLASS EPOXY	JUTE EPOXY	SISAL EPOXY
1	**1**	5.95E-01	5.97E+00	5.29E-01
2	**2**	1.27E+00	1.28E+00	1.13E+00
3	**3**	1.92E+00	1.93E+00	1.71E+00
4	**4**	4.38E+00	4.40E+00	3.90E+00
5	**5**	5.96E+00	5.98E+00	5.30E+00
6	**6**	8.20E+00	8.23E+00	7.30E+00
7	**7**	1.29E+01	1.29E+01	1.15E+01
8	**8**	1.54E+01	1.52E+01	1.36E+01
9	**9**	1.59E+01	1.59E+01	1.41E+01
10	**10**	1.96E+01	1.96E+01	1.74E+01

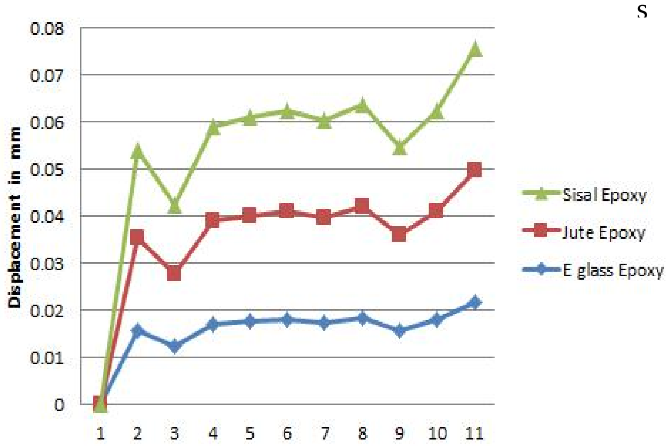

Fig 5: Comparison of Displacement

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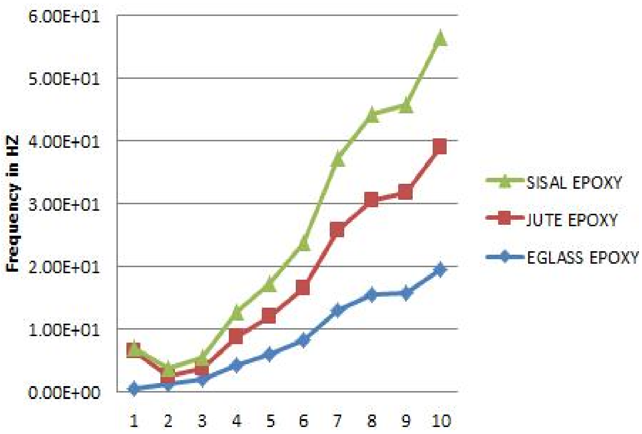

Fig 6: Comparison of Frequency of vibration

5.2 DISPLACEMENT AND STRESS ANALYSIS

The static and dynamic analysis results are shown in Table 4 and comparison of stress values for all the materialsare done in Fig 6 is shown that the Von-Misses stress and Shear stress value of the blade is almostsame in all the material with minimum variation among them in value, at the same time the principal stress value of glass fiber is very less and the jute fiber is very high and that of sisal fiber is in between the two other materials. This is a proof that the natural fiber reinforced composite is equally good with synthetic glass fiber. Among the natural fiber reinforced composite sisal fiber is having less stress value compare to jute fiber irrespective of its slightly higher density value.

Table-5.Dynamic Analysis Result

SI. No	Properties	E glass Epoxy		Jute Epoxy	Sisal Epoxy
1.	Displacement (mm)	Max	$2.020e^{+002}$	$3.230e^{+002}$	$3.579e^{+002}$
		Min	$0.000e^{+000}$	$0.000e^{+000}$	$0.000e^{+000}$
2.	Von-Misses (kPa)	Max	$1.315e^{+005}$	$1.331e^{+005}$	$1.3o07e^{+005}$
		Min	$-2.530e^{-008}$	$-9.73e^{-008}$	$-6.084e^{-008}$
3.	Principal stress (kPa)	Max	$1.131e^{+005}$	$1.336e^{+005}$	$1.259e^{+005}$
		Min	$-1.853e^{+004}$	$-4.128e^{+004}$	$-3.399e^{+004}$
4.	Shear stress (kPa)	Max	$7.539e^{+004}$	$7.677e^{+004}$	$7.541e^{+004}$
		Min	$-1.416e^{-008}$	$-5.461e^{-008}$	$-3.367e^{-008}$

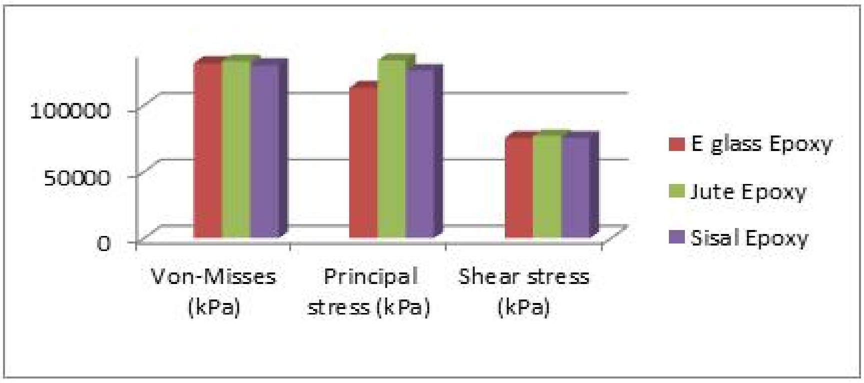

Fig 6: Comparison of stress values for Different Materials

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5.3 MASS PROPERTY ANALYSIS

This work has been started with the interest and aim of reducing the weight of the blade by replaces the material of the blade with less dense natural fiber reinforce resins, which will also enhance the biodegradability of the blade after end of life. The Table 5 isanevidence that it can be definitely achieved with NFRP'S. From the Table 5 it is understood that the blade weight can be reduced up to 35-38% by replacing glass fiber with natural counterpart. Further,Fig 7 is making it clearer that jute fiber blade is lighter than the sisal fiber blade and glass fiber blade.

Table 6: Mass Property with respect to Materials

S. No.	Material	Area m^2	Volume m^3	Density Kg/m^3	Mass Kg
1	E-Glass/Epoxy	400.644	19.778	2100.000	41732.164
2	Jute/Epoxy	400.644	19.778	1300.000	25711.760
3	Sisal/Epoxy	400.644	19.778	1500.000	29667.415

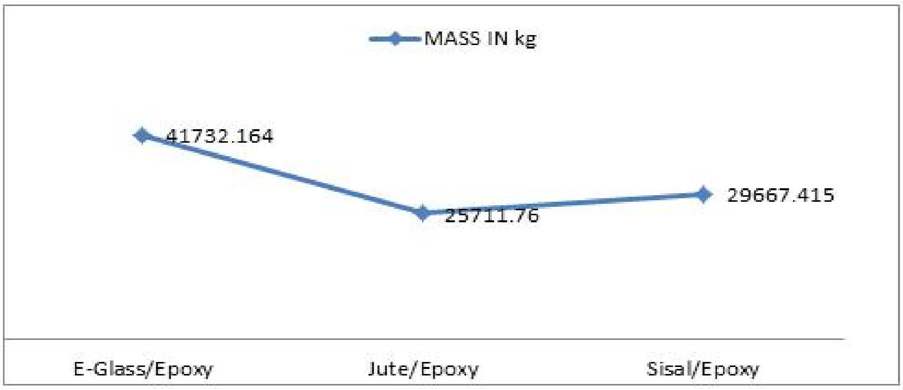

Fig 7: Comparison of Mass of the Blade

6.CONCLUSION

- In this work the 1.5MW wind turbine blade was designed with S809 airfoil profile with 13 sections and analysis were carried out with three different composites one with glass fiber reinforcement and the other two with natural one.
- The blades made of natural fiber reinforced composite (Jute Epoxy and Sisal Epoxy) weigh less than that of a blade made of Glass Fiber Reinforced Composite, by which it can be claimed that the efficiency of the blade will increase.
- Further static and dynamic performances of the blades of both synthetic and natural fiber composite are comparatively same. Jute fiber blades are very less in weight at the same time sisal fiber blades are giving better performance.

Therefore we can infer that natural fiber reinforced composite with till more enhancement in property and hybridization can act as a replacement for synthetic fiber in structural applications. Hence we can conclude that the NFRP can act as a better replacement for GFRP in wind turbine blades by which the weight of the blade will be highly reducing and the CO_2 emission can also be reduced while disposing the blade. The future scope of this work is more dynamic and fluent analysiscan be carried out on natural fiber reinforced structure and more variety of natural fibers can be considered.

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