Comparative Analysis of Composite Materials Based on Stress and Vibration by using Experimental Approach

Yogita U. Medhane[1], Poonam S. Talmale[2], Digambar B. Zoman[3]

[1]*Research Scholar, Department of Mechanical Engineering, Late G. N. Sapkal College of Engg., Nasik, MH, India*
[2]*Assistant Professor, Department of Mechanical Engineering, Late G. N. Sapkal College of Engg., Nasik, MH, India*
[3]*Assistant Professor, Department of Mechanical Engineering, Late G. N. Sapkal College of Engg., Nasik, MH, India*

---***---

Abstract - *Composites are most promising materials for components of current and future engineering structures, with a significant demand at present in aircraft and aerospace industries. Modal analysis is the study of the natural characteristics of structures. Understanding both the natural frequency and mode shape helps to design any structural system for noise and vibration applications. In this paper analysis of free vibration of cantilever beam for the composite as well as steel material are carried out. Natural frequency and mode shape of the plates has been determined using FFT analyzer. Also comparative study of Steel, E glass epoxy and FRP is done for stress analysis with the help of UTM. These materials are used for vibration analysis to observe the effect of a modal parameters of cantilever beam subjected to free vibration is analyzed with the help of FFT analyzer in experimental setup. From this work we found the behavior of structures or mode shapes obtained from FFT analyzer can be utilized to validate results obtained from FEM for mode shapes. Natural frequencies of vibrating structures are susceptible to change under influence of depth & location, where its magnifying views allow getting an idea of significant changes at location. E-glass Epoxy material is the good material as comparatively steel and FRP material.*

Key Words: Fast Fourier Transformer, ANSYS, UTM, Composite, Fiber reinforced plastic, Finite Element Method.

1. INTRODUCTION

In structural acoustics, recent work in sound transmission through laminated structures has shown that the fundamental frequency is a key parameter. The natural frequencies are sensitive to the orthotropic properties of composite plates and design-tailoring tools may help in controlling this fundamental frequency. The understanding of prediction models facilitates the development of such tools. Due to the advancement in computer aided data acquisition systems and instrumentation, Experimental Modal Analysis has become an extremely important tool in the hands of an experimental. Variation of natural frequency with different parameter is studied. E glass is the primary reinforced material of wind turbine blades, having low cost and good applicability. It is a better match with many resins, and the molding process. However, as the density of the E-type fiber is large, it is generally used in smaller blades. Composite materials are gaining popularity because of high strength, low weight, resistance to corrosion, impact resistance, and high fatigue strength. Other advantages include ease of fabrication, flexibility in design, and variable material properties to meet almost any application. Use of composite materials in various construction elements has increased substantially over past few decades. A variety of structural components made of composite materials such as turbine blades, vehicle axles, robot arms, aircraft wings, and helicopter blades can be approximated as laminated composite beams. Materials are particularly widely used, where a large strength-to-weight ratio is required. Fiber Reinforced Plastics (FRP) are commonly used in aircraft structure, high speed, military equipment's, civilian products, automotive and or engineering applications mainly because of high strength-to-weight ratio, high stiffness, good resistance to fatigue, and corrosion resistance advantages include ease of fabrication, flexibility in design, and variable material properties to meet almost any application. Thus vibration technique can be suitably used as a non-destructive test for detection of component to be tested Vibration analysis, which can be used to what types of changes occur in vibration characteristics, The combination of different materials has been used for many thousands of years to achieve better performance requirements. The strength of the composites depends primarily on the amount, arrangement and type of fiber and particle reinforcement in the resin.

2. LITERATURE REVIEW

Yin Li et al, a new way is proposed in this work to reveal the damage evolution law of impacted carbon fiber reinforced polymer (CFRP) laminate under compression-compression fatigue load based on thermo graphic images. Firstly, several specimens are began with impact testing with different energies, followed by compression-compression fatigue testing with different load amplitudes and monitored by infrared camera. Then, the thermo graphic images gathered by infrared camera are analyzed. Finally, the damage area is introduced to quantitatively reveal the damage evolution law of these impacted specimens. The obtained results show that combining appropriate image processing methods, the damage area can be used as an effective damage index to quantitatively reveal damage evolution law of impacted CFRP laminate under compression-compression fatigue load with excellent accuracy [1].

Yurddaskal et al, in this study a numerical and experimental study was carried out to determine the effects of variables such as curvature and foam properties on the natural frequencies of the sandwich panels. A group of sandwich panels with radii of curvature ranging from 90 to 200 mm were analyzed by ANSYS software. Vibration characteristics were obtained for clamped square sandwich panels. The results indicate that the natural frequencies increase with the increasing curvature and foam density. The highest increase in natural frequency due to increasing foam properties is seen in the flat panels. Also, it is found that in values beyond a specific curvature; increasing of the foam properties causes reduction in the natural frequencies [2].
Alzeanidi, Ghasemnejad et al, the present paper aims to provide further understanding of the behavior of Carbon Fiber Reinforced Plastic (CFRP) composite panels under high velocity impact and develop design guideline for repair of damaged composite panels in order to increase the aircraft survivability. This work consists of two parts: part one is a combination of experimental investigation and numerical simulation to evaluate the impact of a woven CFRP laminate which were subjected to selected impact velocities in order to evaluate the induced impact damage in two different thicknesses of CFRP composite panel. In part two a finite element model is developed to design a guideline for repairing of a composite panel. Finite element results were in close agreement with experimental data obtained from different sources [3].

Nagaraja Shetty et al, describes the composite materials are being extensively used in aerospace and automotive industry. Drilling is a major process in manufacturing of holes, required for assembling the components in industrial applications. Drilling of holes in composites leads to a drilling-induced damage called delamination. This paper provides a comprehensive literature review on machining of composites which mainly focuses on conventional methods like turning, milling, trimming and drilling and also on simulation methods including discrete element method and finite element method. Comparison of experimental and simulation results shows an overall vision on machining of CFRP using FEM tools [4].

Faizul Mohee et al, Owing to high tensile strength, corrosion resistance and low weight, pre-stressed carbon fiber-reinforced polymer (CFRP) plates have rapidly increasing applications in bridges, tall buildings, tunnels, high-speed trains, automotive, aviation, and satellite, shipbuilding industries. This novel mechanical anchor can grip and prestress the CFRP plate to its full tensile capacity of 168 kN without any premature failure. This article focuses on the experimental investigation of prototypes of the new anchor, the experimental setup and the experimental results of twenty-two static tension tests. The new anchor was optimized through a sequential testing program for different design parameters. The failure mode of the anchor was the tensile rupture of the CFRP plate at its free length outside of the anchor. This innovative post-tensioning anchor will be used to rehabilitate and retrofit reinforced concrete structures by flexural strengthening of the structures [5].
Katarzyna Mróz et al, in buildings and in civil engineering structures, both active and passive fire protection are used. The aim of fire protection system's usage is to maintain the temperature of the building component (structural steel element, electrical installation) bellow the critical temperature during fire but also is intended to contain a fire in the origin fire compartment for a limited period of time. In this paper the passive fire protection material solutions were described and their action mode explained. In this specific case polypropylene fibers (PP) added to the concrete mix act as a passive protection system. Another group of passive fire protection materials, described in this document, are the intumescent and ablative materials for steel structure protection. The present manuscript describes also the techniques of passive fire protection testing in fire conditions [6].
Karnakar et al, the research carried out in this paper will enable to determine the beam strength due to bending loads. The importance of fiber reinforcement in the manufacturing of the beam is studied in terms of bending strength of the beam. The analytical results are validated by performing experiments on composite beams. For the investigation, two different composition beams have been tested and compared the experimental results with the analytical results. It is found that the bending stress and deflections evaluated with the mat lab code are almost coincided with the values observed in bending experiment [7].
Vishwakarma et al, work presents a stress analysis of Graphite/Epoxy laminated composite plates. The static stress analysis includes the all type of stress behavior in diagrammatic form and results are closed agreement with later work. In this study investigations were carried on square plates starting with 2 to 10 layer 45 degree symmetric angle ply laminated composite plates at clamped boundary condition [8].
Jiri Zach et al, with regard to the requirements of EU directive is necessary in the construction and reconstruction of existing buildings to implement effective measures for reducing their energy consumption should get virtually all new buildings, buildings with almost zero energy. These facts mean that the construction of new and reconstruction of existing structures growing consumption of thermal insulation materials. From the perspective of sustainable development from the perspective of environmental (CO2 emissions) are thermally insulating materials based on natural organic fibers promising alternative to synthetic thermal insulation of mineral fibers and foam-plastic substances.[9].

3. MODAL ANALYSIS

Modal analysis is a method to describe a structure in terms of its natural characteristics which are the frequency, damping and mode shapes, its dynamic properties. Without using a rigorous mathematical treatment, this article will introduce some concepts about how structures vibrate and some of the mathematical tools used to solve structural dynamic problems. Modal analysis is significant in evaluating the mode shapes generated by a component under vibrational excitation, as the mode shapes can be used to determine the displacement or response of the component under the influence vibration in real life application.

3.1 Instruments used for the Experimentation

1. Holding structure -G clamp
It will used to make a cantilever structure as this is best way to make the testing. Here G-clamp is used to hold specimen.

2. Cantilever Beam of Steel and Composite Material
The material selected for testing is steel and FRP, E glass epoxy as it have many advantages in engineering field.

3. FFT Analyzer

Fig -1: FFT Analyzer

For experiment purpose the validation will made by vibration technique so the FFT analyzer will used to measure vibration and the natural frequency and mode shapes. Here 8 Channel FFT analyzer used.

4. Computer Set up

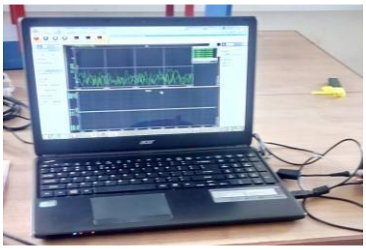

Fig -2: Computer Set up

For the operation of FFT analyzer it will necessary also it was used for display purpose.

5. Impact Hammer

Fig -3: Impact Hammer

Here used Impulse force hammer to give the impact on the beam. The hammer is part of FFT analyzer.

6. Accelerometer

Fig -4: Accelerometer

Accelerometer will used for the signal collecting part of the accelerometer. The accelerometer is the part which will continuously in touch with beam. It will connect to the port of the FFT. Here I used accelerometer having model name 7105A-0050 having calibration frequency range 20Hz – 10000H., Sensitivity @ 80Hz is 101.6mV/g.

3.2 Experimental Set up

Experiments are conducted to determine the natural frequencies on three different material specimen plate having same geometry but different material with the help of following set-up. The test specimens in the present experimental work having following dimensions, E glass/epoxy and FRP cantilever beam for experiment has following dimensions.

Length of Beam (L) = 845mm
Width of Beam (W) = 55mm
Height or thickness of Beam (H) = 5mm

Fig -5: Experimental set up for E-glass epoxy Material

Fig -6: Experimental set up for FRP composite Material

3.3 Experimental Modal Analysis

To do experimentation for calculating the linear response of structures to dynamic loading, experimental modal analysis is one of the best techniques. In modal analysis, we decompose the responses of the structure into several vibration modes. A mode is defined by its frequency and shape. The experimentation was performed as per following steps.

1. First the connections were made as per the modal analysis module given in the user's manual. The connection of FFT analyzer was done with the laptop.

2. The composite plate is rigidly clamped at the one end with the help of G-Clamp. The free end of the cantilever plate is excited with the help of impact hammer which is connected to accelerometer, FFT analyzer, display unit and power switches.

3. A digital display unit is connected to observe the vibration response of cantilever beam after getting the signal from an accelerometer at the tip of the beam. The natural frequencies are measured from the function generator at the point of resonance under the excitation.

4. In the Fig 5 and Fig 6, shows the experimental setup at the time of experiment.

5. In this experimentation we analyzed cantilever composite beam. At first we defined the direction of analysis (orientation up/down, Z axis), Then mark equidistant points, in our case from 1 to 24 on beam of composite material. The higher the number of points, the more detailed the animation will be. It is also helpful to write numbers next to the points. They should be consistent on 1. structure, in 2. channel setup and 3. FRF geometry in software.

6. The hammer will move through the points, so in one point an accelerometer has to be mounted. We select point 12.We define the sampling rate with 5000 Hz. Name the hammer and accelerometer in the channel setup and apply the scaling. In our case both are of IEPE type, hammer is measuring force in N, accelerometer acceleration in g. Then go into the channel setup of the hammer.

7. Do a test impact with the hammer on the structure. In the scope preview memorize the max value.

8. In Modal test setup chose the Triggered FRF type, and use "roving hammer" option. The trigger level should be set somewhere below the max value of the pre-measurement just done.

9. Now that the points are defined, it is time for drawing the structure. When we switch to measure mode, usually we should have an auto-generated screen called "Modal test". There the FRF geometry instrument is already shown (x,y,z axis display). From the left side (properties) select "Editor" and add 24 points and their coordinates. We can draw trace lines between them and finally quads (shapes) between them. - Take care, that the excitation direction Z is upright and should have the same level for all points of this structure.

10. Now it's time for a test hit, and finalizing the display arrangement. In measure mode without storing, we can do a test hit, to fill the displays with signals. Immediately the structure will be animated in the first point. If the auto-generated screen does not look , we might have to assign the channels to the instruments. The idea is showing the excitation on the left and response on the right. Use the Scope and FFT signals of the "Current point" subsection in the channel list.

11. To be absolutely sure that our sampling rate and FFT lines settings are correct, This is the window used for calculation. Your whole signals should be covered. If the structure keeps on ringing and the response signal is cut, increase the window length (use a higher line resolution or lower sampling rate) or select a lower value for the "Response window decay" parameter.

12. Now we are ready for the measurement. Start storing and do 3 hits on point 1 or point which we want to observed mode shape after impact on that point. The scope and FFT graphs will be updated after each hit, so we can visually check for double-hits or "bad" hits and reject them. If we hit a wrong point, we can also reset the whole point. After clicking the "Next point" button, the point number increases, always showing the current transfer function.

13. When finished, go to Analyze mode. Automatically the last stored file is reloaded. The screen gives an idea. It shows the first four transfer functions with amplitude and phase. Here, for easily finding the mode shapes. Just click on the peaks (with the instrument set to Channel cursor mode), on the lower right side the modal circle calculates the exact frequency and damping.
Here are some of the mode shapes got from experimentation as given below in Fig 7, Fig 8.

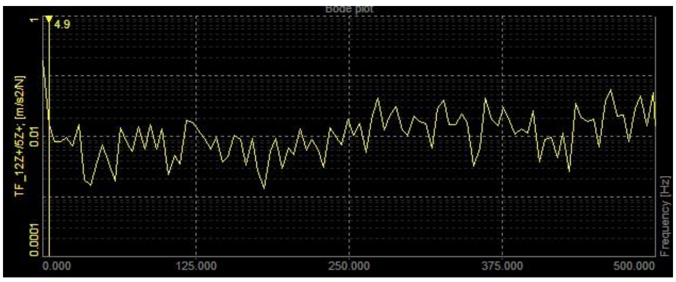

Fig -7: First Mode Shape at 4.883Hz

After carrying out the experimentation the beam response is analyze by the FFT analyzer from the responses, natural frequencies are measured using FRF. The natural frequencies measurement of a whole system is a function of physical parameters, material properties and boundary conditions of the system. The resulting Frequency Response Function (FRF) obtained imparts the modal parameters. Some of the FFT spectrums are shown below,

Here are some of the mode shapes of the snowboard calculated by DEWESoft FRF (you nicely can see bending and twisting).

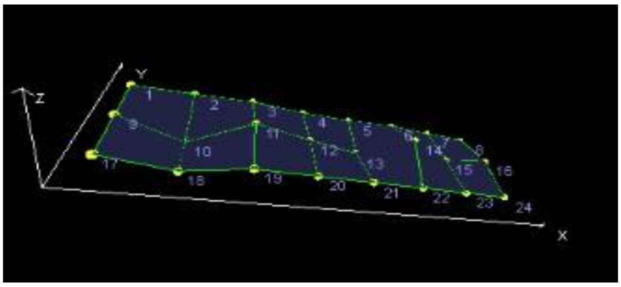

Fig -8: Second Mode Shape at 34.18Hz

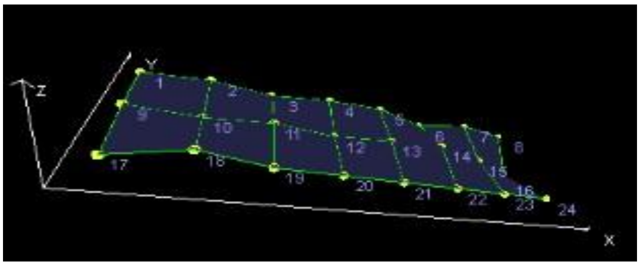

Fig -9: Third Mode Shape at 63.477 Hz

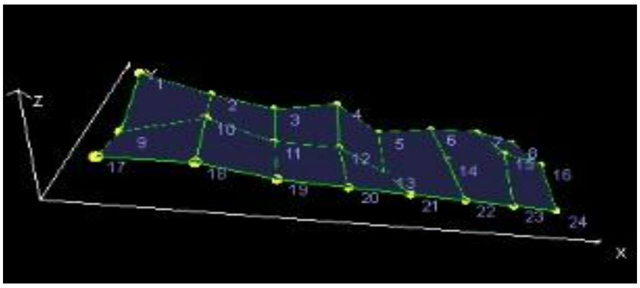

Fig -10: 5.4.5 Fourth Mode Shape at 102.539

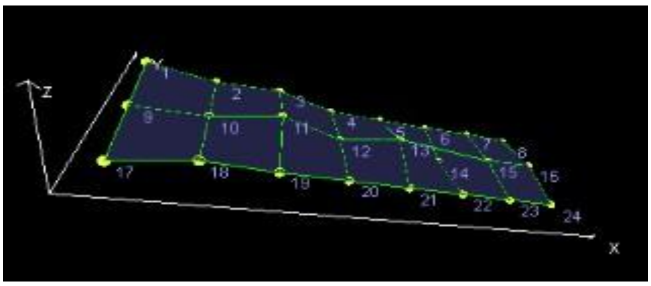

Fig -11: 5.4.6 Fifth Mode Shape at 170.89 Hz

Fig -12: Experimental Stress Measurement Set up

3.4 Experimental Natural Frequency by FFT Analyzer

From the above experimentation work the results are taken from the FFT for natural frequencies corresponding to 1st, 2nd, 3rd,… up to 6th mode are noted for cantilever beam specimen. Table 1 shows the results obtained from experimental analysis by FFT analyzer,

Table -1: Results for Natural Frequency

Sr. No.	Mode shape	Natural Frequency (Hz)
1	First	4.88
2	Second	34.18
3	Third	63.477
4	Fourth	102.539
5	Fifth	170.898
6	Sixth	209.961

4. STRESS ANALYSIS

Here, Stress analysis did to determine stress by experimental analysis using strain gauge indicator and strain gauge. Universal Testing Machine is used for applying load on beam. Dimensions for beam specimen are same as used in vibration analysis. Von Misses stress and Maximum deformation on beam is calculated practically. Therefore to carry out experimentation on beam strain gauge is mounting on composite specimen.

Fig 12 shows the experimental set up for measurement of stress values with gradually increasing load on those different material plates. So we calculate easily their strength to weight ratio.
Specification of universal testing machine
Model: UTM
Maximum Capacity: 1000KN
Make: Fuel Instrument and Engineering Pvt. Ltd.

The beam to be tested is examined for stress analysis for different materials. The value load and strain for different material of the beam are recorded, where the beam mounted on the mounting fixture of the testing machine as a simply supported beam. The surface, where the strain gauges are to be fixed is prepared first. It is cleaned from dust, rust & any grease.

The strain gauge is fixed to the prepared surface by using an adhesive. Strain gauges are placed on the top surface of beam the fiber direction in case of steel beam & in case of composite beam. The beam is loaded from zero to the prescribed maximum deflection & back to zero. The force is applied on the beam and recorded. The vertical deflection of the beam center is also measured. After completion of first test the next material is mounted on the fixture & the same procedure is repeated for stress analysis, the results are obtained below Table 2. For Steel, FRP and E glass epoxy materials stresses values are as in Table 2. The table shows the comparison of all three materials.

Table -2: Comparison of Results for Stress Analysis of Material

Sr. No.	Material	Experimental Stress (MPa)
1	Steel	210.01
2	E-glass Epoxy	110.88
3	FRP	122.57

As the weight is the major problem in most of today's engineering application therefore now a days composites materials are mostly used cause it gives good strength in minimum weight. In this project also approach is given to in that direction that is to maintain strength to weight ratio analysis is done on it.

Table -3: Comparison of weight

Sr. No.	Materials	Steel	FRP	E-glass epoxy
1	Weight of Material	8.63	5.37	5.26

The above Table 3 shows the weight of Steel, FRP and E glass epoxy materials for comparing its strength to weight ratio and to measuring stress value. As per results obtained from 3 point flexural bending test performed on each beam which is made up of Steel, FRP, E glass epoxy materials.

5. RESULTS AND DISCUSSION

In this last part of paper the comparison of results got from experimentation with the help of FFT analyzer is done for Steel, FRP, and E-glass epoxy materials. The basic concept behind this is the experimental results were compared and found out the better results. The results and discussion were based on the observation so for drawing the conclusion the results are very important. Natural frequencies were extracted and compared with those obtained from experiments as shown in following table.

Table - 4: Comparison of Experimental Natural Frequencies for Steel, FRP and E-glass epoxy material

Mode Shape	Experimental Natural Frequency of Steel (Hz)	Experimental Natural Frequency of FRP (Hz)	Experimental Natural Frequency of E-glass epoxy (Hz)
1	2.409	2.188	4.883
2	16.453	15.193	34.18
3	30.19	28.32	63.477
4	49.187	45.92	102.539
5	78.297	75.08	170.898
6	99.97	92.991	209.961

From the result Table 4 we can find different natural frequencies at different mode shape, so we can draw graph on the basis of results to show comparison between experimental work for Steel, FRP and E glass epoxy material. Following Chart 1 shows the graphical representation for experimental results for Steel, FRP and E glass epoxy materials.

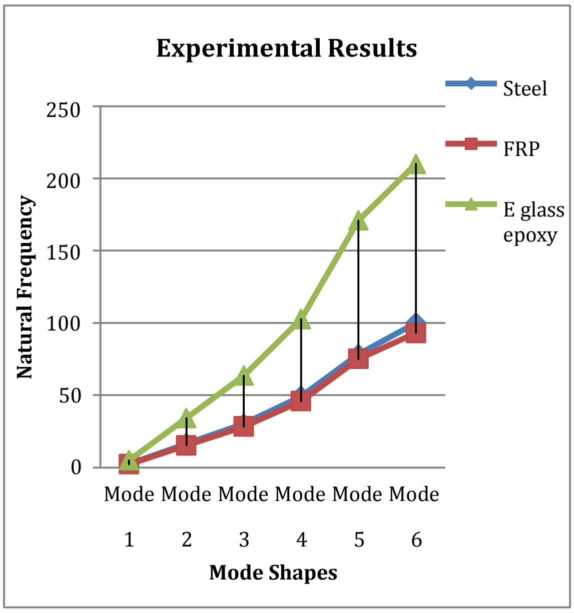

Chart -1: Comparison of Experimental Results at different Mode Shapes and Natural Frequencies.

From the above Chart 1 we can say that the different material shows different natural frequency at different mode shapes. Here, we can observe the comparative analysis of Steel with FRP, E glass epoxy different composite materials. From Chart 1 we can see E glass epoxy gives better frequency values at different mode shapes compared to other FRP composite materials.

6. CONCLUSIONS

In this paper experimental modal analysis of beam are performed for steel, FRP and E-glass epoxy material beam of rectangular shape with vibration measurement technique by using FFT analyzer. The main conclusions that can be drawn from the results of the present investigation are, the strength to weight ratio of material will remain maintain by replacing the steel and FRP material with E glass epoxy material. After calculation we can say, weight of E Glass/Epoxy reduced up to 39.05% compared to steel and 2.05% compared to FRP. The behavior of structures or mode shapes obtained from FFT analyzer can be utilized to validate results obtained from FEM for mode shapes. Natural frequencies of vibrating structures are susceptible to change under influence of depth & location, where its magnifying views allow getting an idea of significant changes at location. E Glass Epoxy material is the good material as comparatively steel and FRP material.

REFERENCES

[1] Yin Li, Wei Zhang, An-bo Ming, Zheng-wei Yang, Gan Tian, "A new way for revealing the damage evolution of impacted CFRP laminate under compression-compression fatigue load based on thermographic images, Composite Structures,2017, Published by Elsevier Ltd.

[2] Melis Yurddaskal, Ugur Ozmen, Mehmet Kir, Buket Okutan Baba, "The Effect of Foam Properties on Vibration Response of Curved Sandwich Composite Panels", Composite Structures, 2017, Published by Elsevier Ltd.

[3] N. Alzeanidi, H. Ghasemnejad, "Analysis of the effect of impact damage on the repairability of composite Panels", Composite Structures 176 (2017) 304–312,2017 Elsevier Ltd.

[4] Nagaraja Shetty, S.M. Shahabaz, S.S. Sharma, S. Divakara Shetty, "A review on finite element method for machining of composite materials", Composite Structures, 2017, Published by Elsevier Ltd.

[5] Faizul M. Mohee , Adil Al-Mayah, Alan Plumtree , "Development of a novel prestressing anchor for CFRP plates: Experimental investigations", Composite Structures 176 (2017) 20–32, 0263-8223/_ 2017 Elsevier Ltd.

[6] Katarzyna Mróz, Izabela Hager, Kinga Korniejenko, "Material solutions for passive fire protection of buildings and structures and their performances testing", International Conference on Ecology and new Building materials and products, ICEBMP 2016, Procedia Engineering 151 (2016) 284 – 291. 1877-7058 © 2016 The Authors. Published by Elsevier Ltd.

[7] Y.Karnakar, K.Madh,"Experimental analysis on glass/epoxy composite beams", IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 12, December 2015, ISSN 2348 – 7968.

[8] Rakesh vishwakarma, C. M. Mishra and Dr. D. K. Patil, "streses analysis of laminated Composite plate using FEM", International Journal of Application or Innovation in Engineering & Management (IJAIEM), Volume 4, Issue 1, January 2015 ISSN 2319 – 4847.

[9] Jiri Zacha,, Jitka Hroudovab, Jiri Brozovsky, Zdenek Krejza, Albinas Gailius , "Development of Thermal Insulating Materials on Natural Base for Thermal Insulation Systems", 11th International Conference on Modern Building Materials, Structures and Techniques, MBMST 2013, Procedia Engineering 57 (2013) 1288 – 1294. 1877-7058 © 2013 The Authors. Published by Elsevier Ltd.

BIOGRAPHIES

Yogita U. Medhane, PG 2nd year student, Department of Mechanical (Design) Engg. Late G. N. Sapkal College of Engineering, Anjaneri, Trimbak Road, Nashik - 422213

Prof. P. S. Talmale, Assistant Professor in Late G. N. Sapkal college of Engineering, Nasik. She completed her masters in CAD/CAM from Sant Gadgebaba Amravati University. Her working areas are Manufacturing, Design and Analysis. She has an experience of 12 years in teaching as well as Industry.

Prof. D. B. Zoman, Assistant Professor in Late G. N. Sapkal College of Engineering, Nasik. He is PG Coordinator. He completed his masters in Design from Savitribai Phule Pune university. His working areas are Design and Analysis. He has an experience of 10 years in teaching as well as Industry.