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Static and Dynamic Analysis of Basalt Fiber Reinforced Sandwich Composite Laminates with Aluminium Honeycomb Core

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Abstract: ***Honeycomb core sandwich composites are extensively used in aerospace and other industries due to its less weight, high in-plane, radar transparent and design flexibility properties .The most common type of failure occurs due to core compression which leads to adhesive failure on the structure. This paper studies about the compressive behavior of honeycomb core sandwich composite which is made up of basalt fiber as face sheet and Aluminium as core in the sandwich structure. In order to reduce the experimental cost and have a clear idea on real life problems modeling and simulation type of work have got well importance. In this analysis the modeling of sandwich composite is done in CATIA. After that the static analysis of beam and plate structure of sandwich composite is performed in FEM environment (ANSYS), by taking the face sheet of equal thickness and different thickness of core. Finally the total deformation is obtained for both the cases by applying different uniform distributed load and point load on the composite structure in ANSYS by importing the solid model. Again modal analysis of sandwich structure is done in ANSYS, which determines the various characteristics like natural frequency, mode shapes for a static load condition.***

Keywords: Honeycomb core Sandwich composite, Basalt fiber, Modal analysis, Static analysis

1. Introduction

In case of modern engineering, the composite materials are mostly included in aeronautical, marine materials. Apart from strength properties, low weight of the final element is a crucial aspect. The most common purpose of manufacturing of sandwich material is to obtain the greatest stiffness at minimum density. The main concept of the sandwich panel is that exterior surfaces transfer loads is caused by bending while the core transfers load is caused by shearing. Sandwich composite materials belong to the group of anisotropic materials. It means that their strength properties change depending on the applied load. The most significant requirements are as follows: stiffness, strength, specific volume, thermo insulating power, acoustic resistance, ability to absorb energy, and hydrostatic weighing.

Commonly Honeycomb core is used in sandwich composites. It is a cellular structure where highly ordered thick cells are separated by thin walls of material to form a planar structure. The honeycomb cells are available in different shapes i.e. hexagonal, square and rectangular shapes. The structure was originally observed in natural honey beehives. Honeycomb materials belong to a special class of engineering materials called cellular solids. These solids have a highly porous structure with many voids and bubbles inside. The porosity is normally more than ninety percent by volume. Honeycombs can be made of almost any material depending on the application. The materials can be metal, polymer, ceramic and glasses. Aluminium honeycombs are most commonly used as the core material in sandwich composites to impart lightweight and high strength properties. As such, they are used in automobiles, aerospace, naval and other lightweight yet strong load supporting application.

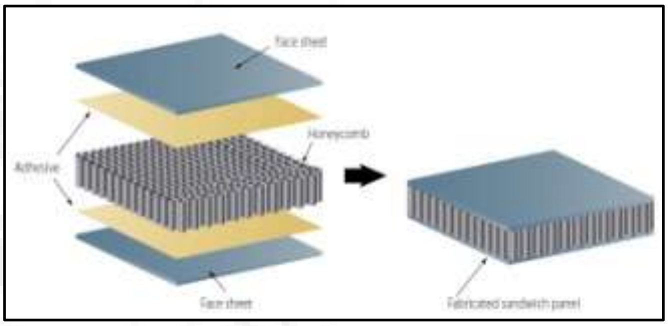

Figure 1.1: Sandwich structure

This paper mainly uses the properties of basalt fiber as skin material and thick hexagonal Al honeycomb as the core material of the sandwich structure. For the comparison study of different fiber materials, carbon and e-glass fiber properties were taken. The honeycomb sandwich structure was modeled in CATIA software and for the finite element analysis the ANSYS workbench was used to determine the results of sandwich structures (beam and plate).

2. Literature Survey

Piyush Sharma [1] has done extensive research on basalt rock fiber due to its widely spread applications. This paper also describes the comparative study of basalt and natural fibers. A. Dorigato and A.Pegoretti [2] have investigated on the fatigue behavior of basalt fibers (BF) laminates and comparing the elastic modulus, tensile strength with other fibers like GF, CF etc. S. Raj et al. [3] studied the experimental behavior of basalt fiber reinforced composite under flexural loading condition by using web shape profile sheet as core material. The overall study of panel was also carried out on FEM which gave details about strength and stiffness. Rathbun et al. [4] studied the functions of metallic honeycomb structure core sandwich beam under the impact of shock loading. From the FEA calculations proved that the structure was shock resistant.W.H. Xie et al. [5] studied the damage of honeycomb sandwich structure at high speed impact mechanism at high temperature. The experimental results showed the effect of the temperature, initial velocity, impact angle, projectile diameter etc of the sandwich panel.G.D.Shri Gandhi and P. Deshmukh [6] studied free vibration of sandwich panel and the modeling was done by FEA. The analytical results was based on classical bending theory, which showed the result of sandwich design parameters like face thickness, core thickness, pitch, vibration responses etc. Here the mode shapes and natural frequencies were studied for simply supported and cantilever sandwich panel.

Sushmita et al. [7] studied the hybrid sandwich composites were prepared by using Jute and Glass fiber under curing process. These composites were subjected to tensile and flexural testing and the damping characteristics were studied using free vibration and forced vibration test.Chun Lu et.al [8] prepared honeycomb composite by using carbon and epoxy resin in compression modeling technique and it undergoes FEA and three point bending performance test.O.Y.Bozkurt et al. [9] investigated on damping and vibration characteristics of basalt epoxy fiber-reinforced composite laminated materials on the basis of fiber orientations. It was showed that the composite were strongly affected by the fiber orientation, with increase in angle of fiber orientation resulted an increase in damping ratios and decrease in natural frequencies.Bhat et al. [10] studied that the fire structural resistance property of a basalt fiber composite Experimental and analytical result showed that the basalt fiber composite heated up more rapidly and reached higher temperatures due to its higher thermal emission than other fibers. B. Wei et al. [11] observed the tensile behavior of basalt fibers and glass fibers after the chemical treatment of NaOH and HCl respectively .The mass loss ratio and the strength maintenance ratio of the fibers were analyzed before and after the treatment. It showed that the basalt fiber was alkali proofed. Arivalagan.S.[12] was studied that, the compressive strength and splitting tensile strength of basalt fiber concrete specimens were higher than other control concrete specimens and also proposed the usage of basalt fiber composites in civil infrastructure applications due to its cost effective nature.I.C. Sukmaji et al. [13] investigated on the application of sandwich honeycomb carbon/ glass fiber-honeycomb composite in the floor component of electric car by experimental method and FEM. In this experiment the results found the factor of safety and critical strength of geometry against variable loads.

3. Theory

3.1 Sandwich Structure Principle

The prerequisite for high-performance structural component parts as used in aerospace and other industrial applications is light-weight design. An essential component of these light-weight structures is load bearing capacity and buckling optimized shell elements. The performance of a sandwich structure depends primarily upon the effectiveness of skin fiber and the distance between them. This arrangement subjects to Al honeycomb core of the sandwich undergoes relatively small amount of stress, it can be reduced in weight significantly. Extremely thin-walled of sandwich structure present the problem of how force is introduced and the sandwich structure's sensitivity towards impact loads. This means that a minimum wall thickness is required for the surface skin fibers to be able to ensure that it is adequate.

3.2 Materials

3.2.1 Aluminium Honeycomb core:

Here in this study Aluminium is chosen for core material of sandwich structure and it is honeycomb shaped. The foil thickness of Al honeycomb core is 50 to 70 micron. Honeycomb cores are available in variety of materials but Al cores are light weight in nature. It has a higher strength to weight ratio than the foam structure. Aluminium cores are highly fire resistance, corrosion resistance and also have high stiffness than other materials.

Table 3.1: Material properties of Aluminium Honeycomb core

Property	*Value*
Density	80 Kg m^-3
Compressive Yield Strength	4.e+006 Pa
Young's Modulus	1.0885e+009 Pa
Poisson's Ratio	0.3
Bulk Modulus	9.0708e+008 Pa
Shear Modulus	4.1865e+008 Pa

3.2.2 Basalt Fiber

The modulus of elasticity of basalt fibers is 18% higher than that of other fibers like glass fibers, carbon fibers particularly E-glass fiber. The working temperature range of basalt fibers products are higher (-260 °C to 700 °C). Vibration-resistance of basalt fiber is also much higher than that of glass fiber. So Basalt Fibers finds widest application in constructions, aerospace military industry and shipbuilding engineering, etc. Basalt fibers are also effective sound insulator, which is not broken itself under effect of acoustic vibrations that owes, for instance, their exclusives application as insulation in aircrafts. The fibers are also resistance in acidic and basic environments as compared with glass fiber, so it used for concrete reinforcement in form of chopped or bars.

3.2.3 Carbon Fiber

For the comparison study of fibers carbon fiber is chosen as skin fiber. This is a high tensile fiber or whisker which made by heating of rayon or poly acrylonitrile fibers or residues of petroleum at a given temperature. These are more than 90% of carbonized fibers, may be 7 to 8 micron in diameter based on strength, modulus and final heat treatment temperature carbon fibers can be classified in various categories. Carbon fibers are the strongest and stiffest reinforcing fibers so it is mostly used for polymer composite materials. These fibers have low density and a negative coefficient of longitudinal thermal expansion. Physical strength of carbon fiber composites depends on the fiber orientations and also has high dimensional stability, high damping and fatigue resistance.

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3.2.4 E-Glass Fiber

For the strengthening and reinforcement this glass fiber is mostly used. E-glass fibers are alkali free and made by alumina calcium borosilicate. They have high strength, stiffness, electrical and good chemical resistance. The fibers are insensitive to moisture as well as nonflammable.

Table 3.2: Material properties of Fibers

Property	*Basalt*	*Carbon*	*E-Glass*
Density(kg m^-3)	2670	1770	2500
Tensile Ultimate Strength(Pa)	3.10E+09	3.95E+09	2.00E+09
Young's Modulus(Pa)	8.70E+10	2.38E+11	7.20E+10
Poisson's Ratio	0.26	0.24	0.22
Bulk Modulus(Pa)	6.04E+10	1.53E+11	4.28E+10
Shear Modulus(Pa)	3.45E+10	9.59E+10	2.95E+10

4. Analysis

4.1 Static Analysis

Modeling of Sandwich Beam Structure

The size of sandwich beam is (100×50×17) mm, thickness of Al honeycomb core is 15 mm and both the basalt fiber face sheets thickness are 1mm taken. Fig 4.1 shows the model of Sandwich Beam structure in CATIA. Then the sandwich beam model is imported to ANSYS software and then the skin properties, core properties are given to the model. The connectivity is maintaining in the model, the lower skin sheet is fixed and force applied on the top skin. Finally meshing of the model is done in ANSYS. Fig 4.2 shows the meshing of Sandwich beam structure.

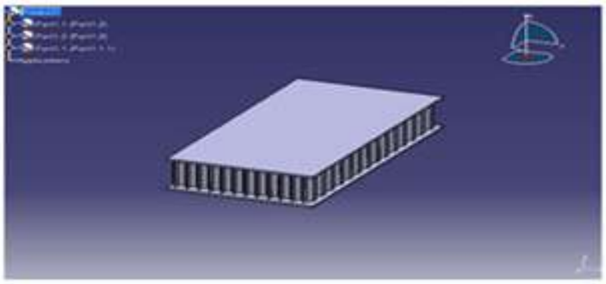

Figure 4.1: Sandwich Beam Structure

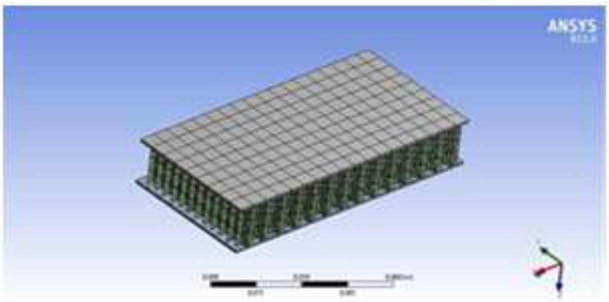

Figure 4.2: Meshed Sandwich Beam Structure

Case 1: UDL on Basalt Fiber Sandwich Beam

In the Static analysis a free boundary condition is given to the sandwich beam structure. Then uniformly distributed loads are applied to the beam. Finally the total deformation, equivalent stress, elastic strains are obtained for different loading condition. By applying 10N load on honeycomb sandwich beam for UDL condition, the pictures are taken from ANSYS workbench .These pictures are shown below. The table 4.1 shows the results of this analysis at different loads.

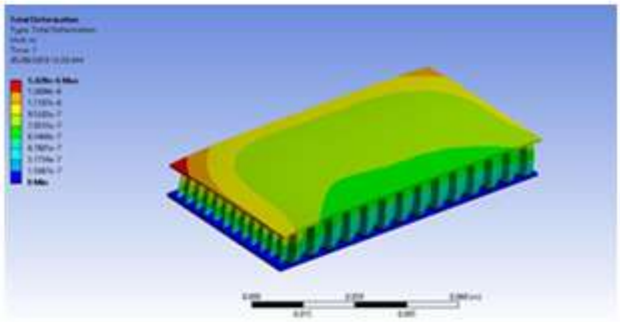

Figure 4.3: Deformation of Basalt Fiber at 10N (UDL)

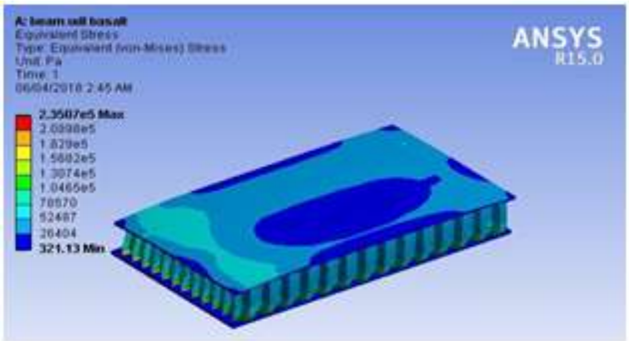

Figure 4.4: Equivalent stress at 10N (UDL)

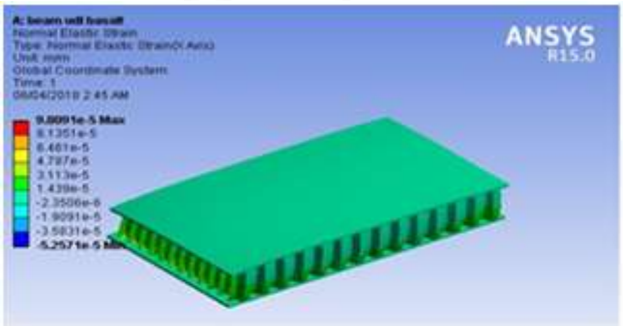

Figure 4.5: Elastic Strain at 10N (UDL)

Table 4.1

Load (N)	*Deformation (m)*	*Equivalent Stress(Pa)*	*Elastic Strain (m/m)*
UDL 1	1.428e-007	23507	9.8091e-006
5	7.1401e-007	1.1753e+005	4.9045e-005
10	1.428e-006	2.3507e+005	9.8091e-005
15	2.142e-006	3.526e+005	1.4714e-004
20	2.8561e-006	4.7013e+005	1.9618e-004

Case 2: Point Load on Basalt Fiber Sandwich Beam

The point loads are applied to the sandwich beam. Then the total deformation, equivalent stress, elastic strains are obtained for different loading condition. By applying 10N load on honeycomb sandwich beam for point condition, the pictures are taken from ANSYS workbench .These pictures are shown below. The table 4.2 shows the results of this analysis at different loads.

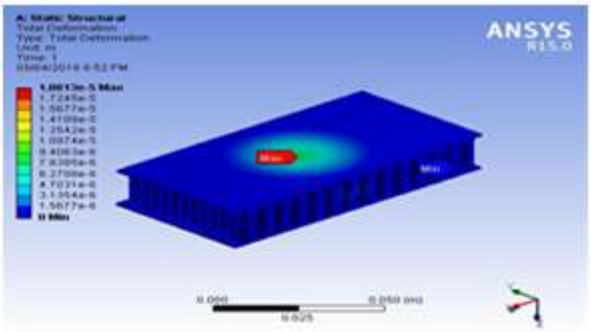

Figure 4.6: Total Deformation at 10N (Point Load)

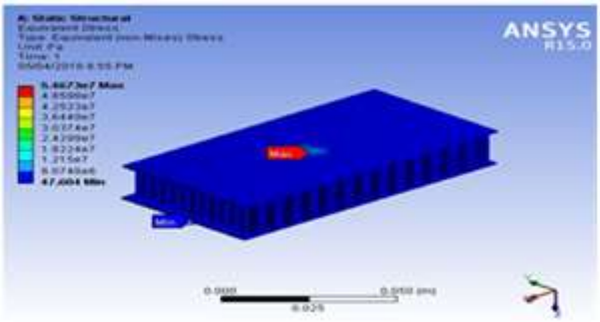

Figure 4.7: Equivalent stress at 10N (Point Load)

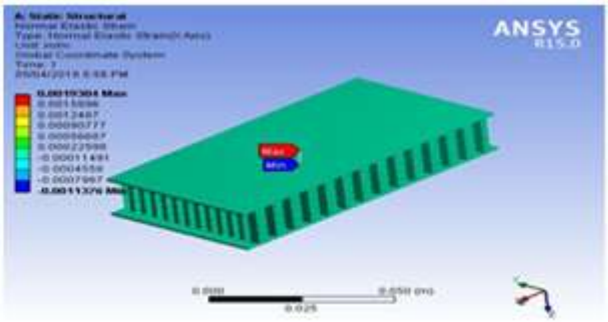

Figure 4.8: Elastic Strain at 10N (Point Load)

Table 4.2

Load (N)	*Deformation (m)*	*Equivalent Stress(Pa)*	*Elastic Strain (m/m)*
Point 1	1.8813e-006	5.4673e+006	1.9304e-004
5	9.4063e-006	2.7336e+007	9.6522e-004
10	1.8813e-005	5.4673e+007	1.9304e-003
15	2.8219e-005	8.2009e+007	2.8957e-003
20	3.7625e-005	1.0935e+008	3.8609e-003

Finally a graph is plotted between Force and Deformation which shows behavior of Sandwich beam Structure for both UDL and Point load case in Fig 4.9.

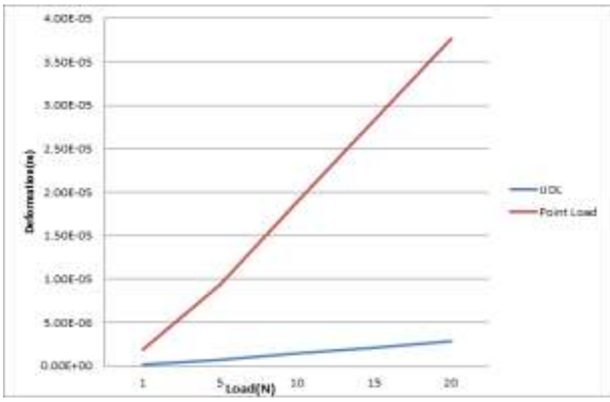

Figure 4.9: Force-Deformation behavior of Sandwich beam Structure

Modeling of Sandwich Plate Structure

The size of sandwich plate is 55*45*17 mm. The thickness of Al honeycomb core is 15 mm and both the face sheets thickness are 1mm taken. Fig 4.10 shows the model of honeycomb sandwich plate in CATIA. Then sandwich plate model is imported to ANSYS software and then the skin properties, core properties are given to the model. The connectivity is maintaining in the model. Finally meshing of the model is done. The meshed sandwich plate is shown in the fig 4.11.

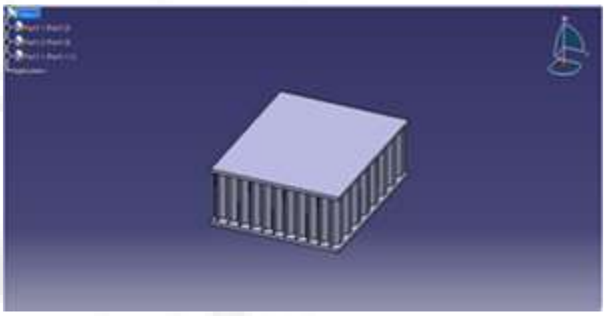

Figure 4.10: Sandwich plate structure in CATIA

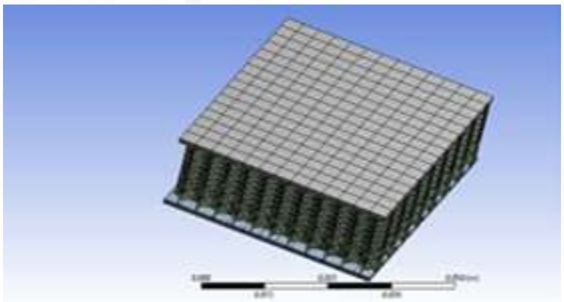

Figure 4.11: Meshed Sandwich Plate in ANSYS

Case 3: UDL on Basalt Fiber Sandwich Plate

In the static analysis, free boundary condition is given to the sandwich plate. Then uniformly distributed loads are applied to the plate. Finally the total deformation, equivalent stress, elastic strains are obtained for different loads. Here the pictures are taken by applying 10 N loads on the sandwich plate; which are shown below.

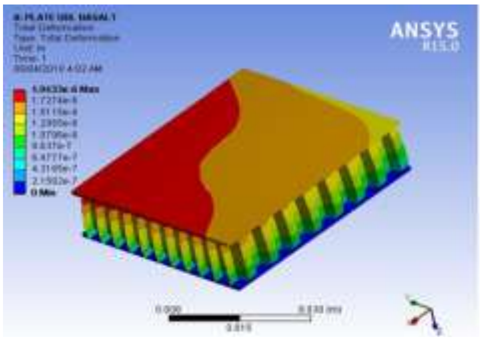

Figure 4.12: Total Deformation of Basalt Fiber at 10N (UDL)

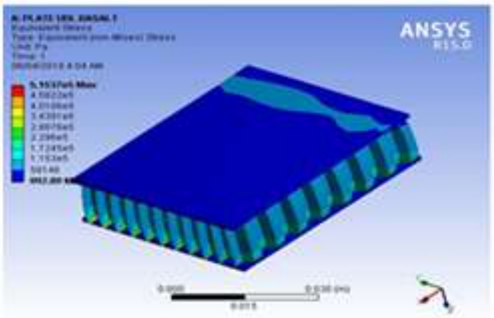

Figure 4.13: Equivalent stress at 10N (UDL)

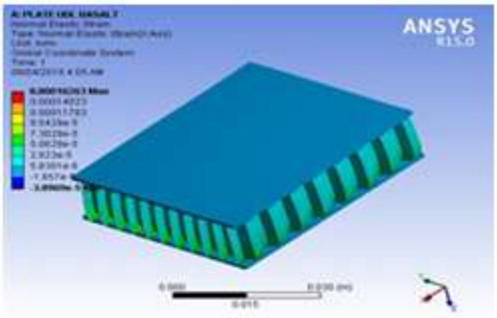

Figure 4.14: Elastic Strain at 10N (UDL)

Table 4.3

Load (N)	Deformation (m)	Equivalent Stress(Pa)	Elastic Strain (m/m)
UDL 1	3.7935e-009	53076	2.6491e-007
5	1.8967e-008	2.6538e+005	1.3245e-006
10	3.7935e-008	5.3076e+005	2.6491e-006
15	5.6902e-008	7.9614e+005	3.9736e-006
20	7.587e-008	1.0615e+006	5.2982e-006

Case 4: Point Load on Basalt Fiber Sandwich Plate

The point loads are applied to the plate. Finally the total deformation, equivalent stress, elastic strains are obtained for different loads. Here the pictures are taken by applying 10 N loads on the sandwich plate; which are shown below.

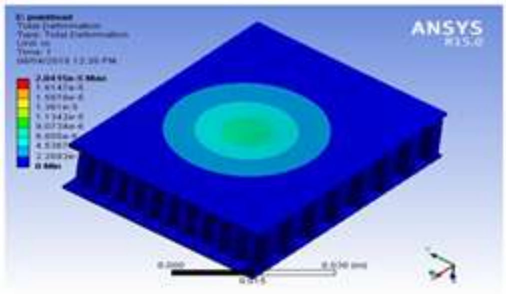

Figure 4.15: Total Deformation at 10N (point load)

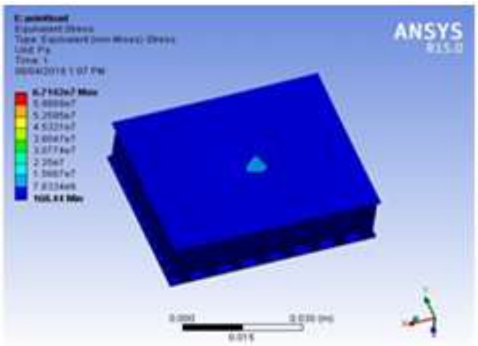

Figure 4.16: Equivalent Stress at 10N (Point load)

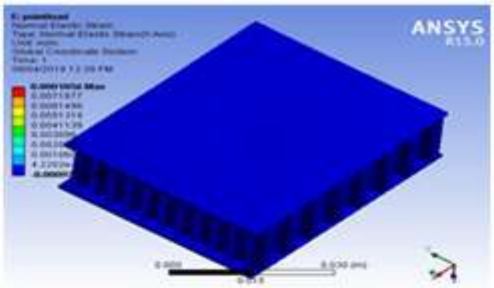

Figure 4.17: Elastic Strain at 10N (Point load)

Table 4.4

Point Load(N)	Deformation (m)	Equivalent Stress(Pa)	Elastic Strain (m/m)
1	8.3554e-008	1.0143e+007	8.0489e-006
5	4.1777e-007	5.0714e+007	4.0245e-005
10	8.3554e-007	8.3554e-007	8.0489e-005
15	1.2533e-006	1.5214e+008	1.2073e-004
20	1.6711e-006	2.0285e+008	1.6098e-004

Finally a graph is plotted between Force and deformation by taking the result of both the UDL and point load condition, which is shown in fig 4.18.

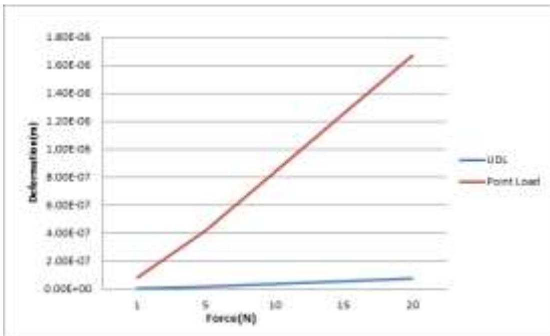

Figure 4.18: Force-Deformation behavior of Sandwich Plate

Case 5: Comparison Study

In this work three different fibers (Basalt, Carbon and E-glass) are chosen for the static analysis of aluminium honeycomb sandwich beam structure. The Von mises Equivalent stress, total deformation of these fibers are calculated for various loads. The pictures are taken from ANSYS workbench at 10N UDL by using carbon and E-glass as skin fiber of sandwich beam are shown below. Table 4.5 shows the deformation of three fibers and table 4.6 shows the equivalent stress of all the fibers. Fig 6.5 shows the graph plotted between force and deformation and fig 6.6 shows the bar graph between Equivalent stresses and force of all fibers at different loading condition.

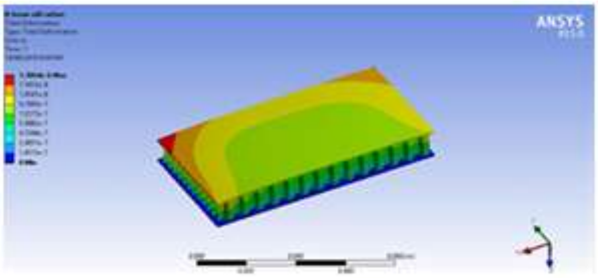

Figure 4.19: Deformation of Carbon fiber sandwich beam at 10N (UDL)

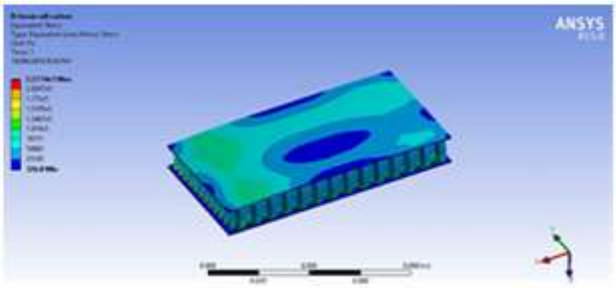

Figure 4.20: Equivalent stress of Carbon fiber sandwich beam at 10 N (UDL)

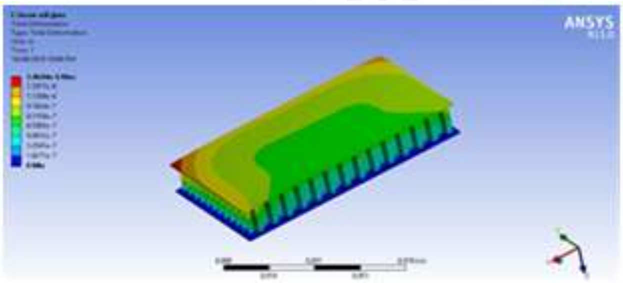

Figure 4.21: Deformation of E-glass fiber sandwich beam at 10 N (UDL)

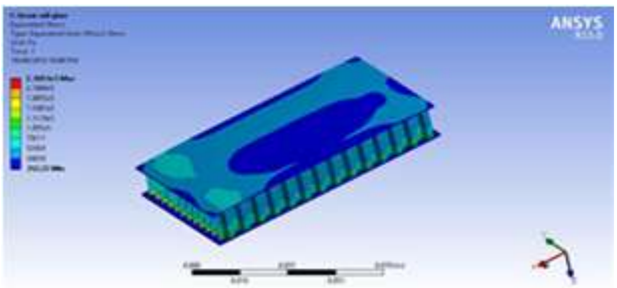

Figure 4.22: Equivalent stress of E-glass fiber sandwich beam at 10 N (UDL)

Table 4.5

UDL (N)	Total Deformation (m)		
	Basalt	*Carbon*	*E-Glass*
1	1.43E-07	1.31E-07	1.46E-07
5	7.14E-07	6.05E-07	7.32E-07
10	1.43E-06	1.31E-06	1.46E-06
15	2.14E-06	1.96E-06	2.20E-06
20	2.86E-06	2.61E-06	2.93E-06

The following graph shows the load and deformation behavior of all three fibers at different loading condition.

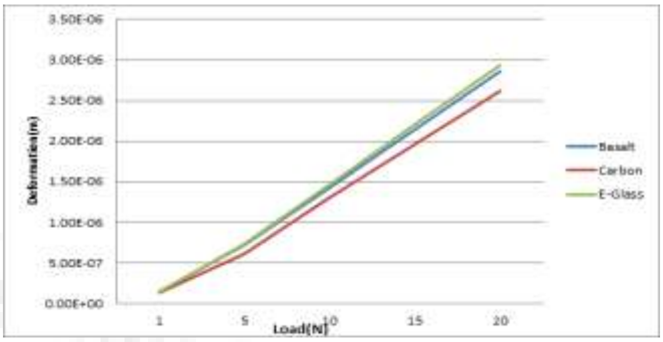

Figure 4.23: Force-Deformation of all fibers in Sandwich Beam

Table 4.6

UDL(N)	Equivalent Stress(Pa)		
	Basalt	*Carbon*	*E-Glass*
1	23507	22774	23693
5	1.18E+05	1.14E+05	1.18E+05
10	2.35E+05	2.27E+05	2.37E+05
15	3.53E+05	3.42E+05	3.55E+05
20	4.70E+05	4.55E+05	4.74E+05

The following bar graph shows the equivalent stress of all three fibers at different load.

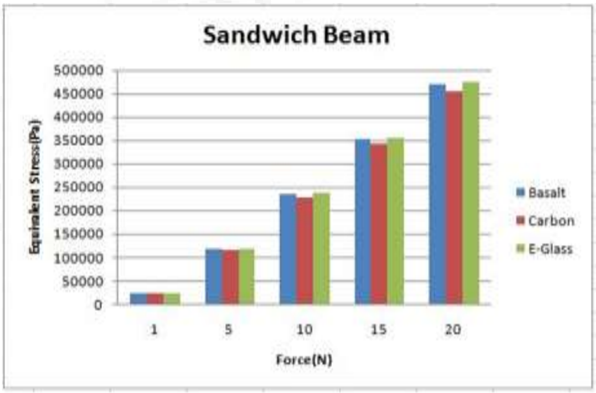

Figure 4.24: Force- Equivalent Stress of all fibers (UDL)

4.2 Modal Analysis

Case 6: UDL on Basalt Fiber Sandwich Beam

In this analysis 6 mode shapes are considered for determine the frequency at different mode in the sandwich beam structure. The different mode shape pictures are shown below and the bar chart in fig 4.31 indicates the frequency at each calculated mode. Table 4.7 shows the results of this modal analysis.

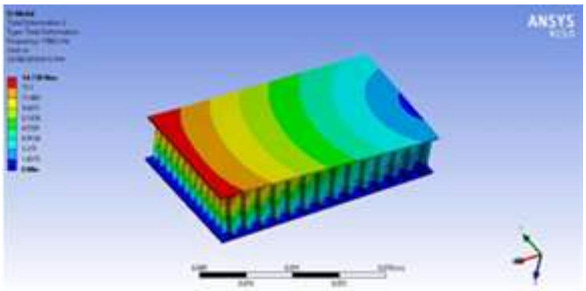

Figure 4.25: First Mode Shape of Sandwich Beam

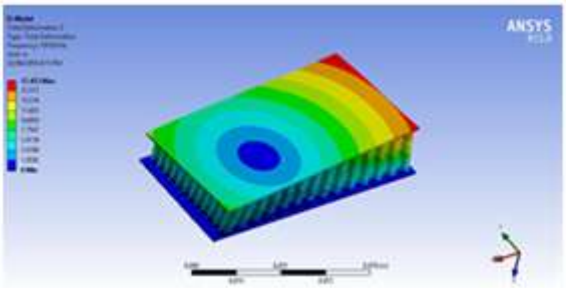

Figure 4.26: Second Mode Shape of Sandwich Beam

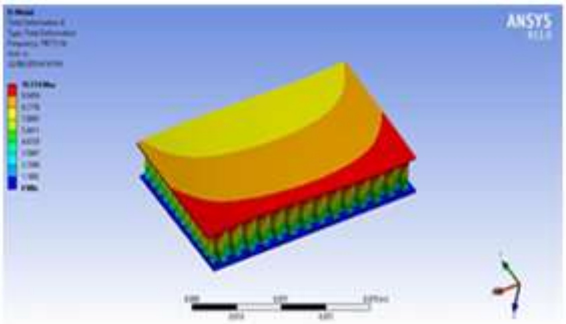

Figure 4.27: Third Mode Shape of Sandwich Beam

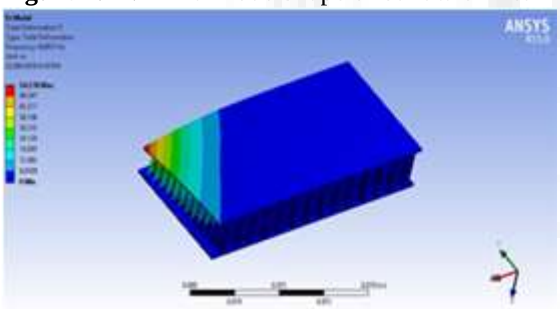

Figure 4.28: Fourth Mode Shape of Sandwich Beam

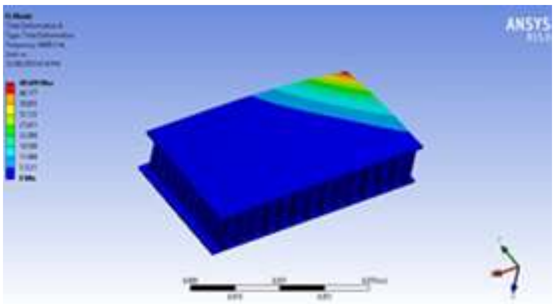

Figure 4.29: Fifth Mode Shape of Sandwich Beam

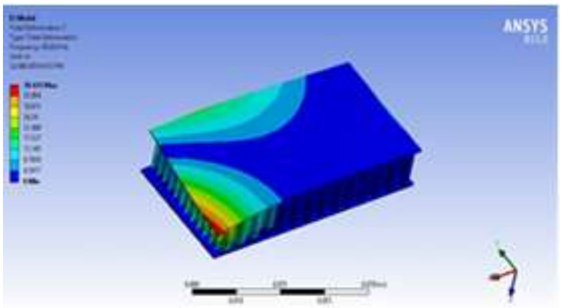

Figure 4.30: Sixth Mode Shape of Sandwich Beam

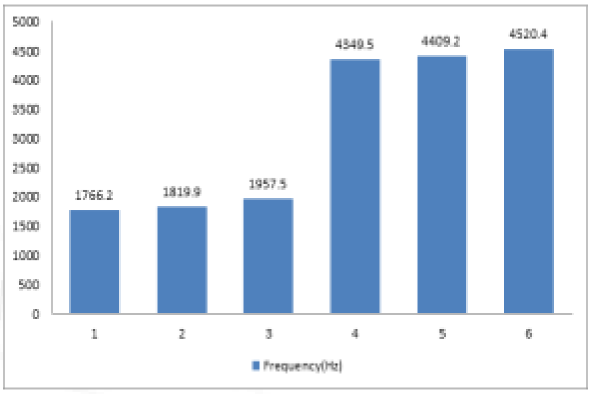

Figure 4.31: Frequency at each calculated mode

Table 4.7

Mode	*Frequency(Hz)*
1	1766.2
2	1819.9
3	1957.5
4	4249.5
5	4409.2
6	4520.4

Case 7: UDL on Basalt Fiber Sandwich Plate

In this analysis 6 mode shapes are considered for determine the frequency at different mode in the sandwich plate structure. The mode shapes are shown below and fig 4.38 bar chart indicates the frequency at each calculated mode. Table 4.8 represents the results of modal analysis.

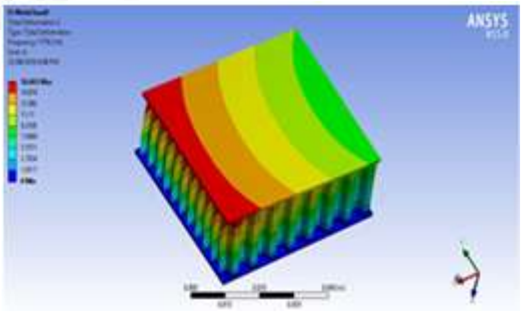

Figure 4.32: First Mode shape of Sandwich Plate

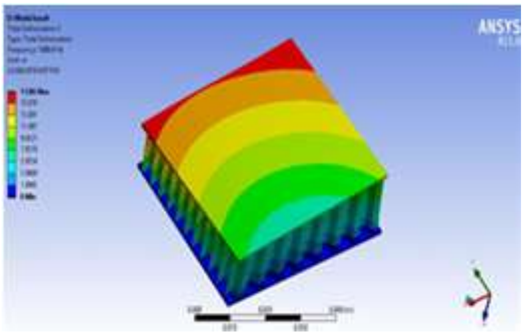

Figure 4.33: Second mode shape of Sandwich Plate

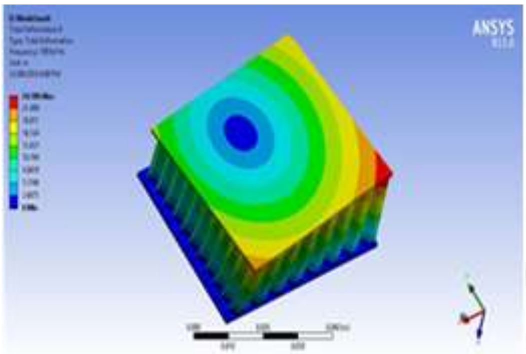

Figure 4.34: Third mode shape of Sandwich Plate

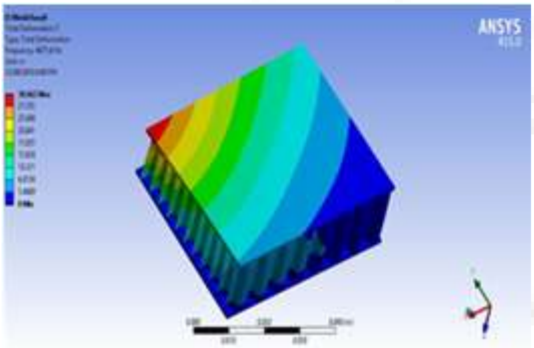

Figure 4.35: Fourth mode shape of Sandwich Plate

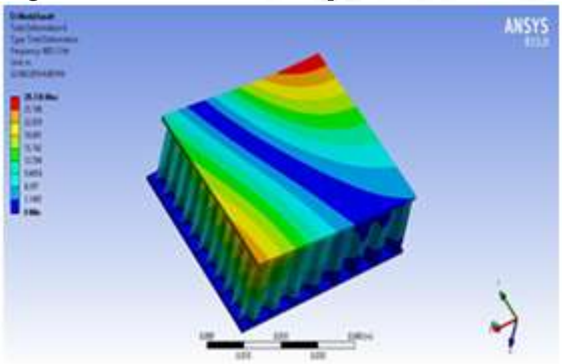

Figure 4.36: Fifth mode shape of Sandwich Plate

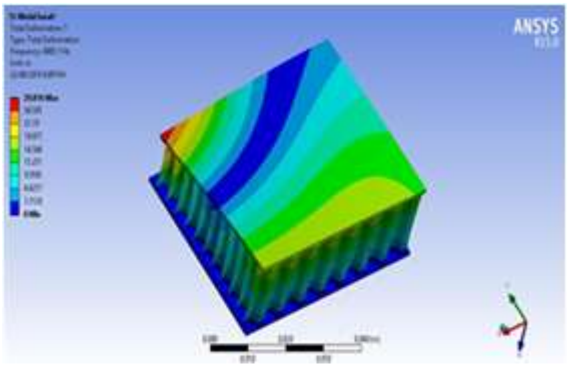

Figure 4.37: Sixth mode shape of Sandwich Plate

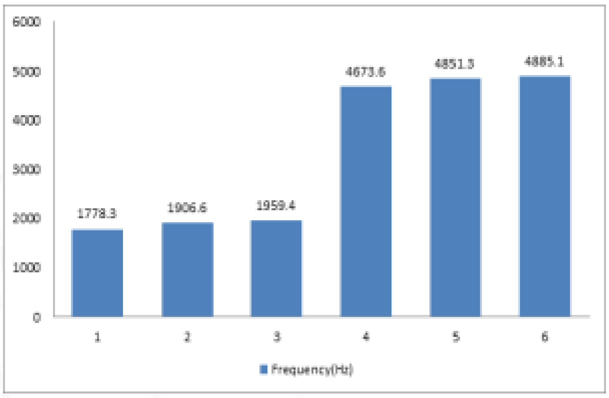

Figure 4.38: Frequency at each calculated mode

Table 4.8

Mode	*Frequency [Hz]*
1	1778.3
2	1906.6
3	1959.4
4	4673.6
5	4851.3
6	4885.1

5. Conclusion

This present work concerned with the static and modal analysis of Basalt fiber laminated with honeycomb sandwich structure under different loading condition. For simulation process ANSYS environment has been used. Various sandwich structures, loads and boundary configuration have been considered in the present study. From the various analyses, the results obtained are summarized below.

1) In the case study of 1 and 2, the results found that the deformation, equivalent stress and the elastic strain of a sandwich beam linearly increases with increase in load. And the deformation of beam is more with applying of the point load than the applying of uniformly distributed load.
2) From the case study of 3 and 4, for the sandwich plate the results of total deformation, equivalent stress and the elastic strain increases with increase in load. The deformation due to point load is more than the deformation due to the uniformly distributed load.
3) From the comparison study of deformation in case 5 it is found that, Carbon fiber sandwich beam has minimum deformation as compared to the other two fibers. The deformation of E-glass fiber sandwich beam has slightly more deformation than the Basalt fiber sandwich beam.

4) Again from the case study of 5, it is found that the equivalent stress of E-glass fiber sandwich beam has more stress than the other two fibers on the application of uniformly distributed load.
5) In the sandwich beam structure, the second and third mode frequencies are nearly same. The frequency increases with increase in the number of point of mode. The above figures of different mode shapes have proved this fact.
6) In the sandwich plate structure with increase with mode point the frequency increases. The second and third mode frequencies are nearly same whereas the fifth and sixth mode frequencies are same. The figures of different mode shapes have proved this fact.

From the above case studies it is proved that the basalt fiber honeycomb sandwich structure has good opportunities in the field of composite industries. As the continuous basalt fiber is more efficient than other two fibers, it is more convenient for the future growth of composite structure.

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