Health Monitoring of Static Composite Beam for Material Uncertainty and its Numerical Validation

P. S. Kachare, A. K. Parkhe, A. A. Utpat, S. Y. Salunkhe

***Abstract*— This paper aims at experimental analysis of composite box beam to estimate the material uncertainty. The deflection parameter has considered for analyzing the uncertainties present in material. The composite box beam is like a cantilever beam, where one end is fixed and at free end load is applied. In previous study free end deflection is calculated using Dial Gauges whose stylus will make point contact with proposed setup. But due to this contact it will create instrumental errors or manual error during experimentation. To avoid such situation the non contact device is developed called as Hall Effect Sensor which is the electronic device and it is works on electromagnetic field. If magnet is come in front of sensor it create magnetic field between them. The change in voltage or field is calibrated in terms of deflection of beam. In this paper, experimentation has carried out on four composite box beams which are manufactured by same process to find the material uncertainties and then the results are validated with COMSOL Multiphysics, software for same parameters.**

***Index Term*- Composite Box Beam, Deflection, Hall Effect Sensor, COMSOL.**

I. INTRODUCTION

The use of composite materials has increased in different industries like civil engineering, mechanical engineering, aerospace engineering due to their advantageous characteristics and properties. One of the most remarkable properties that structure made of composites posses is their very large stiffness to weight ratio. During the manufacturing of composite material or beams the uncertainties has formed due to some manufacturing defects and it has analyzed by the different parameters like deflection, stress, strain, natural frequency etc.

The experimental study has carried on composite box beam to measure it’s deflection at free end to analyze the uncertainties present in material. The composite box beam is like a cantilever beam, where one end is fixed and load is applied at free end. Due to this load deflection is take place at free end of beam. In previous study deflection is calculated using Dial Gauge. The dial gauge is placed at bottom side of beam by making its stylus in point contact with beam and will shows zero reading. If load is applied at free end of the beam will move in downward direction. Due to point contact of beam with stylus it also moves and shows some reading. But due to some contact between them will create instrumental errors during measurement.

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To avoid this situation non-contact device is developed called as Hall Effect Sensor. The Hall Effect sensor is electronic device which is works on electromagnetic field. If magnet is come in front of Hall Effect sensor it creates magnetic field between them. If magnet will move away from it change in voltage will take place due to change in distance between them. The change in voltage is calibrated in terms of deflection of beam. The output of this sensor is to another electronic device named as Arduino (Uno) will give required output only.

Various researches have carried out work composite box beams. SushantaGhuku et al. [1] presented a theoretical and experimental study on deflection behavior of initially curved cantilever beams subjected to different types of loadings. A physical systemof a straight cantilever beam subjected to a tip concentrated load is considered. The results are validated with existing results for straight beams and few new results are furnished for initially curved cantilever beams. Mohammad Dado et al. [2] studied the deflection behavior of a prismatic and a non-prismatic cantilever beams subjected to different types of loadings. The formulation is based on representing angle of rotation of beam by a polynomial on the position variable along deflected beam axis. By minimizing the integral of residual error of the governing differential equation and by applying the beams boundary conditions, the coefficients of the polynomial are obtained. Beléndez, T. et al. [3] presented the classical problem of deflection of cantilever beam of linear elastic material, under the action of a UDL (uniformly distributed load) along its length (its own weight) and an external vertical concentrated load at free end, is numerically and experimentally analysed. Various researchers have studied the experimental and numerical analysis of cantilever beam and reported the deflection under various loads [4-5]. For numerical analysis, different researchers have used COMSOL and ANSYS software for studying the performance characteristics of bearings, microchannels, etc. [6-9].

In this paper, experimentation has carried out on four composite box beams which are manufactured by same process to find the material uncertainties and this analysed by considering the deflection parameter. After the experimentation on the four beams the deflection results for different loads are compared with each other to analyze the uncertainties presents material. Simulations are carried out with the help of COMSOL Multiphysics 5.0 software. COMSOL Multiphysics is a powerful interactive environment for modelling and solving all kinds of scientific and engineering problems. This is used to perform the modelling of the composite box beam and calculation of Deflection at free end.Numerical results are carried out for same above parameters. Finally, comparison is done between experimental &numerical results to find percent error between them.

II. Introduction Composite Box Beam

The composite beam having dimension 800x60x22 mm, of uniform cross section is considered. This is an eight layer sandwich composite box beam. The beam used for experimentation is shown below with its material properties.

Fig. 1 Cantilever Composite box beam for experimental analysis

- *Material Properties:*

TableI Material Properties of Composite Beam

Young's Modulus	Poisson's Ratio	Mod. of Rigidity	Density
135 Gpa (Ex Dir.)	0.26	5 Gpa	1600 kg/m^3
10 Gpa (Ey Dir.)			
10 Gpa (Ez Dir.)			

III. Theory of Hall Effect Sensor and Arduion (Uno)

Hall Effect Sensor:

After combining the Hall element with the associated electronics, a Hall Effect sensor is formed. The working principle of a hall effect sensor is very easy. It consists of a current carrying metal strip. EMF is developed across the edges of the current carrying metal strip, when this current carrying metal strip is placed inside any transverse magnetic field. The magnitude of this developed EMF is depending upon the density of the flux and mobility of electron. This hall effect element is typically employed for sensing current and magnetic field measurements.

Arduion is an open-source platform employed for building electronics projects. Arduino consists of both a physical programmable circuit board (referred to as microcontroller) and a piece of software which runs on your computer, used to write and upload computer code to the physical board.

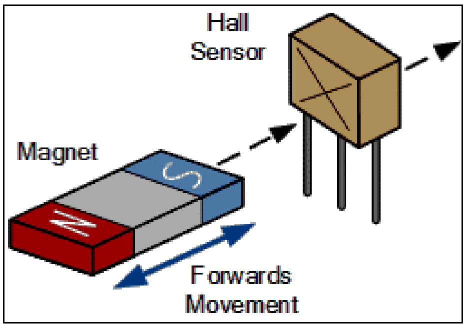


Fig.2 Principle of Hall Effect Sensor

Fig.3 Arduino Uno

IV. Experimental Analysis of Composite Box Beam

Theexperimentation has carried on composite beam for by varying load at free end to find the deflection using Hall Effect sensor. The designed Hall Effect sensor will generate maximum voltage up to 220 volt, if distance between sensor and magnet is up to 6 mm. Initially, we put 1 to 2 mm distance between sensor and magnet then it shows some voltage will assumed as zero. When 10 N load is applied at free end of the beam the voltage difference is generated between initial and final reading. The change in voltage difference is calibrated in terms of deflection of beam. The same process is carried out for other loads (20N to 80N) and its voltage differences are calculated using in graphical form which are generated during experimentation.

The experimental setup for the above proposed work and beam in loading and unloading condition is shown by following figures.

Fig.4 Experimental setups for Deflection of beam using Hall Effect Sensor

During experimentation it analyzed that for 10 N load 16 v voltage generated and by using this voltage we calculate the deflection of beam for this particular load. The same process has carried on four beams. The sample calculations of first beam for 10 N and 20 N loads are given below.

1) **Sample calculation for 10 N:**

$$\frac{6\text{ mm}}{220\text{ V}} = \frac{\delta}{16\text{ V}}$$

Therefore, $\delta = 0.43$ mm

2) **Sample calculation for 20 N:**

$$\frac{6\text{ mm}}{220\text{ V}} = \frac{\delta}{25\text{ V}}$$

Therefore, $\delta = 0.68$ mm

By the same process deflection is found out for other loads and remaining three beams. The voltage difference in initial and final reading for different loads is shown by following graphs.The following graphs are generated during the experimentation of first beam. The same voltage differences are calculated for remaining three beams by generating the same graphs to find its deflection for different loads.

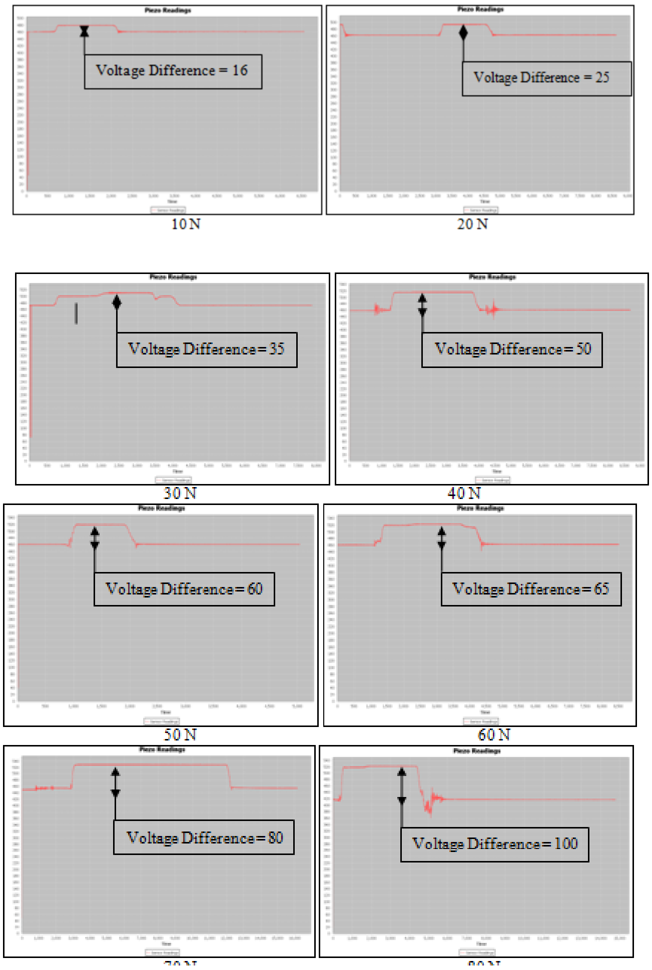


Fig.5 Voltage difference in initial and final reading of first beam for different loads

Table II Deflection of composite beams (Experimental Results)

Sr. No.	Load (N)	Voltage difference between Initial & Final Reading				Experimental Deflection (mm)			
		B1	B2	B3	B4	B1	B2	B3	B4
1.	10	16	15	16	14	0.43	0.40	0.43	0.38
2.	20	25	25	23	27	0.68	0.68	0.62	0.73
3.	30	35	37	35	36	0.95	1.00	0.95	0.98
4.	40	50	48	51	50	1.36	1.30	1.39	1.36
5.	50	60	61	62	58	1.63	1.66	1.69	1.58
6.	60	65	65	63	62	1.77	1.77	1.71	1.69
7.	70	80	81	79	82	2.18	2.20	2.15	2.23
8.	80	100	102	102	98	2.72	2.78	2.78	2.67

Above table represents voltage difference of four composite beams along with its free end deflection for different loads. The experimental results for deflection of four beams for different loads are also shown by following graph. The deflection is gradually increased with increasing load.

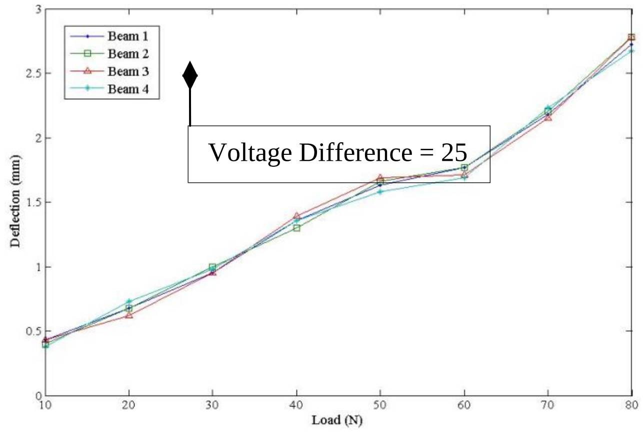


Fig.6 Graph of Load Vs Deflection (Experimental Results)

V. Numerical Analysis of Composite Box Beam

Specification of Problem:

The Composite box beam has a ply lay-up $[0_3/90]$ s on all the four sides of composite beam contain 8 layers. With the help of solid mechanics module in COMSOL Multiphysics, Deflection is calculated.

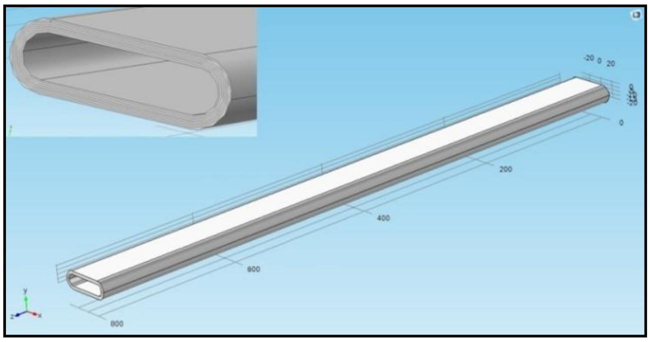


Fig.7 Geometry of Composite box beam in COMSOL

Meshing &Boundary Conditions of Geometry:

Normal meshing is used for meshing the geometry in COMSOL Multiphysics. The geometry of composite box beam with extremely coarse mesh is shown in figure below.The Composite box beam is considered as cantilever type. Hence, one end of the beam is fixed and at other end point load is applied from 10N to 80N. Figure 8shows boundary conditions for given geometry.

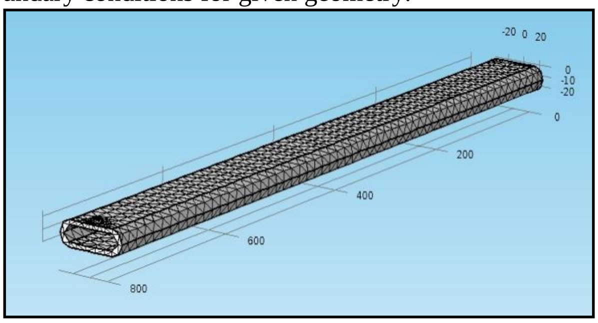


Fig.8 Meshing of Composite box beam

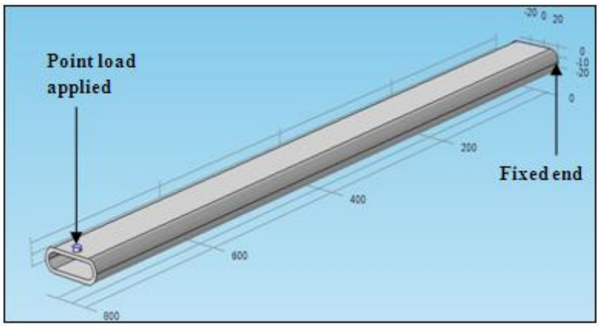
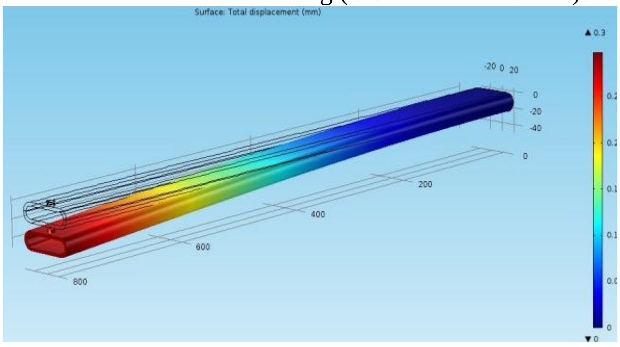
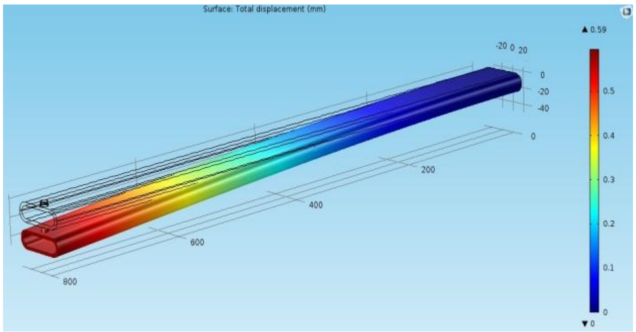


Fig.9 Boundary conditions applied to box beam

Numerical or Simulation Result:
Simulation is performed for Composite beam by varying load at free end. The simulated sample results are given are shown by following figures. The red color in following figures indicates the maximum deflection is taking place at free end of the beam for different loading (i.e. from 10N to 80N).



For 10N



For 20N

Fig.10Sample Simulation Results

Table III Deflection at free end of beam (Numerical Results)

Sr. No.	Load (N)	Numerical Deflection (mm)
1.	10	0.3
2.	20	0.59
3.	30	0.89
4.	40	1.19
5.	50	1.48
6.	60	1.78
7.	70	2.08
8.	80	2.37

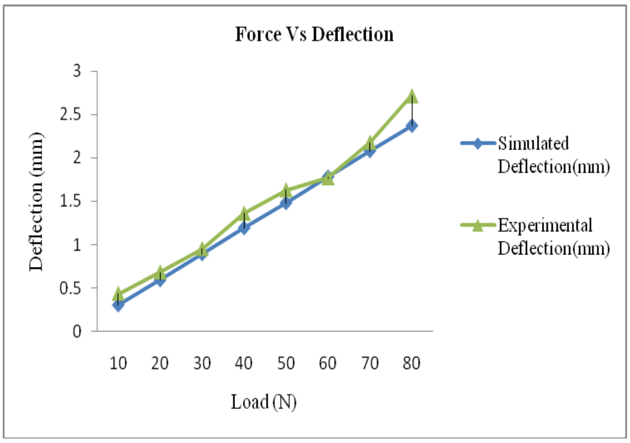


Fig.11 Graph of Force Vs Experimental and Numerical Deflection

VI. Conclusion

During the manufacturing of composite material or beams the uncertainties has formed due to some defects or errors manufacturing process and it has studied by the different parameters like deflection, stress, strain, natural frequency etc. The experimentation has carried on composite beam for deflection measurement and this is of for all four beams by the same process and it is carried out to analyse the uncertainty present in material or beam and results are validated with numerical results using COMSOL.
From the above study on composite beam following conclusions are drawn:

- The use of dial gauge indicator for deflection measurement will create problems during measurement due its contact with composite beam.
- To avoid this situation non contact device is designed and developed for deflection measurement named as Hall Effect Sensor.
- As deflection results of all four beams are compared with each other then there is no more difference between them. All the results are near to each other to their respective load is also shown in graphical form.
- Finally, from the comparison of all results it is observed that there is no any uncertainty present in material or in composite beams.
- Also, the numerical analysis is carried out using COMSOL software for same parameters and validation is done with experimental results which is shown by above graph

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