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Delamination Detection in Composite Sandwich Beam: Experimental Study

Ranjeet A. Patil[1]*, M. V. Kavade[2]

[1]Mechanical Department, Rajarambapu Institute of Technology, Sakhrale

[2]Mechanical Department, Rajarambapu Institute of Technology, Sakhrale

Abstract – Sandwich structures are a key member for many structures. They are finding increasing application in aerospace, marine and construction industries. In some of these applications, these materials are subjected to dynamic loads. Predictive maintenance is important consideration to predict and prevent future problems. A comprehensive maintenance and operations programs can identify and eliminate many potential problems, helping to avoid catastrophic failures. Delamination damage leads to stiffness loss of the structure, the modal properties like natural frequencies, damping ratio and mode shapes may vary. The present article does the experimental study on the free vibration analysis of multilayered laminated sandwich beam.

Keywords—Sandwich structure, free vibration analysis, laminated composite, Delamination damage.

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INTRODUCTION

The importance of use of composite materials has been increasing consistently in different industries like civil, mechanical, and aerospace engineering, etc. due to their advantageous characteristics. One of the most remarkable properties is that the structures made of composites possess very large stiffness to weight ratio. Composites have an excellent combination of high strength and stiffness with low weight. This property among many others has flexibility to adapt different shapes, protection against corrosion, has the possibility to look for new engineering challenges and replace the traditional materials with composites. Composite laminates are widely used in different areas due to their ease of fabrication and effectiveness and because of their versatility in the orientation of the fibers.

SANDWICH STRUCTURE

Sandwich structure consists of two thin skins and one thick core that is inserted between two skins. Core generally is made up of isotropic materials such as foam; honeycomb, balsa wood, etc., and two skins are made up of composite sections. Due to light weight of core, sandwich structures are very light in weight and they are most preferable in aerospace applications where high flexural rigidity is required. Fig. 1 shows the sandwich panel with normal PVC core.

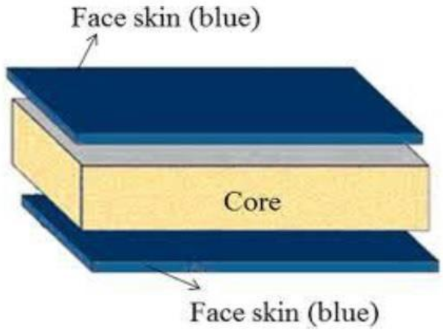

Fig.1 sandwich panel

Despite benefits, composite materials also have their disadvantages. Due to their layered nature and the interaction between both materials, fibers and matrix, composite materials are prone to different failures modes, the most common of them being delamination, which can cause irreversible damage. This failure causes the separation of the layers and induces significant loss of mechanical strength. Delamination is probably the most dangerous defect in composite materials because it can appear suddenly without any prior notice and it keeps developing to collapse the structural member. Composite materials with the defect of delamination can lose up to 60% of their stiffness and remain visibly unchanged.

The development of robust techniques for detection of delamination is essential to avoid such a failure. Since delamination damage leads to stiffness loss of the structure, the modal properties like natural frequencies, damping ratio and mode shapes may vary also.

LITERATURE REVIEW

Tate et al [1] investigated the effect of delamination on natural frequency with piezoelectric transducer (PZT) on upper part of the laminated beam. Dynamic responses of the structures were obtained from performing transient analysis using ANSYS, finite element analysis software. From dynamic responses, frequency response function obtained using MATLAB (FEA) software. They concluded from the results that as damage increases natural frequency decreases.

Zou et al [2] investigated vibration based model-dependent methods with piezoelectric sensor and actuator incorporated into composite structures for health monitoring of composites. These methods utilize finite element analysis techniques together with experimental results to detect damage. They locate and estimate damage events by comparing dynamic responses between damaged and undamaged structures.

K. Torabi et al [3] investigated the effects of delamination size and its thickness wise and lengthwise location on the vibration characteristics of cross-ply laminated composite beams. They observed in each mode, when the delamination is located in the regions of mode shape antinodes, low reduction observed. Conversely maximum reduction in frequency was observed when delamination is located in the regions of mode shape nodes.

Garcia et al [4] developed a method for analysis of the vibration response of structures made of composites. It also used to develop a vibration-based health monitoring procedure for such structures. Not only the healthy scenario but also different delamination scenarios are successfully detected. This demonstrates the potential of the methodology for delamination localization due to the ability to cluster different delaminated plate scenarios.

Sadilek et al [5] performed frequency response analysis of hybrid aluminum beam with piezoelectric actuators. They implemented finite element model in MATLAB software. The piezoelectric actuators driven by harmonic signals around the first Eigen frequency and the beam oscillations investigated.

Shahdin et al. [6] studied impact strength of two types of entangled (heavy and light) sandwich beams using vibration responses. They conducted impact test on heavy as well as light sandwich beam and effect on modal parameters is observed for two levels of impact damage, one of which is barely visible impact damage (BVID) and other one is damage not apparent on surfaces. BVID corresponds to 0.6-0.8 mm indentation measured just after impact and damage not apparent on the surface corresponds to 0.1-0.2 mm indentation measured just after impact. They found that light entangled sandwich beam is more sensitive to impact damage and possess good damping properties than heavy one. They also investigated that damping is more sensitive parameter for damage detection than natural frequency.

F. Ju et al [7] investigated the free vibration analysis of delaminated composite beams using finite element formulation. Results from finite element formulation are compared with other theories which state the effects of size, location and number of delamination on frequencies of delaminated composite beams. He concluded that layer-wise approach is sufficient for free vibration analysis of composites.

Zeki et al. [8] studied the effect of root crack on lateral buckling loads and natural frequencies of sandwich composite beams numerically as well as experimentally. Natural frequencies and buckling loads in thin sandwich composite cantilever beams are determined. Cracks are generated at the interface of skin and core of sandwich beam at various lengths such as 50mm, 100mm, 150mm, and 200mm. For numerical analysis ANSYS finite element software is used. Numerical results are compared with experimental results and finally concluded that presence of root crack affects the natural frequencies of the sandwich composite beam and frequencies for 50mm and 200mm crack lengths are higher for bending modes. They also concluded that for torsional vibration modes natural frequencies decrease, as crack length increases.

Li et al. [9] studied the damage of localization in composite lattice truss core sandwich structures based on vibrations using non-destructive evaluation techniques. The method is based on uniform load surface curvature and developed according to synergy of Grapped smoothing method and Teager energy operator. Numerical simulation of lattice truss sandwich core for damage detection is performed and results are compared with experimental results. It is concluded that Grapped smoothing method and Teager energy operator are more reliable for damage detection in lattice core sandwich structures.

By studying all the above literature, it is found that for health monitoring of composite structures, vibration responses have wide scope. Many of finite element tools are available for health monitoring of composite structure in which simulation is performed. Sandwich structure is most demandable in the fields where higher flexural rigidity is required and here we see the effect of delamination on frequency response of sandwich structure by experimentation.

EXPERIMENTAL WORK

Introduction

The experimental work was carried in Vibration lab at RIT College, Islampur. The aim of this experimental work is to investigate the modal parameters (Frequency, mode shape). The test beam is prepared by manual layup method.

Steps performed to manufacture sandwich beam:

- As per specification, the pieces of carbon fiber and PVC foam are made.
- Then cleaned the PVC foam to make sure that it is clean from any dust and any other atmospheric particles.
- Then mixed the epoxy resin base coat at the ratio of 2:1 with the epoxy hardener.
- The base coat was evenly applied on one side of PVC foam by using laminating brush.
- Then it is left to cure to a tacky hardness for about 2 to 3 hours.
- After resin layer reached tacky hardness the carbon fabric layer was applied.
- The steps 3 to 6 are repeated until desired layers are completed.
- Then part is left to fully cure. It takes nearly 8 hours.
- Same procedure is applied to other side of the PVC foam.

Fig.2 Specimens for experimental study

Beam's Specifications are given in Table 1 below,

Table 1 Sandwich Beam's Specifications

Dimensions			Sandwich beam
Length(mm)	L		300
Width (mm)	B		30
Thickness (mm)	t	Case 1: 2 laminate	6.2
		Case 2: 3 laminate	6.8
		Case 3: 4 laminate	7.4
		Case 4: 4 laminate with delamination defect	7.4

In case 4 delamination defects of 100mm are at second laminate from core material on both sides and it is located 100mm from fixed end. The block diagram of the experiment set up contains the specimen Accelerometer, Impact hammer and Data acquisition system.

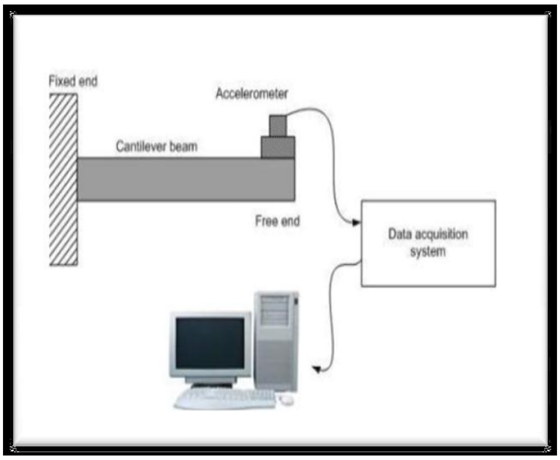

Fig. 3 Block diagram of experiment set up

Impact hammer

Using an impact hammer is the simplest and fastest way of exciting a structure into vibration. It is very suitable to use in operational conditions. Moreover, it does not influence the structure by attaching the exciter, which is an advantage itself. The hammer consists of a head, force transducer, tip and handle. The equipment of a hammer is usually completed with a set of tips of different stiffness and with a set of heads of different masses. A force transducer detects the magnitude of the force felt by the impactor which is assumed to be equal and opposite to that experienced by the structure.

"Modal Tuning" is a feature that ensures the structural characteristics of the hammer do not affect measurement results. This is accomplished by eliminating hammer resonances in the frequency range of interest from corrupting the test data, resulting in more accurate and consistent measurements.

The force sensor serves to provide a measurement of the amplitude and frequency content of the energy stimulus that is imparted to a test object. Accelerometers are used in conjunction with the hammer to provide a measurement of the object's structural response due to the hammer blow. A variety of tips supplied with each hammer permit the energy content of the force impulse to be tailored to suit the requirements of the item under test.

Fig. 4: Impact hammer

Data acquisition card

The data acquisition card used in the experiment is displayed in figure 5. It is a four-channel dynamic signal acquisition module for making high accuracy measurements from IEPE sensors.

The data acquisition system includes a Data Acquisition Box (DAQ) and a host computer which displays the data in real-time and provides a graphical-user interface (LabShop). Combined with LabShop and the PC, we can analyse and process acquired signals and control simple processes anytime, anywhere. DAQ provides analog input (AI), analog output (AO), digital input and output (DIO), audio, power supplies, and digital multimeter (DMM) functions in a compact USB device.

Fig. 5 Data acquisition card

Fast Fourier Transform (FFT)

Frequency analysis based on the Fast Fourier Transform (FFT) algorithm is the tool of choice for measurement and diagnostics of vibration. The FFT analyser is recently developed PC based virtual instrument. It uses impulse execution and either frequency domain analysis or time – domain analysis to entrant the model parameter from the response measurement in real time. Following impulses are execution of the specimen, the measured analog response signal maybe digitalized and analysed using the domain techniques or transformed for analysis in the frequency domain using FFT analyser. The peaks in the frequency response spectrum are the location of natural frequency. The model parameter can be entranced from a set of Frequency Response Function (FRF) measurements between one or more reference positions and measurement position required in model. The response frequency and damping value can be found from any of the FRF measurements. On the structure, the execution of the model parameter from FRF can be done using a variety of mathematical curve fitting algorithm. The FRF can be obtained using multichannel FFT measurements.

The Piezo-Electric accelerometer

This accelerometer is based on the piezo-electric effect. When a piezo-electric crystal is subjected to a mechanical force or stresses along specific planes, a voltage is generated across the crystal. If the force on the crystal is due to an accelerometer, a measure of the voltage across the crystal becomes a measure of the acceleration PCB's single axis and three axis (triaxial) accelerometer configuration parameters include sensitivity, temperature, frequency response, amplitude response, form factor and lead wire grounding. Accelerometers are critical for evaluating proper performance of equipment or structures. Such applications usually require proof of calibration of the entire measurement system from the sensor through to the final output.

Fig. 6 Piezo-electric accelerometer.

EXPERIMENTAL PROCEDURE

Free vibration test is conducted on the test specimens. To obtain its included natural frequencies, the beam is clamped on the table with the help of clamping device arrangement. The impact is applied by striking at the marked portion near the fixed end of the test specimen. During free vibrations, the dynamic responses of the beam are measured through the accelerometer as shown in figure. For this test, the location of accelerometer is at different marked positions in order to extract the signals of vibration. The layout of the sensors on the test specimen is depicted in Figure A data acquisition system, i.e., Data card is used to store the record data and transfer measured data to the PC for post processing. Frequency response functions (FRFs) were obtained and analysed using ME Scope software.

Fig. 7 Schematic diagram of experiment arrangement

Measurement procedure

1. A composite sandwich beam of carbon fibre and PVC foam with dimensions (L, B, t) was used as a cantilever beam.
2. The fixed end was made by fixing the beam with the help of G-clamp fixed on the table.
3. The connections of the accelerometer were properly made.
4. Accelerometer was placed at different positions of the cantilever beam, to measure the vibration response.
5. The cantilever beam was struck with an impact hammer and beam starts vibrating.
6. All the data obtained from the vibrating beam was recorded with the help of accelerometer attached to it.
7. The experiments were repeated to check the repeatability of the experimentation.
8. The whole set of data was recorded and then the data was imported into the PC. Further processing and analysis was done using PULSE software.

The signal obtained from the data acquisition system is used to extract the mode frequencies. In the next section, results are discussed in brief.

RESULTS AND DISCUSSIONS

The natural frequencies obtained from the experimental analysis are as follows-

Table 2 Natural frequency of sandwich beams in Hz

Modes	Case1 Hz	Case2 Hz	Case3 Hz	Case4 Hz
Mode 1	640	832	960	576
Mode 2	832	1088	1152	768
Mode 3	1024	1344	1408	1280
Mode 4	1344	1664	1792	1536
Mode 5	1536	1920	2112	1856

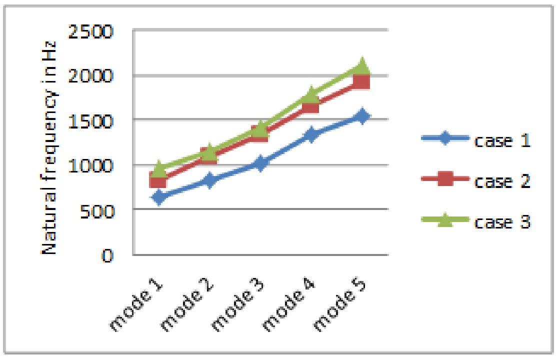

Fig. 8 Variation of natural frequencies with variation in number of laminates in facesheet

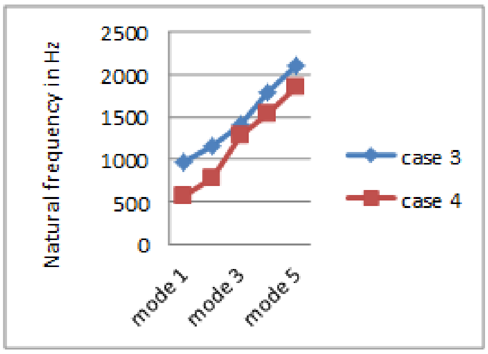

Fig. 9 Natural frequencies of healthy and delaminated sandwich beam

From case 1 to 3 we can say that the natural frequency increases as we increase the number of laminates as stiffness of structure increases and in the case 4 which is laminate with core and delamination defect we get decrease in natural frequency compared to case 3, i.e., 4 laminate with core and no defect because delamination defect causes reduction in stiffness so natural frequency decreases.

CONCLUSION

The following conclusions can be made from the present study of the composite sandwich beam from the experimental modal analysis.

- The natural frequency increases as we increase the number of laminates due to increase in stiffness of the structure.
- The natural frequency variation study was conducted on the interfaces of the models. The reductions in natural frequencies were found on the delaminated model of composite sandwich beam.
- The crack and delamination in the composite plate has an effect on the stiffness of the beam; this affects the frequency of the composite sandwich beam.
- So with the presence of the crack and the delamination, the stiffness of beam decreases and this causes a decrease in the natural frequency of the corresponding mode (bending mode for crack and torsion mode for delamination) of the composite sandwich structure.

So, we can develop the robust techniques for detection of delamination which is essential to avoid failure by using frequency response of composite sandwich structure.

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Corresponding Author

Ranjeet A. Patil*

Mechanical Department, Rajarambapu Institute of Technology, Sakhrale

E-Mail – **patilranjit542@gmail.com**