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Research Article

Damage Detection in Aluminium Honeycomb Structure using Vibration Analysis

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Abstract

Honeycomb sandwich structures have wide application in the manufacture of the aerospace structures due to their high specific bending stiffness, lightweight and strength under distributed loads with good energy-absorbing capacity. Damage in any type of structure is a serious threat to the machines performance. In the present study we have prepared a structure and created an artificial damage in between the interface of faceplate and core. The natural frequency is used to identify the defect in the honeycomb structure using the vibration analysis for the damage detection in the Aluminium plate of the specific size and the results are obtained with the help of the Fast Fourier transform (FFT) Analyzer. The results obtained by experimentation are compared with the Finite Element Method. The main objective is to detect presence and the location of damage in the Honeycomb Structure which may be generated during manufacturing or during working condition. For analysis purpose defect is created artificially during manufacturing and analyzed with the help of the experimental and finite elements method.

Keywords: *Aluminium Honeycomb Structure, Damage Detection, FFT Analyser.*

1. Introduction

Honeycomb sandwich structures have wide application in the manufacture of the aerospace structures due to their high specific bending stiffness, lightweight and strength under distributed loads with good energy-absorbing capacity. (Wahyu Lestari, *et al*, 2005; A.Boudjemai, *et al*, 2012). Damage in any type of structure is a serious threat to the machines performance. Due to this reason, methods making localization and detection of damages have been the research subject for many researchers. Vibration results in dynamic stresses and strains in the structures, which can cause fatigue and failure in it, also the fretting corrosion between contacting elements and noise in the environment; and can, impair the function and life of the blade itself. In order to predict the natural frequencies, it is necessary to analyze the vibration and the response to the required excitation. Structural damage detection can be classified as global-damage detection and local-damage detection. Vibration-based structural damage detection is a relatively new and emerging area of research within SHM and its development can be divided into traditional and modern type.

In traditional types of damage detection methods mechanical characteristics of structures like natural frequencies, modal damping, modal shapes, were utilized. However, these kinds of method are not convenient for online detection of structures since they require experimental modal analysis or transfer function measure. The modern-type such as techniques incorporating vibration signatures for analysis refer to the damage detection methods based on response signals acquired from excitation of structures. Its advantages can be summarized as: (1) compared with the traditional type techniques, it is less dependent on experiments. Vibration responses at few points on the structure are sufficient for damage detection. (2) Using the more modern-type techniques, smaller structural damage can be detected by the construction and extraction of better characteristic information from structural dynamic response signals. From the modern methods for structural damage detection, some of them include Wavelet analysis, Genetic algorithm (GA) and Artificial Neural Network (ANN).

Generally vibration theory is correlated with the modal parameters like frequency, mode shapes and damping. These physical systems consist of the structure physical properties (mass, stiffness, and damping). These model parameters are the solutions of the homogeneous part of the differential equation of motion of a physical model expressed in terms of its mass, damping, stiffness, acceleration, velocity, and displacement. (A.V. Deokar, *et al*, 2011)

(Wahyu Lestari, *et al*, 2005) experimented for damage detection in sandwich structures using some smart sensors dynamic responses for healthy and damage structures were collected and its curvature modes shapes were used to identify and quantify the damage. (A.Boudjemai, *et al*, 2012) studied the multidisciplinary design and analysis for honeycomb panels used for satellites. The results shown that material properties and geometrical parameters shows an effect on modal frequencies. (Missoum Lakhadar, *et al*, 2013) studied the damage detection in composite

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structure and the results were compared with the numerical models. (A.V. Deokar, *et al*, 2011) used the first three natural frequencies for the crack detection in the cracked beams and the crack location & crack depth was identified. (H. Nahvi, *et al*, 2005) also studied the crack detection in the cracked cantilever beams and the location was identified using the first three natural frequencies and the intersection of the contour plots were used for the crack location. (J T Kim, 2003) studied the detection of the crack in a beam using non-destructive technique i.e. using the natural frequencies; an algorithm was prepared for the location of the crack. The feasibility and practicality was checked for the several crack in the structure and observed that the crack size can be evaluated with small error. (Marta B, *et al*, 2009) have presented the two approaches for the crack detection in Euler Bernoulli's beam as Power series technique (PST) and Artificial neural network (ANN). Also comparison in the both method suggested that PST provides simple results with relatively small error.

2. Honeycomb Theory

2.1 Constituent of honeycomb sandwich structure

The honeycomb sandwich structure is designed generally on the applications like the core, adhesive and the face plate. Again the criteria of designing may be the mechanical properties of the constituents but price of the structure is the another parameter may be considered for designing due others several factors of the magnitude. It is also used in skin frame design. A honeycomb sandwich structure consists of two thin face sheets attached to both sides of a lightweight core (see figure 1).

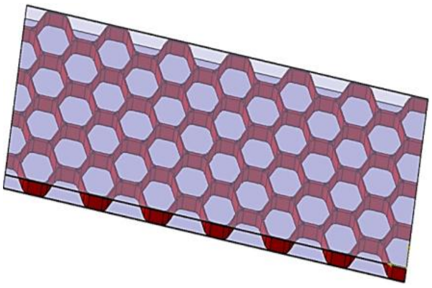

Fig.1 Honeycomb Sandwich Structure

The sandwich structures are usually subjected to the axial loads, bending moments and shear stresses while the core may carry flexural shear. Sandwich structures may fail due to concentration of the normal local stress due to heterogeneous structured core. Sandwich panel face sheets are commonly fabricated using aluminium or graphite/epoxy composite panels. The core is typically fabricated using a honeycomb or aluminium foam construction.

2.2 Material of Structure

The material for the honeycomb structure should be selected such that it should have high strength and low weight. So materials are like Aluminium or Carbon Epoxy composite. The material for our test is of Aluminium and its composition with the detail dimension of plate is as given below:

Table 1 Composition of Aluminium

Al	Rem
Mg	0.09
Cu	0.084
Si	0.41
Fe	0.67
Mn	0.1
Ni	0.1
Zn	0.1
Pb	0.05
Sn	0.01
Ti	0.2

Table 2 Material Properties of Aluminium

Material property	Value
Density	2700 kg/m^3
Young's Modulus	71070 MPa
Yield Strength	268 MPa
Compressive Strength	2.5 MPa
Compressive Modulus	540 Mpa
Tensile Strength	367 Mpa

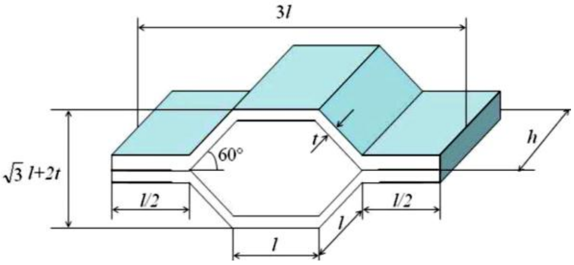

Fig.2 Single cell of Honeycomb plate

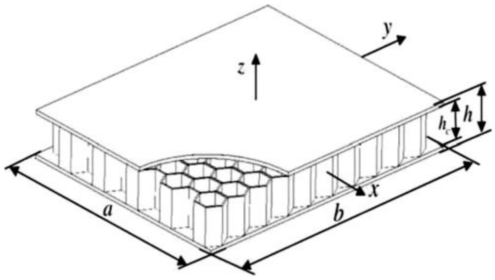

Fig.3 Geometrical model of honeycomb plate

3. Defects in Honeycomb Structure

Generally the defects or the damage emerges in the sandwich honeycomb structures are due to the skin problems, core defects or due to the delamination in the core and the skin. So the practical types of the damages in honeycomb structure are as follows:

3.1 Debonding of Honeycomb structure

In this type of defect of honeycomb structure the contact between the skin plate and the honeycomb core cut and then at that position the section becomes weak and there is irregular frequency distribution finally results in crack in the structure. This generally occurs due to intra cell buckling or panel buckling.

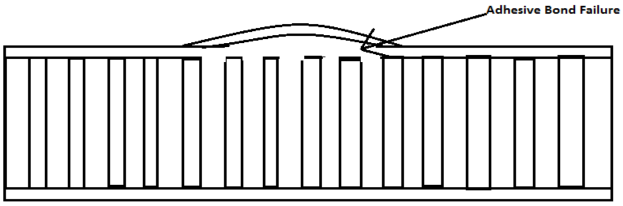

Fig.4 Debonding in honeycomb plate

3.2 Delamination in Honeycomb structure

This type defect is incurred due the change in the temperature conditions and the impact load on the specific point. Local compression may lead to the delamination of the skin or adhesive contact between the core and the adhesive as shown in fig 5

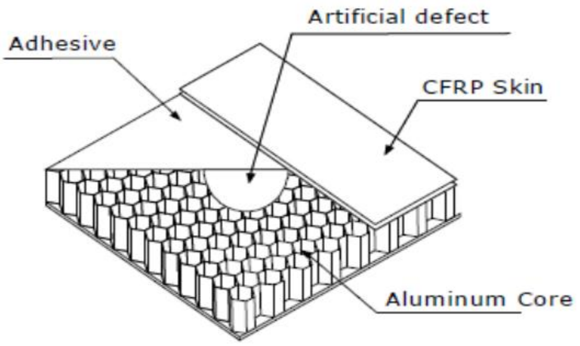

Fig.5 Artificial Delamination in honeycomb plate

3.3 Core crushing in Honeycomb structure

In this type of damage in honeycomb structure the sudden impact may result in the inner part of the honeycomb to be damaged by getting crushed at some parts. Maximum deflection, local compression and shear wrinkling mar result in the crushed core.

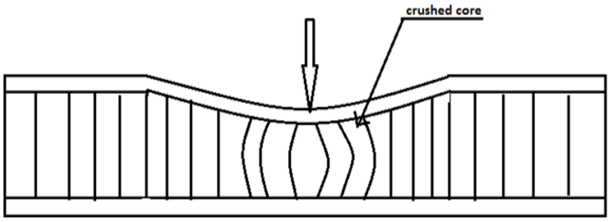

Fig.6 Core crushing in honeycomb plate

4. Experimentation

4.1 Experimental Measurement Setup

In this test setup as shown in fig 7 FFT Analyser is used to obtain the frequency response function of the specimen. It consists of the impact hammer and accelerometer for excitation of the specimen and collecting the frequency response. The specimen is Honeycomb structure plate which is fixed at a support which is the rigid support used for supporting the different types of jobs. It is an I-section support with a clamping provided with the upper plate of the clamp attached with the nut and bolt arrangement. The total arrangement with FFT Analyser is as shown in the fig 7 and fig 9.

The specimen is made of aluminium material having two skin plates attached from top and bottom and the intermediate portion consists of the honeycomb core as shown in fig 8. The detail of the geometry of the honeycomb structure plate is as given in the table 3.

Table 3 Dimensions for the Honeycomb Structure Plate

Parameter	Dimension
Length (a)	200mm
Width (b)	75mm
Thickness of the skin (t)	0.5mm
Cell size (l)	3mm
Cell thickness (tc)	0.5mm
Core height (h)	9mm

Fig.7 FFT Analyser

Fig.8 Specimen of Honeycomb Structure

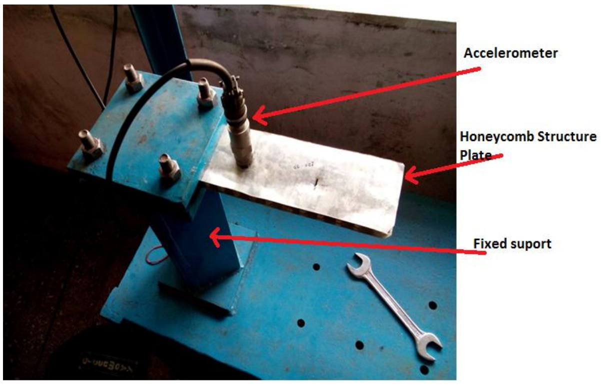

Fig.9 Test Setup

4.2 Specifications of FFT Analyser

- Multichannel (four) spectrum analyser, data collector and balancer with software along with acceleration sensor sensitivity 100 mV/g (g = 9.81m/s2).
- Impact hammer (dynamic quartz sensor -9772A-for light to medium structures at medium to high frequencies), Measuring range up to 2000N with cable and other accessories, sensitivity at 100Hz = 2mV/N, overload capacity = 500N, Resonant frequency = 27 KHz, hammer mass = 100 gm, Rigidity = 0.8 KN/micron, temperature range = -20 to 70^{o}.
- Microphone with cable, sensitivity = 46.17 mV/Pa.

4.3 Experimental Procedure

The manufactured honeycomb structured aluminium plates were tested with the one end fixed like cantilever beam model. The plate was supported on the rigid I-section structure girder. The plate was excited with the impact hammer. The first three natural frequencies were measured for healthy plates (without crack). The crack was artificially created in the plates at different locations for the total 9 plates with varying distance. Also the Honeycomb structure at the specific location was crushed where the crack was created. This was to achieve the delamination between the skin plate and the honeycomb plate. Then all models were excited separately and the first three natural frequencies of each plate were taken. The response of the each plate was measured with the help of the accelerometer placed on the plate during testing. The responses were acquired one at time for each plate using the FFT Analyzer.

5. Results and Discussions

5.1 Result

The modal frequency analysis was carried out experimentally for the honeycomb structure plate. It’s one end was fixed in the fixed structure. The first three natural frequencies were determined for all 9 plates including healthy plate. The results are shown in the table 4. It is found that there is small deviation in the modal frequencies of each plate. It is due to the difference in crack location in each plate.

Table 4 Experimental Results

Case	Crack position X	Crack Position Y	Frequencies (Hz)		
	mm	mm	f1	f2	f3
1	Healthy		287	1671	4368
2	100	15	279	1693	4194
3	100	30	240	1632	4242
4	100	45	354	1650	4306
5	120	15	252	1655	4167
6	120	30	240	1671	4265
7	120	45	300	1674	4224
8	140	15	222	1719	4272
9	140	30	269	1691	4232
10	140	45	261	1610	4311

5.2 Ratio of Natural Frequencies

The results obtained from the experimental analysis for all cracked plates including the healthy plates with normalized ratio i.e. ratio of frequency of damaged plate to the frequency of healthy plate are shown in the following table’s 5, 6, 7. It is observed that the first and second frequency is more affected as compared to the third frequency which is least affected since the nodal point of the third frequency at the center of the plate.

Table 5 Normalized Frequencies Mode I

First mode shape frequency ratio			
X\Y	15	30	45
100	0.972125436	0.836236934	1.233449477
120	0.87804878	0.836236934	1.045296167
140	0.773519164	0.93728223	0.909407666

Table 6 Normalized Frequencies Mode II

Second mode shape frequency ratio			
X\Y	15	30	45
100	1.013165769	0.976660682	0.987432675
120	0.990424895	1	1.001795332
140	1.028725314	1.011968881	0.963494913

Table 7 Normalized Frequencies Mode III

Third mode shape frequency ratio			
X\Y	15	30	45
100	0.960164835	0.971153846	0.985805861
120	0.953983516	0.976419414	0.967032967
140	0.978021978	0.968864469	0.986950549

Again the fig 10, 11, 12 shows the 3D plots of the frequency ratio of damaged plate to healthy plate with the position of the damage in the plate i.e. the location X and Y. Also it shows the contours for the 3D plots for each of the graph. This was drawn with the help of the Design Expert 7.0 software which provided the exact detection of the crack or the damage in the plate using the contour plots.

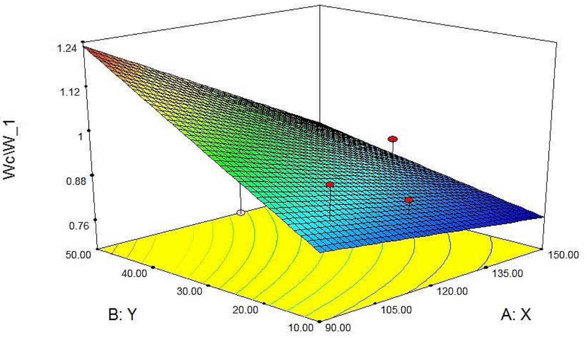

Fig.10 3D plot of frequency ratio versus the position of the damaged location for first mode shape

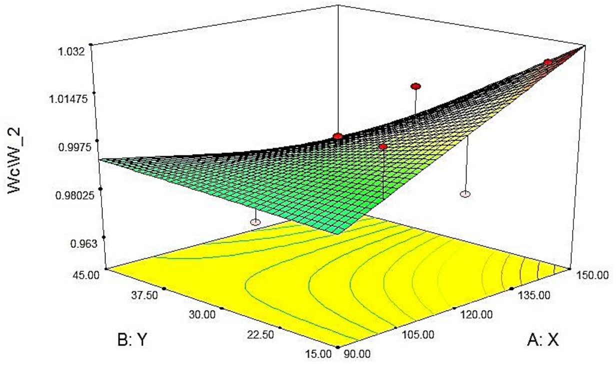

Fig.11 3D plot of frequency ratio versus the position of the damaged location for second mode shape

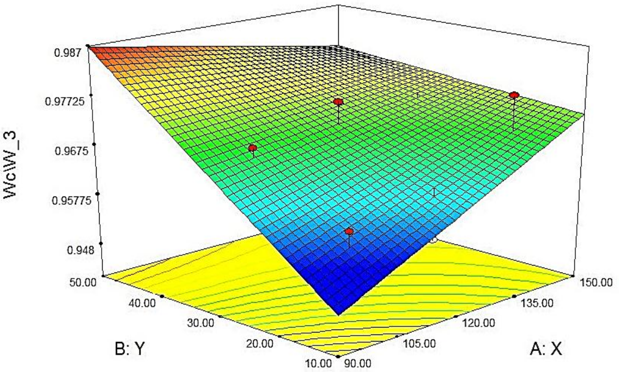

Fig.12 3D plot of frequency ratio versus the position of the damaged location for third mode shape

5.3 FFT Analyzer Spectrums

For example the spectrums obtained from FFT Analyzer are as below in Fig 13 which shows the FRF (Frequency Response function) spectrum analysis for the first three natural frequencies for damage location 100-15 in honeycomb structure plate.

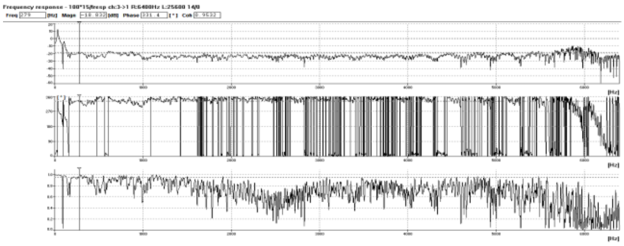

Fig.13 FRF spectrum for damage 100-15 honeycomb plate

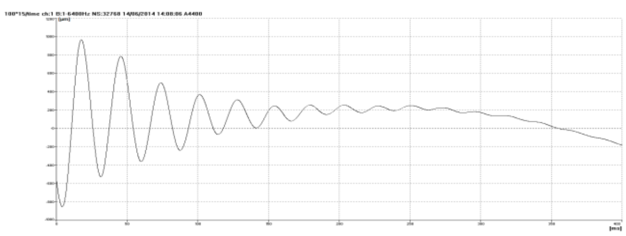

Fig.14 Time spectrum for damage 100-15 honeycomb plate

Similarly for other crack location can be obtained. Also Fig 14 is the time spectrum graph in which there is much variation up to 200sec and spectrum varies between 4.5 to -4.5 m/s2. And the fig 15 shows the graph of amplitude vs. frequency for same crack location. The cursor in the respective spectrum represents the first natural frequency for the damage location.

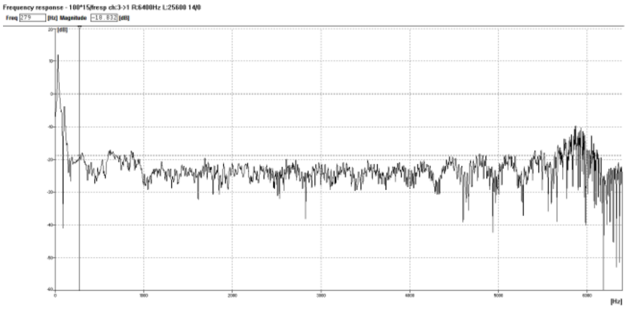

Fig.15 FRF amplitude spectrum for damage 100-15 honeycomb plate

5.4 Detection of the Damage Location

For the locating the position of the damage the contour plots for the first three normalized natural frequency for experimental are plotted using Design Expert. Since two contours for first two natural frequencies cannot locate the exact location the third frequency contour is used for locating it. The intersection point for all three contour plots specifies the location of the damage. In the Fig 16 shows that 0.890559 is the normalized frequency ratio for first mode, 0.95784 for damage i.e. equal to X=100mm and Y=15mm

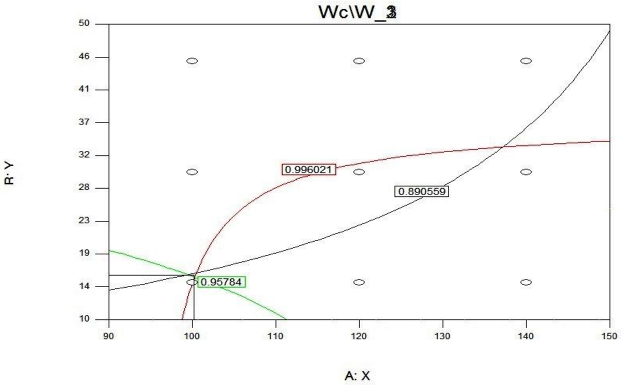

Fig.16 Contour plot for location X 100 Y15

When we are using the method of frequencies of contour plots for identification of damage or crack of such type of structure following steps should be followed for prediction of the unknown damage parameters:

1. Measure the first three frequencies
2. Normalization of the frequencies
3. Plotting of the contour graphs for different mode shapes on the same axes
4. Location of the point of intersection of the different contour lines

The point of intersection common to all the three modes indicates the damage length and width. This intersection will be unique due to the fact that any normalized crack frequency can be represented by governing equation that is dependent on damage length and width. Therefore a minimum of three curves is required to identify the two unknown parameters of damage/crack length and width.

Conclusions

In this study, an attempt has been made to detect presence and the location of defect in honeycomb plate using vibration measurement utilising Fast Fourier Transform analyser. The following conclusions are drawn

- It indicated that the proposed technique can be effectively and appropriately applied for detection of defect in full scale composite structures (e.g., large FRP honeycomb sandwich structures) used for aerospace application.
- The locations of the damage for both damage configurations (i.e., the core–faceplate debonding and core crushing, respectively) can be identified properly using the contours plotted in Design Expert, while the magnitude of the damage can also be evaluated through the stiffness loss
- The location of the damage can be easily found out with the help of first three natural frequencies and mode shapes.
- By using frequency contour it is possible to find normalized crack location along with approximate crack location.

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