The Effects of Honeycomb Parameters on Transient Response of an Aircraft Sandwich Panel Structure

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In this paper, an experimental and numerical investigation were conducted to develop an understanding of the importance and role played by honeycomb design parameters in transient response of aircraft sandwich with honeycomb core under the transient load. Forced vibration under transient load test was implemented on sandwich panel with honeycomb core specimens. Vibration rig with specific equipment was manufactured. Finite element simulation for the sandwich panel with honeycomb core were developed and analyzed by Ansys software package. Modal analysis and transient response analysis have been carry out to obtain the numerical transient response. The obtained results show a good agreement between above approaches with conformity by 85% percentage. The core high, cell size and cell wall thickness were selected to explore the effect of honeycomb parameters on the transient response of sandwich structure. In order to obtain the optimum condition, Response Surface Methodology (RSM) was used. Results showed that minimum transient response were found at 20 mm core height, 25 mm size cell and 1.5 mm cell wall thickness. Where, the optimal value minimum transient response equal to 0.0019 mm.

Keywords: aircraft sandwich panels, honeycomb core, vibration, transient response, optimization and surface methodology

1. Introduction

Most of the engineering applications require materials of high strength/stiffness ratio such as civil, mechanical, prostheses and orthoses, biomedical and nuclear structures. Recently, the sandwich materials have shown a good characteristics which can be used in the above applications such as high fatigue and structure design [1-3]. Basically, the honeycomb structure is constructed of two thin faces of high stiffness and separated by a soft thick core [4]. The researchers directed their work on the using of sandwich construction with a honeycomb core to reduce the weight of the structure. G. Sakar [5] analyzed the aluminum honeycomb beams by employed the
numerical and experimental techniques to investigate the dynamic analysis of beams subjected to dynamic loading with the use of modal analysis technique. His work covered the finding of natural frequencies and mode shapers by selecting a cantilever beam of a honeycomb sandwich panel and investigating different honeycomb design parameters such as the lower and upper sheet thicknesses, foil thickness, material type of the core, cell diameter angle, and different support conditions. The effects of variation of honeycomb core height on the free vibration of sandwich panels structure was conducted experimentally by Harish et al. [6]. They tested the following boundary conditions C-F-F-F and C-F-C-F and found that the core height has an effect on the honeycomb panel due the increase in moment of inertia which in turn increase the stiffness and eventually the fundamental natural frequency. The researchers Naresh et al. [7] studied some design parameters of the honeycomb structures sections such as the type of the core material, cell shapes and the plate faces and assessed their effects on the fundamental natural frequency by using a numerical modeling using the finite element technique and employing the hexagonal and square core shapes. An analytical solution was suggested by Muhsin J. Jweeg [8] for the honeycomb structure type. The equations of motion were derived for calculating the natural frequencies by taking into consideration the honeycomb design parameters into consideration such as core height and cell size. He concluded that the stiffness of the honeycomb cell is increased with the increase of the cell size and height which in turn increases the natural frequency and hence the stiffness/ratio is increased consequently. Souhir Zghal and Rachid Nasri [9] concentrated their work on using Nomex and Aluminum materials to be used in the core structure. An experimental program was achieved on a honeycomb beam model using the suggested materials and estimating the natural frequencies. The results indicate that Nomex core has greater value of natural frequency from aluminum material. A combination of finite element approach and an experimental investigation were employed by Yash Parikh and Pranav Mahamuni [10] for the free vibration analysis of a plate of hexagonal honeycomb plate. Their interest was on the determination of the effectiveness of using epoxy with carbon, aluminum and titanium materials for
the skin and core. It was found that the carbon material with epoxy gives the highest stiffness compared to the other types of used materials in their work which results in high natural frequencies. The dynamic analysis of a spacecraft structures were examined by M.Marythraza et al. [11] by using the honeycomb sandwich panels for the construction the spacecraft. The finite element technique was employed for the spacecraft simulation in addition to the analytical approach using the simply supported and clamped support boundary conditions. Their solution approaches were employed by Zhengfeng Bai [12] for modal analysis of small satellite structure. Many researchers were conducted the dynamic analysis for plates using a suggested analytical solutions and numerical investigations [13-18].

The presented previous researches mainly were focused on the free vibration of honeycomb sandwich panel structures. A limited work deals with the forced vibration of especially the transient type which a common source of the excitation in the engineering applications. Therefore, the current work will be concentrated mainly on these loading effects numerically using the finite element modeling and an experimental program. The core height, cell size and cell wall thickness will be taken into consideration in this study. The optimum design parameters of the honeycomb will be estimated using RSM technique in order to define the minimum transient response.

2. Experimental Test

The standard procedure examined by many investigators for different aspects is followed [19-26].

2.1 Details of specimens

Figure 1 shows a simple schematic of honeycomb sandwich. In this investigation, the face sheet and the core are made of aluminum alloy (AA3003) sheet, which is used for manufacturing the automotive and aircraft structures [27]. Via fixing the thickness of face sheet about (0.5 mm), the thickness of cell wall is 0.5 mm and cell side length at 10 mm. The specimen effective dimension was fixed at
(300 mm × 300 mm) for the simply supported boundary condition. The dimensions of sandwich specimens that were tested are given listed in Table 1.

Table 1: The dimensions of sandwich specimens. (all dimensions in mm)

| No. specimen | Material of core and face | Dimension of specimen (a×b) | Thickness of face sheet (h<sub>up</sub>=h<sub>lp</sub>) | core height(h) | specimen height |
|--------------|--------------------------|-----------------------------|-------------------------------------------------|----------------|----------------|
| 1            | AA3003                   | 300 x 300                   | 0.5                                             | 10             | 11             |
| 2            | AA3003                   | 300 x 300                   | 0.5                                             | 15             | 16             |
| 3            | AA3003                   | 300 x 300                   | 0.5                                             | 20             | 21             |
| 4            | AA3003                   | 300 x 300                   | 0.5                                             | 25             | 26             |

2.2. Experimental setup

Forced vibration with transient load test was implemented in this section. A specific test rig was manufactured with a special mechanism for applying a transient load. An instrumented hammer, Laser Displacement Sensor (Keyence lk-031), data acquisition Ni-6009 and PC have been used. LABVIEW software program are installed in PC to capture and save data of forced vibration test. Simply supported boundary condition is used for all sides of sandwich specimen. The setup of the test is revealed in Figure 2-A.

Transient force mechanism consists from: high-speed DC motor with gearbox and special pulley and hammer arm configuration. It is used for the experimental
application of a transient force for a short period as shown in Figure 1-B. Figure 1-B shows the special configuration of pulley and hammer arm; this configuration is adjustable to control the transient force magnitude and its time. Power supply model PS-305D provides the DC power to the DC motor. When the DC motor turns with a specific voltage, the pulley rotates with the attached the hammer arm after some rotation distance; the hammer hits the sandwich specimen instantaneously, as illustrated in Figure 1-C.

Exerting an impact force via a hammer to the specimen, the piezoelectric of the hammer generates a relevant voltage. This voltage is calibrated to force. Subsequently, Laser Displacement Sensor measures the response of vibrated sandwich plate. The signals from the Laser Displacement Sensor and the hammer are transferred to a PC by data acquisition NI-6009 that is interfacing with LABVIWE software. Then, Microsoft excel 2019 used to draw the results.

2.3. Experimental results

Beyond the excitation utilizing the shock hammer, the measured results transformed from the sensors into the computer by data acquisition. The measured results were the displacement vs time domain and the impact force depicted in Figure 3. Table 2 shows the maximum transient response (peak displacement) for the sandwich specimens.

3. Finite Elements Analysis of the Honeycomb Sandwich Structure.

Ansys software (version 18) employed to simulate the forced vibration of honeycomb sandwich under transient load as shown in Figure 4. Meshing the skins and core were performed separately, and the entire model of honeycomb plate was assembled.
A- Vibration rig

B- Components of the transient force mechanism

C- The impact hammer attachment with specimen

Figure 2: Forced vibration rig
The whole elements and nodes of FEM models are 105384 elements and 107500 nodes, respectively for the honeycomb sandwich plate. Solid 168 was used as element type of meshing process. The boundary condition in the finite element model simulation was simply supported for all edges. The used mesh has shown a good convergence of the results and gave a confidence of finite element modeling.

The modal analysis was performed implicitly to obtain the natural frequency and the results are transformed into the transient response analysis as the initial setting. The total time of simulation was 0.025 Sec, It is divided into 11 steps; each step of them has a time step equal to 0.00004. Amplitude vs. time of honeycomb sandwich was obtained as a result of the transient response as display in Figure 5.
Table 2. Shows the numerical maximum transient response (peak displacement) for all sandwich specimens.

Figure 4: FEM model of the honeycomb sandwich panel.

Figure 5: Numerical transient response

4. Comparison Study

Table 2 elucidates a comparison between the results of experimental tests and finite element model which created by Ansys software for model analysis of sandwich plate. Table 2 exhibits a good agreement between the results obtained for maximum transient response. Where, the discrepancy does not exceed 11.42%. Variation of the maximum transient response with the core height as plotted in Figure 6. Similarly, a plausible interpretation is that the discrepancy may be incorporated via
neglecting the adhesive films influence between faces and core of honeycomb, in addition to the probability of industrial defects of the sample.

It is obvious that the model of Ansys yields a good sandwich panel representation with the core of honeycomb for the forced vibration analysis under transient load, and it can be utilized for the intricate and big honeycomb structures, and that decreases the time and cost of analysis. Therefore, ANSYS software employing to study the effect other parameters on the sandwich behavior under transient load

Table 2: The experimental and numerical value of max. Transient response.

| h  | Experiential | Numerical | Error % |
|----|--------------|-----------|---------|
| 10 | 0.0135       | 0.0152    | 11.1    |
| 15 | 0.009951     | 0.010559  | 2.5     |
| 20 | 0.00624      | 0.007019  | 11.42   |
| 25 | 0.00446      | 0.004991  | 10.63   |

Figure 6: The experimental and numerical maximum transient response variation with core high.

5. Results and Discussion

For investigating the honeycomb parameters effects upon the maximum transient response behavior of honeycomb sandwich plate, a numerical solution is
Honeycomb parameters and its variation were listed in Table 3. The effected length and width of sandwich plate are \((L=300 \text{ mm})\) and \((b=300 \text{ mm})\), respectively.

Table 3 : Dimensions of honeycomb

| Parameter                  | Range (mm)   |
|----------------------------|--------------|
| Core high \((h)\)         | (5-20) mm    |
| Cell size \((a)\)         | (5-25) mm    |
| Cell wall thickness \((t)\)| (0.5 – 1.5) mm |

1. **Honeycomb parameters effect**

The results evaluated is maximum transient response \((X_{\text{max}})\) which is maximum peak in the transient response of the honeycomb sandwich plate with various cell size, cell wall thickness and core high.

Figure 7 shows that the maximum transient response has an inverse proportion with core high \((h)\). However, increasing the core high leads to reduce the maximum transient response. It is reduced from 0.0347987 mm to 0.0048175 mm when the core height increases from 5 mm to 20 mm for certain values of cell wall thickness and cell size of values 0.8 mm and 5 mm, respectively as shown in Figure 7- a.

Same behavior of maximum transient response with cell size \((a)\) was noticed. However, increasing the cell size leads to decrease the maximum transient response, it decreases from 0.04335175 mm to 0.03245175 m when the cell size increase from 5 mm to 25 mm at the core high and cell wall thickness are 5 mm and 1.5 mm, respectively, see Figure 7- c.

In contrary, cell wall thickness \((t)\) has a positive effect on maximum transient response; it is increasing when the cell wall thickness increases. It increases from 0.03479875 mm to 0 0.04335175 mm when the cell wall thickness increases from 0.5 mm to 1.5 mm at the core height and cell size are equal 5 as shown in Figure 7.
To understand the influence of honeycomb parameters on the maximum transient response of sandwich plate, Figure 8 shows the 3D surface plot of the variation of the $X_{\text{max}}$ with honeycomb parameters. The sandwich structure bending stiffness was highly affected via the core high and cell size of honeycomb. This is due to that the sandwich plate second moment of inertia can be highly influenced via the core height of honeycomb; therefore, the bending dynamic deflection is reducing with the increase of core high and cell size. On the other hand, the increasing of cell size leads to increase the core density, as result, the maximum transient response increase.

**II. Optimum Solution**

The main goal of this study is to find the optimal parameters that give the minimum transient response, thus avoiding the failure of this structure due to transient load. RSM was utilized to achieve the numerical optimization and to obtain the optimum factors. For establishing a new predicted model, an objective function, which is named “Desirability” to allow for a proper combining the goals, was estimated. This desirability must be maximized via the numerical optimization, and its range is from (0) to (1) [27]. In present analysis, Desirability equal to one which means that the optimization process meet the main goal. Figure 9 illustrates the optimum honeycomb parameters as 20 mm core high, 25 mm cell size and 1.5 mm cell wall thickness where minimum value of $X_{\text{max}}$ is 0.0019mm.
Figure 7: Numerical maximum transient response
Figure 8: 3D surface plot of maximum transient response in term of honeycomb parameters

a - $X_{\text{max}}$ in term of cell size and core high

b - $X_{\text{max}}$ in term of cell size and cell wall thickness

c - $X_{\text{max}}$ in term of cell wall thickness and core high
6. Conclusions

In this study, the forced vibration behavior of aircraft sandwich with honeycomb core has been investigated by the finite element modeling and experimental tests. Forced vibration been implemented. The effects of the core height, cell size, and cell wall thickness on transient response. Finally, a discrete optimization algorithm was conducted by DOE with SRM technology for obtaining the optimum design for the sandwich panel. Based on the results, the following conclusions can be drawn:-

1. Increasing the core high from (5 to 25) mm leads to reduce the maximum transient response percentage by about 82.78 % for certain values of cell wall thickness and cell size, which are 1.5 mm and 5 mm, respectively.

2. The variation of cell wall thickness from (0.8 to 1.5) mm leads to increase the maximum transient response by 16.023 %; at the core height and cell size are equal to 5mm.
3. Cell size has a negative effect on the maximum transient response; it is decreased by 25.14% percentage when cell size rises from 5 mm to 25 mm at the core high, and cell wall thickness are 5 mm and 1.5 mm, respectively.

4. Variation of the core height has a greater influence than the other parameters, where the cell wall thickness has a smaller influence than them.

5. Optimum values of honeycomb parameters that give the minimum transient response are 20 mm, 25 mm, and 1.5 mm for core high, cell size, and cell wall thickness, respectively, where the minimum value of transient response is 0.0019 mm.

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