PAMM · Proc. Appl. Math. Mech. **9**, 179 – 180 (2009) / **DOI** 10.1002/pamm.200910064

Free vibration of sandwich plates with impact-induced damage

Vyacheslav N. Burlayenko[1,*] and **Tomasz Sadowski**[2]

[1] Department of Applied Mathematics, National Technical University 'KhPI', 21 Frunze str., Kharkov, 61002, Ukraine
[2] Department of Solid Mechanics, Lublin University of Technology, 40 Nadbystrzycka str., Lublin, 20-618, Poland

Free vibrations of impact-damaged sandwich plates with honeycomb and foam cores are studied. It is assumed that damages caused by impact events are to exist before the vibration start and to be constant during oscillations. The influence of the impact damage modes involving the core crushing (planar damage), face sheets fracture (indentation) and the core to face sheets interface degradation (debonding) on the natural frequencies and associated mode shapes of the sandwich plates was investigated using commercially available finite element code ABAQUS.

1 Introduction

A major concern of sandwich materials, which are widely used in a structural design, is damage induced by impacts by foreign objects. Depending on the shape and size of impact objects, their mass and velocity as well as material properties and geometry of target sandwich structures the number of damage modes can be identified. Low velocity impact-induced damage is often difficult to detect (barely visible damage level), but it can considerably reduce the residual strength of the structure and may even lead to final failure mechanisms [1]. Therefore, inspection procedures and structural analysis are to be used to detect and predict damage extension within sandwich structures. One of non-destructive testing methods (NDT) of damage presence is the vibration-based damage detection technique that observes the natural frequencies and associated mode shapes of damaged structures. Numerical approaches based on the finite element method can be alternatively used along with complex and expensive experiments for acquisition of the structural vibration responses of damaged structures. Then, to establish an accurate and efficient dynamic models of sandwich structures containing defects caused by impact events is an important precondition in the context of the health monitoring and damage detection of sandwich structures.

Thereby, the main goal of the present study is to evaluate the sensitivity of natural frequencies and associated mode shapes of sandwich plates with respect to presence of the impact damage induced previously by low velocity impact events.

2 Finite Element Modelling

A number of assumptions were adopted in this study to analyze the influence of impact-induced damages on free oscillating sandwich plates: firstly, the impact damage is assumed to be predetermined before the vibrations start and to be constant during oscillations; secondly, the linear free vibrations are considered; thirdly, the complicated impact-induced damage geometry is idealized by a regular spherical form; fourthly, the honeycomb core is treated as an orthotropic homogeneous material, whereas an isotropic material presents the foam core.

The simulation of the free vibration responses of sandwich plates were carried out by using the commercial software ABAQUS/Standard Version 6.6 [2]. Continuum shell elements and solid elements were used for 3D modelling of the face sheets and the core, respectively. The homogenization technique based on the unit cell conception is used to treat the honeycomb core as a homogeneous orthotropic material with equivalent material constants and density. While the cores made of PVC foams of various densities were considered as homogeneous isotropic materials with data from the manufacturer [3].

The FE model taking into account geometric nonlinearity of the impacted region associated with the the residual face sheet indentation, the core crushing (cell buckling or core fracture) and the face sheet to core interface degradation (debonding), as well as reduced material elastic properties of the face sheet and the core was created. According to this the general mesh was subdivided into three different zones: fine meshed impacted region, the next zone surrounding the impacted region with gradually decreased mesh density, and the coarse meshed fully bonded zone in order to minimize CPU time. Multi-point constrains (MPC) were imposed in all nodes of elements between the face sheet and the core of the sandwich plate. The loss of adhesion between the elements in the debonded region was modelled by removing of those constrains. To prevent the debonded face sheet from overlapping with the core and to model opening and closing of the interfacial damage in the vibration state, 3D spring elements `SPRING2` were introduced between nodes of the debonded region. This element had zero stiffness in tension and very big stiffness in compression, if relative displacement goes to zero. The part of the core crushed due to the impact was simulated by reducing gradually the stiffness of the element along the damaged area. For this purpose the initial stiffness coefficients were multiplied by reduction factors.

* Corresponding author E-mail: burlayenko@kpi.kharkov.ua, Phone: +38 057 707 6032, Fax: +38 057 707 6601

3 Numerical results

The free vibration analyses were performed using the linear perturbation load step within ABAQUS software, where the Lanczos or the subspace iteration methods for eigenvalues extraction were used [2]. Effects of the impact damage on vibration responses of sandwich plates were assessed by comparing numerical results of free vibration analysis between intact and damaged plates. The sandwich plates subjected to the impact, that are used for the numerical analyses, are the same as those from the experimental observations reported in [4, 5].

Convergence studies were carried out at the beginning. A honeycomb sandwich beam with rectangular cross-section containing damage at the middle span is used for this purpose. The experimental data of the five first modes of this sandwich beam were obtained in [6] and, thereby, were used to compare against the numerical calculations performed with ABAQUS. The close results were observed. A comparative study with respect to the first two eigenfrequencies and mode shapes of an intact perfectly free honeycomb rectangular sandwich plate was fulfilled as well. Dimensions and material constants of the plate were accepted as those in work [7], where numerical and experimental results were found. The differences between results given in the Tanimoto's work and calculated with ABAQUS were within the engineering limit.

The effect of the indentation region size was further studied. For this purpose, simply supported rectangular honeycomb sandwich plate containing circular impacted zone at the center was considered. The size of the indentation region was defined as a planar damage parameter D, denoting the ratio of the area of indentation zone to the total area of the sandwich plate. The calculations showed that the natural frequencies as well as some mode shapes of sandwich plates subjected to the impact are shifted from intact plates and this effect on the higher modes is greater than the lower ones. Also, it does not exhibit monotonous trends as mode number increases. Moreover, the numerical results revealed that natural frequencies decrease with increases of the planar damage parameter. Besides, the frequencies change more rapidly as mode number increases. Although this trend of frequencies changing can be violated due to local thickening phenomenon caused by debonding, which in some cases makes the frequencies of the damaged plates even higher than intact ones. The decreasing of the natural frequencies with the increasing of the planar damage is greatly dependent on boundary conditions. It was found that the more strongly the plate is restrained, the greater this effect on the frequencies. To show the influence of the impact planar damage on different core systems, simply supported sandwich plates cored by PVC foam and aluminum honeycomb approximately the same weight, were considered. The shifting of the natural frequencies and mode shapes were found for both honeycomb and foam cores. However, the sensitivity of the frequencies concerning impacted zone presence for them was different. The stiffer honeycomb sandwich plate was observed as more sensitive to the impact damage.

Parametric studies over a wide range of sizes of various damage parameters produced by impact events were further carried out. It was assumed that the plate is impacted an object with a semi-spherical tip and the planar dimension of the impacted region is known and will be kept constant during all parametric calculations. The influence of a depth of the debonded zone on vibration responses of the damaged sandwich plates was firstly investigated. It was found that natural frequencies of the impacted plates slightly decrease with cavity depth increasing, but curvatures of their mode shapes slightly increase. This effect of an inexpressible changing of the lower frequencies keeps for higher ones as well. The same insignificant influence of the residual face sheet indentation depth on natural frequencies was obtained. Although the curvatures of the mode shapes were more changeable with the residual face sheet indentation increasing. Finally the influence of face sheet property degradation due to the impact on dynamic characteristics of damaged sandwich plates was examined. Six separate cases of face sheet properties were assumed as an inclusion at the impacted region corresponding to 100%, 80%, 60%, 40%, 20% and 0% of the virgin face sheet properties. The last case simulates a face sheet with open hole. One can be seen that appreciable decreasing of natural frequencies with increases face sheet degradation level takes place.

4 Conclusion

The main results of this study can be summarized as: 1) natural frequencies of sandwich structures subjected to low velocity impact will usually decrease due to loss in stiffness caused by damage; 2) the higher natural frequencies and mode shapes are more sensitive to the impact damage presence; 3) the sensitivity of natural frequencies and mode shapes are affected by boundary conditions and core type; 4) natural frequencies and associated mode shapes are the most sensitive to the planar size of the impact domain; 5) natural frequencies and associated mode shapes are poorly sensitive to the damage extended through the thickness and are moderately dependent on the face sheet damage.

References

[1] C. Kassapoglou, J. Comp. Technol. Res. **18**(4), 274–284 (1998).
[2] ABAQUS User Manual, Version 6.6, ABAQUS Inc., Pawtucket, Rhode Island, USA, 2006.
[3] DIAB International AB, Divinycell H: Technical Manual, Eastville Close, Gloucester, 2007.
[4] T. E. Lacy and Y. Hwang, Comp. Str. **61**, 115–128 (2003).
[5] V. Koissin and A. Shipsha, Comp. Sc. Techn. **68**, 57–74 (2008).
[6] H. Schwarts-Givil, O. Rabinovich, and Y. Frostig, J. Sand. Str. and Mat. **10**, 99–131 (2008).
[7] Y. Tanimoto, T. Nishiwaki, T. Shiomi, Z. Maekawa, Compos. Inter. **8**, 393–402 (2001).

