STRUCTURAL HEALTH MONITORING OF COMPOSITE SANDWICH BEAM WITH PIEZOELECTRIC PATCHES.

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Introduction

Light-weight structures are necessary components in modern state-of-the-art products in all sorts of industries. The increasing requirements on structural performance call for the usage of embedded sensors and actuators [2, 4], resulting in the construction of the so-called adaptive, smart or even intelligent structures that can respond to loading conditions in real time. This enables for instance to monitor the condition of the structure [3], suppress vibrations or to adapt the desired shape, provided that proper electronic control circuits are applied [1].

Sandwich structures are one of the most practical forms of composite light-weight structures. Their applications are found in civil and transportation industries, namely in aeronautics and shipbuilding. Their main advantages over the conventional materials are the high flexural stiffness ratio to weight, reasonable price and service life, or damping properties. Sandwich structures consist of soft flexible core enclosed in two outer skins. The skins carry the bending load, while the core transfers the shear forces and thus increases the flexural stiffness by holding the outer coating layers together.

The purpose of the presented research is to design a numerical model of sandwich beam with piezoelectric components which will be used for the identification of the structural properties and eventual damage using experiments and corresponding numerical simulations.

Experiment

A sandwich beam is investigated herein. The beam consists of foam core and composite skins (see Fig. 1). The foam is Rohacell and the skins are made of Panex unidirectional carbon-epoxy prepregs with fibers running along the axial direction. The thickness of the core is 5.6 mm, each skin is 0.7 mm thick and the beam's length and width are 450 mm and 50 mm, respectively.

At first, the two lowest eigen-frequencies of the beam were measured for free and cantilever (length 350 mm) configurations. The oscillations caused by impact were recorded with laser sensor. The frequencies were then extracted using the combination of Fourier transform and correlation techniques. In case of the free beam, the beam was supported at the estimated nodes of the modal shapes.

Secondly, a pair of collocated piezoelectric patches (DuraAct P876.A12) was glued to the skins close to center. The dimensions of each patch are 61×35×0.5 mm but the size of the active piezoelectric material, which is enclosed in a protective foil, is only 50×30×0.2 mm (see Fig. 1). The eigen-frequencies of the hybrid beam were measured again using the impact technique and also by exciting one of the patches (connected to signal generator and voltage amplifier) while the latter was used as a sensor. Good correspondence between the methods was found. Example of the obtained signal and its spectrum is shown in Fig. 2 and Fig. 3, respectively, and all the derived eigen-frequencies are in Tab. 1.

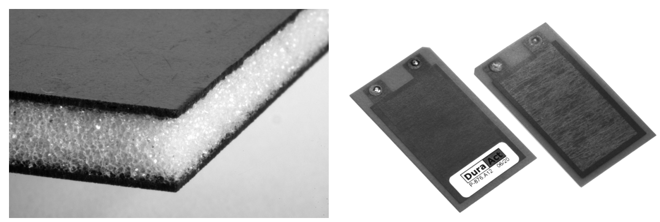

Fig. 1 Detail of sandwich and piezoelectric patches.

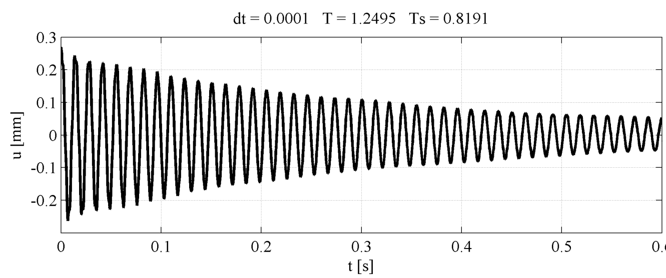

Fig. 2 Signal from piezoelectric sensor.

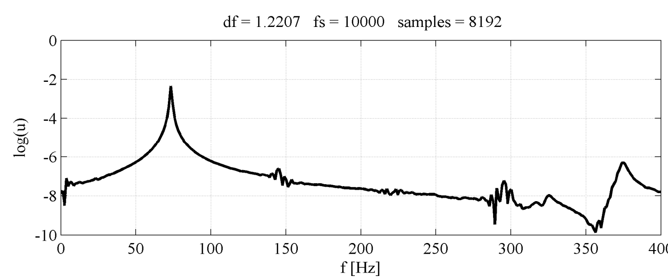

Fig. 3 Frequency spectrum obtained from patch signal.

Numerical simulation

Finite element analysis (FEA) of the investigated structure was performed in MSC.Marc software. The beam consisted of solid elements (with assumed strain option). The mesh of the hybrid beam is shown in Fig. 4.

In the beginning, the material properties obtained from manufacturer's data sheets or previously obtained tensile tests were used but the results of the modal analysis even in the case of the sandwich beam did not correspond well with the experimental data. Therefore, the identification of material parameters – axial Young's modulus of the composite material and Young's modulus and density of the foam – was performed. Optimization with gradient method was carried out in order to minimize the sum of all squared percentage errors for each eigen-frequency. When the identified properties were used in the model of the hybrid beam, the discrepancy was less than 2% compared to the experiment. The resulting frequencies are summarized in Tab. 1 with corresponding error values. Examples of the modal shapes of hybrid beam are in Fig. 5.

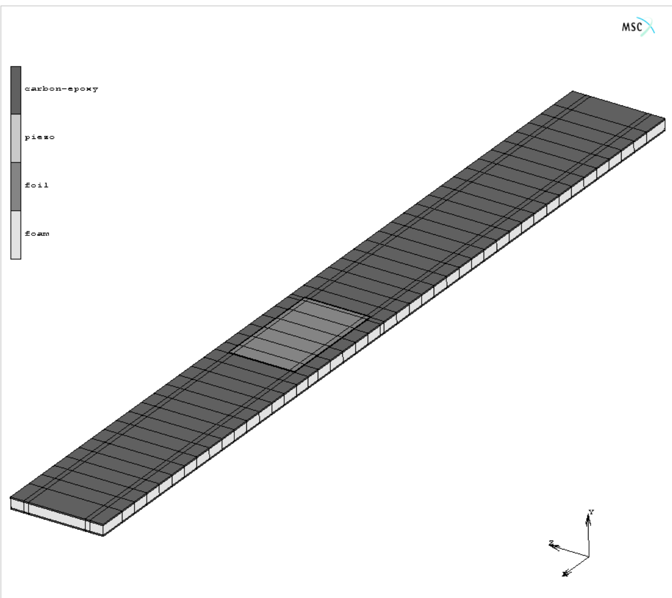

Fig. 4 Finite element model of hybrid sandwich beam.

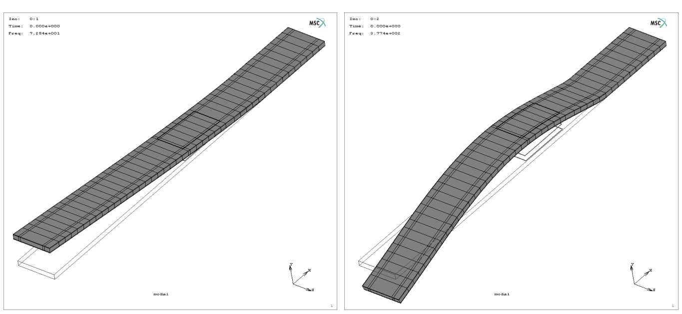

Fig. 5 First two eigen-modes of cantilever hybrid beam.

Tab. 1 Comparison of measured (EXP) and calculated (FEA) eigen-frequencies of both investigated beams.

Boundary condition		Free		Cantilever		
Eigen-frequency		f_1 [Hz]	f_2 [Hz]	f_1 [Hz]	f_2 [Hz]	Δf_{max} [%]
Sandwich	EXP	330	770	73.5	408	–
	FEA	330	770	73.1	415	2.0
Hybrid	EXP	313	745	73.2	375	–
	FEA	312	743	72.5	377	1.1

Damage simulation

As the numerical model of the sandwich structure has been prepared a simulation of structural damage and its influence on the modal properties was carried out in order to analyze the possibility of structural health monitoring. The damage of the composite upper skin (total rupture) in selected location was simulated by node-splitting (NS) and stiffness degradation (SD – Young's modulus decreased to 10% of its original value) approaches. The dependency of the eigen-frequency values on the position of the damage in the case of cantilever beam (measured from free end) is displayed in Fig. 6. The experimental damage analysis will be performed in future.

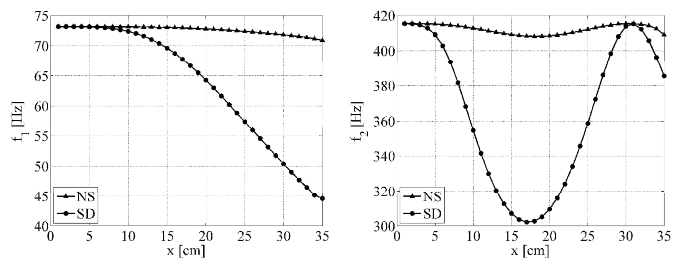

Fig. 6 Influence of simulated damage on values of the first (left) and second (right) eigen-frequencies for cantilever sandwich beam.

Conclusions

The methodology to set-up a reliable numerical model of a sandwich structure and hybrid structures is presented. The crucial material properties are identified with the use of experimental and numerical analyses and optimization method. The piezoelectric patches proved to be good source of information for future monitoring applications.

Acknowledgements
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References

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