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AN IMPROVED DAMAGE INDEX FOR NON-DESTRUCTIVE TESTING OF A HONEYCOMB SANDWICH PANEL USING GUIDED WAVES

Lifu Wang[1], Yichi Zhang, Bhav Patel, Leonardo Araque, Steffen Tai, Ajit Mal
University of California, Los Angeles
Los Angeles, CA

Fei Gao[2]
Beihang University
Haidian District, Beijing, China

ABSTRACT

Honeycomb sandwich panels (HSP) are widely used in the aerospace industry due to their high strength to stiffness ratio. Conducting non-destructive evaluation (NDE) of HSP is a topic of great current interest. However, the geometric complexity of honeycomb core makes NDE of HSP extremely difficult. Guided ultrasonic waves are ideal for large scale testing due to its large range and high sensitivity to defects in their path. Previous research has been successful in detecting disbonds at the core-skin interface using guided waves, but few of them have focused on the detection of disbonds at the bottom interface. An improved NDE method for detecting disbonds at the top and bottom interfaces is proposed based on experimental results. By applying excitation signals for different frequencies, the responses at the top and bottom skins are compared and analyzed. The response in a specific frequency range is further studied by introducing disbond at the bottom interface. It is shown that some components of the recorded signal in specific frequency range are more sensitive to the disbond and can be related to the size of the disbond. Finally, an improvement of the conventional damage index based on propagation velocity of guided waves is provided. The results show that the optimized damage index greatly improves the resolution and flexibility of NDE on HSP.

Keywords: honeycomb sandwich panel, non-destructive evaluation, guided waves, damage index, excitation signal design, disbond

1. INTRODUCTION

Guided wave propagation problem was first investigated by H. Lamb in 1917 [1] and later introduced into composite material [2] and NDE. For a long time, HSP has been considered and studied as a laminate. Features for waves propagation in HSP are studied by many researches [3] [4]. The paper explores the possibility of increasing the resolution in NDE of HSP. Later research is done for detecting disbonds in HSP using mode conversion characteristics of ultrasonic guided waves [5]. Another approach to analyze wave propagation in HSP is the conventional finite element method [6]. The results show that there is a complicated frequency-dependent mechanism of wave propagation in HSP. Part of the ongoing work is to find the best excitation signal and the damage index most sensitive to disbond. With this combination, improved damage index is used for damage detection using a sparse sensor array with the conventional Delay and Sum (DS) algorithm and Reconstruction Algorithm for Probabilistic Inspection of Damage (RAPID). Finally, image resolutions are compared for different damage index graphs.

2. MATERIALS AND METHODS

Two different types of HSP are used for the experiment: one woven CFRP/aluminum core symmetric HSP, and HSP from the Airbus A330 elevator. For wave propagation analysis, a chirp signal that ranges from 30kHz to 500kHz is applied to the elevator for more input energy. With confirmation of linearity, narrowband signals are extracted from the broadband signal.

2.1 Test-plate

The HSP (914.4 x 914.4 x 16.26 mm) used in this study consists of a 12.7-mm-thick aluminum honeycomb core embedded between two 1.78-mm-thick composite facesheets (material properties shown in Table 1). The honeycomb core is made of 5052 aluminum and has a hexagonal cell structure of 12 mm in width (material properties shown in Table 2).

TABLE 1. EFFECTIVE MATERIAL PROPERTIES FOR WOVEN CARBON FIBER COMPOSITE FACESHEETS

E_{11} (GPa)	E_{22} (GPa)	E_{33} (GPa)	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)	ν_{12}, ν_{21}	ν_{31}, ν_{32}	ν_{13}, ν_{23}
38.8	38.8	9.77	14.7675	2.937	2.937	0.3137	0.0816	0.324

[1] Contact author: kiriswang2012@gmail.com
[2] Contact author: youfeigao@buaa.edu

TABLE 2. EFFECTIVE MATERIAL PROPERTIES FOR 5052 ALUMINUM HONEYCOMB CORE

E_{11} (GPa)	E_{22} (GPa)	E_{33} (GPa)	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)	ν_{12},ν_{21}	ν_{31},ν_{32}	ν_{13},ν_{23}	ρ (kg/m^3)
3.43×10^{-3}	3.43×10^{-3}	2.99	0.86×10^{-3}	0.413	0.413	1.00	0.33	3.79×10^{-4}	114.1

2.2 Experiment Set-up

Laboratory experiments are carried out on the HSP using disk-shaped Piezoelectric Transducers (PZT), which are bonded to the plate with epoxy. The detailed properties of these PZTs are shown in Table 3. The schematic of the experiment set-up is shown in Figure 1 and Figure 2.

TABLE 3. MECHANICAL AND ELECTRIC MECHANICAL PROPERTIES OF PZT

Transducer Type:	PI company Piezoceramic Disk, PRYY+0442.
Outer Diameter:	10 mm
Thickness:	1 mm
Resonant Frequency (radial):	227 kHz
Resonant Frequency (thickness):	2 MHz
Coupling Factor (radial)	0.56
Coupling Factor (thickness)	0.46

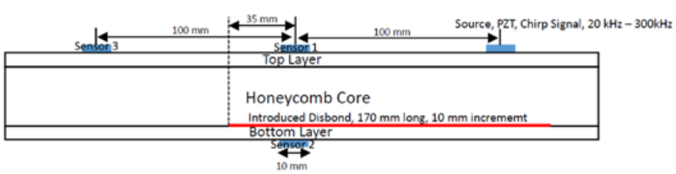


FIGURE 1. EXPERIMENT SET-UP FOR STUDYING WAVE PROPAGATION IN HSP (SIDE-VIEW)

A disbond is introduced at the bottom layer of HSP in 10-mm increments. The baseline signal recorded without disbond is named "sequence 0" and with the introduction of disbond, the sequence number represents the number of 10-mm increments of disbond, e.g. sequence 5 signal is when a 50-mm disbond is present.

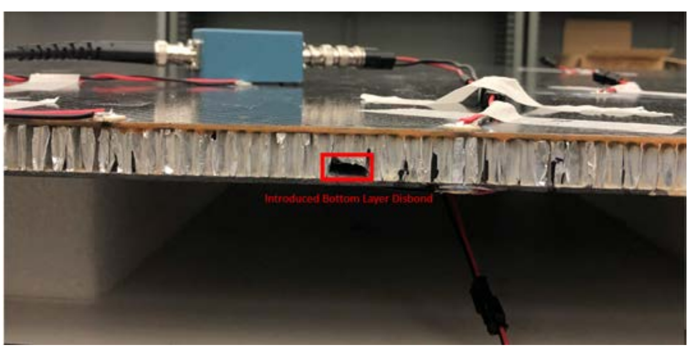


FIGURE 2. HSP AND BOTTOM INTERFACE DISBOND

3. RESULTS AND DISCUSSION

3.1 Wave Propagation with Bottom Interface Disbond

Different excitation signals are applied to the honeycomb sandwich panel without the introduction of disbond. It is shown that there are at least three different phases in a signal. Phase one happens when the frequency is relatively low. As an example, the responses of 40-kHz 9-cycle Hann-windowed signals on top and bottom surfaces are presented below:

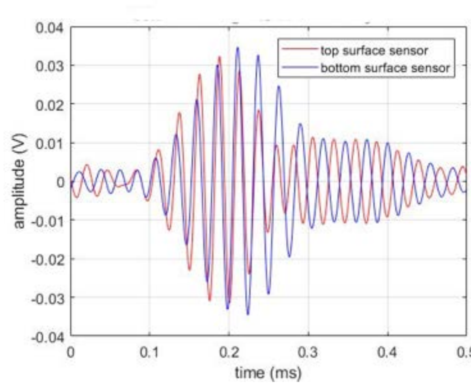


FIGURE 3. TOP AND BOTTOM SIGNAL COMPARISON FOR LOW FREQUENCY RANGE

The top and bottom surface signals have comparable amplitudes and phases. However, the low frequency response has very long time duration and long wavelength. Therefore, it is not applicable to the testing of small defects.

As the frequency increases, the packets become clearer and two different modes are can be seen in the graph.

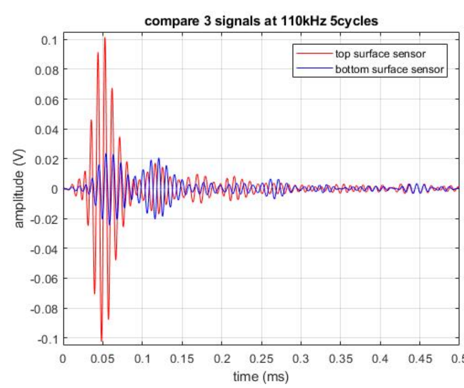


FIGURE 4. TOP AND BOTTOM SIGNAL COMPARISON FOR INTERMEDIATE FREQUENCY RANGE

The 110-kHz 5-cycle Hann-windowed signal is extracted from the broadband signal. The first arriving mode has a larger amplitude for the top surface response than the bottom surface response. Apart from that, the top surface response has a clearly higher group velocity than the bottom surface response. However, for the second packet, both top and bottom surface responses are almost the same in magnitude with the same time of arrival (ToA).

With the multimode characteristic, the 110-kHz 5-cycle Hann-windowed signal is considered to be a strong candidate for detecting damages. For experiment sequence 0-2, the signal comparison between top and bottom surfaces is shown in Figure 5.

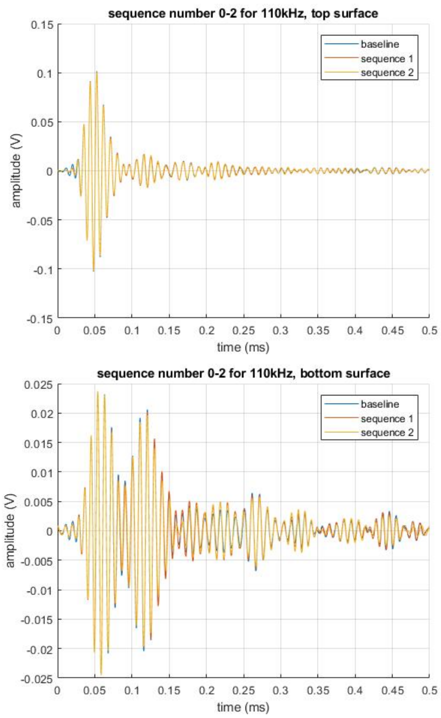
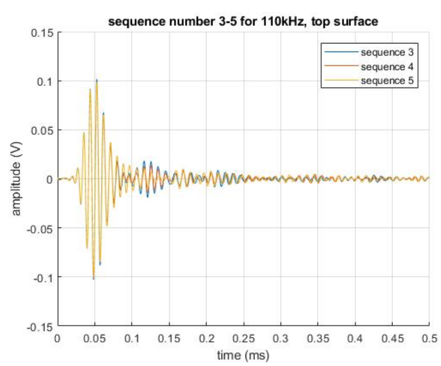


FIGURE 5. SEQUENCE NUMBER 0-2 SIGNALS, TOP SURFACE AND BOTTOM SURFACE

In Figure 5, the residual signal can only be seen for the bottom surface, which means that for the HSP bottom surface disbond, the signal difference at this frequency is hardly detectable.

However, when the disbond passes the sensors, with experiment sequence 3-5, the results for the top and bottom surface responses are shown below:



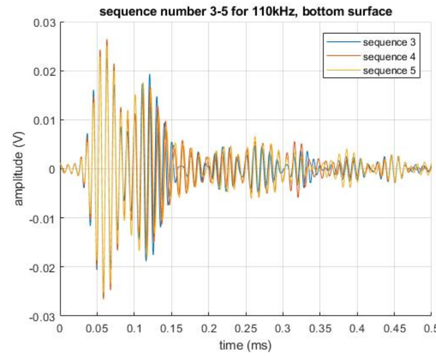


FIGURE 6. SEQUENCE NUMBER 3-5 SIGNALS, TOP SURFACE AND BOTTOM SURFACE

In Figure 6, for the transmission signal, the second packet on the top surface is way more sensitive to the bottom interface disbond, while the bottom surface shows clear phase shift.

4. CONCLUSION

Ongoing experiment results show that the wave propagation inside HSP is highly dependent on the frequency range. With 110-kHz excitation signal, the transmission signal presents changes in the second packet, which can be further used as a damage index for the bottom interface disbond.

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