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Defect Detectability in Composite Plates with Variable Thickness Using Lamb Waves

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Abstract. In this work thermoplastic composite plates with constant and variable thickness were subjected to multiple impact damages. The network of PZT transducers was utilized to excite Lamb waves at different frequencies. Influence of the variable thickness on the guided wave propagation was evaluated and compared to the constant thickness plate. Optimal frequency was chosen from the point of a clear mode shape. Signals before and after impacts were evaluated using two parameters: correlation coefficient and time delay of the particular wave mode. Finally, RAPID (Reconstruction Algorithm for the Probabilistic Imaging of Damage) algorithm was used to visualize impact damages. Damage induced time delay parameter showed correct impact localization on both plates. However, time delays measured on the variable thickness plate were about four times smaller.

Introduction

Defect detectability plays an essential role in the area of non-destructive testing (NDT) and structural health monitoring (SHM) and ultrasonic guided wave testing is considered as one of the promising methods [1]. Aircraft composite parts suffer from impact damages which can consequently cause failure threatening the structural integrity. Therefore, new composite materials and structural parts are tested for impact damages that should be reliably detected using different NDT and SHM systems. In the area of NDT ultrasonic phased array methods and laser shearography belong to the reliable detection and visualization techniques of impact damages [2, 3]. SHM research area is focused on the guided wave testing, measurements using FBG (Fiber Bragg Grating) sensors, and also a promising work regarding electrical resistance tomography (ERT) have been done lately [4].
Algorithms for impact damage visualization by means of guided waves are described for example in [1, 5]. RAPID algorithm is probably the most exploited one. It enables to use any signal parameter evaluating signal before and after the damage [6, 7].

Materials and methods

Test specimens were manufactured from carbon composite with thermoplastic matrix ABS5045. The first plate (P1) had dimensions of 280×530 mm and thickness of 2.2 mm and the second plate (P2) had dimensions of 240×615 mm and thickness of 3.5-4.3 mm. The second plate with variable thickness was stacked from 4 or 5 glass layers and 10 or 15 carbon layers according to the thickness. PZT disc transducers (Stem, Inc.) used for guided wave measurements were placed along the edges and served as both actuators and sensors. Measurements were performed before and after each impact. Standard 5-cycle sine wave modulated by Hanning window was used as the actuation signal for the frequencies of 40, 50, 60, 70, 80, 100, 150, 200, 250 and 300 kHz. The frequency of 50 kHz was chosen based on the clear A0 mode shape (no distorsion of the wave packet).

Signal processing

Impact damage evaluation was performed using 3 methods. All of them are based on the signal comparison of all the actuation–sensor pairs before and after the damage. The first one exploited SW Acess provided with the Acellent Scan Genie II measuring device. The correct determination of the impact location was unconsistent. It was not possible to choose one frequency and methodology to correctly locate all the impacts. Therefore, the RAPID algorithm was programmed in order to use arbitrary signal parameters. Correlation coefficient and time delay was used as a damage index (DI). Evaluation of the wave time delay was performed according to the following steps:

1. Group velocity determination of the A0 mode in all actuator–sensor directions
2. Extraction of the particular wave modes
3. Time delay determination of the maximum amplitude of the relevant waves

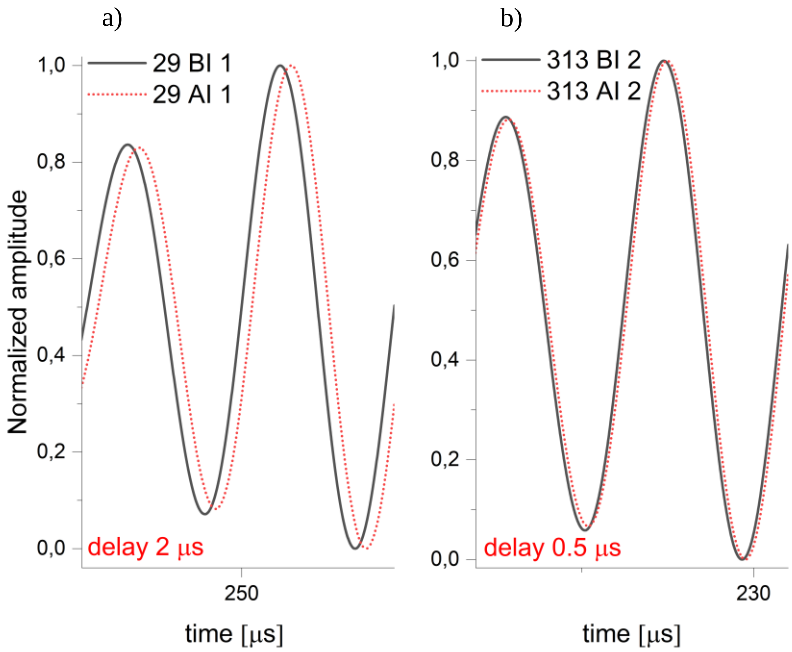

Fig. 1: Comparison of the wave delay for a) constant thickness plate and b) variable thickness plate

Results

The comparison of the three methods is shown in Fig. 2 and Fig. 3 for the constant thickness plate and variable thickness plate, respectively. Designations a), b), c) denote evaluation using SW Acess, RAPID - Correlation coefficient and RAPID - Wave time delay, respectively. The time delay parameter showed correct localization of all impacts. The real impact location is marked with the red cross. Delays for the variable thickness plate were about 4 times smaller than for the constant thickness plate (Fig. 1). However, normalized values are used in the RAPID algorithm, so the impact is clearly visualized.

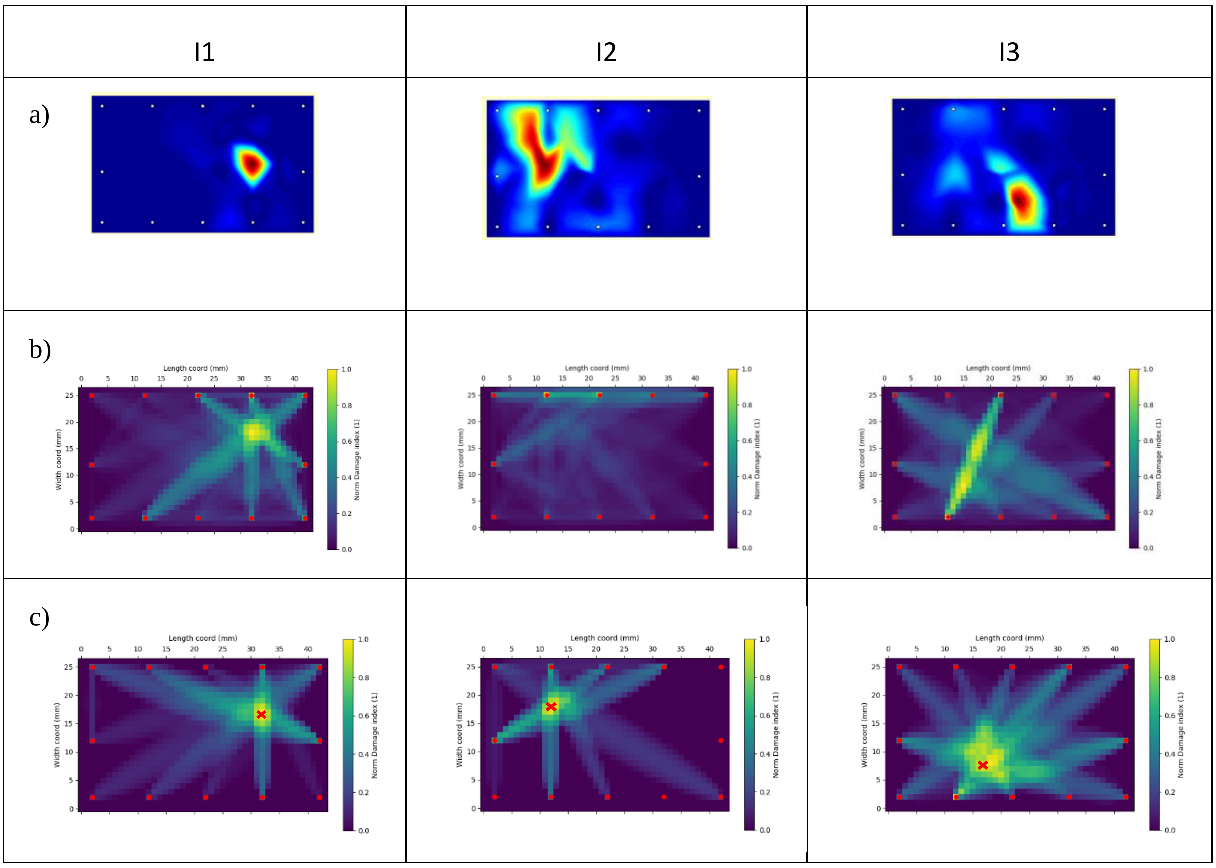

Fig. 2: Comparison of impact evaluation for the constant thickness plate using a) SW Acess, b) RAPID - correlation coefficient, c) RAPID - time delay

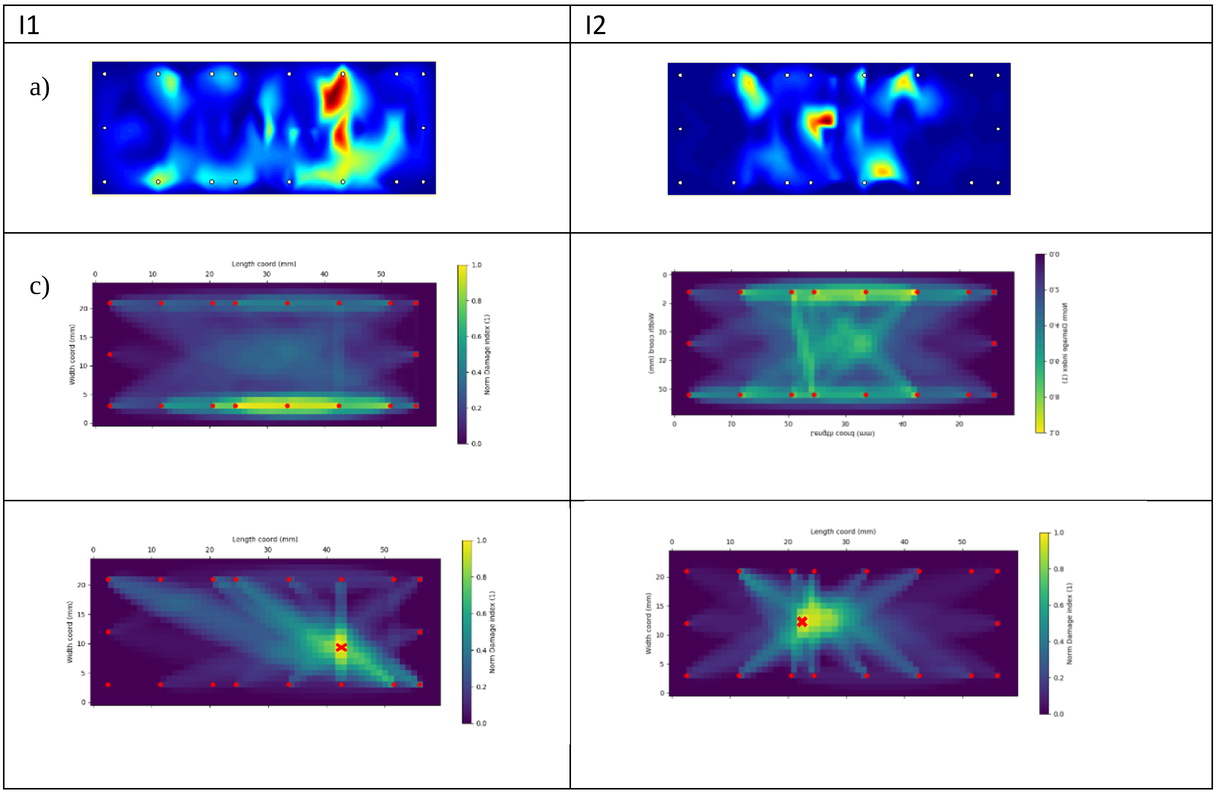

Fig. 3: Comparison of impact evaluation for the variable thickness plate using a) SW Acess, b) RAPID - correlation coefficient, c) RAPID - time delay

Conclusion

Two thermoplastic composite plates were subjected to multiple impact damages. Three methods were used to damage evaluation. SW Acess with unknown algorithm and RAPID algorithm with two different DI (correlation coefficient and time delay) were used to evaluate impacts. Results using SW Acess did not locate correctly all impact damages at the given frequency so this method was not effective. Correlation coefficient used in RAPID algorithm did not show correct results either. Time delay extraction of the relevant waves detected correctly location of all 5 impacts. However, time delays measured on the variable thickness plate had four times smaller values than on the constant thickness plate. Normalized values in the RAPID algorithm enabled clear visualization. Significantly smaller time delays are probably caused by the material itself. The variable thickness plate contains multiple glass layers which influence the guided wave propagation.

It can be concluded that extraction of the particular wave is essential, especially for the variable thickness plate. Using the same time window length for different actuator-sensor distances include multiple wave reflections which can cause false damage indications.

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