Impact damage detection in light composite sandwich panels

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Abstract

The paper presents a comparative study on impact damage detection in light composite sandwich panels. Three different nondestructive testing methods were used to characterize damage in a test specimen that resulted from a controlled low velocity impact event. The analyzed test methods include the ultrasonic c-scan, vibrothermography and shearography. All considered techniques were positively verified for detecting damage in a sandwich panel. The paper gives details about the experimental procedures and equipment required to perform the tests.

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1. Introduction

Composites are multiphase materials that are designed to obtain a desirable combination of the best properties of the constituent phases. Structural composites, which include laminates and sandwich panels, are widely used in many engineering areas including aerospace, automotive, energy industries, civil engineering and sporting goods [1,2]. Sandwich panels, which are in the scope of the present work, have desirable mechanical properties combining high strength and stiffness with low densities. The face sheets of sandwich panels are made of stiff and strong materials, such as steel, aluminum alloys or carbon fiber reinforced polymers (CFRPs). They are designed to withstand the tensile and compressive stresses that result from the applied loads. The core material on the other hand needs to be lightweight and typically has low modulus of elasticity. There are different materials that are used for

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this purpose which include rigid polymeric foams, wood (balsa), honeycomb and chiral structures [2]. Sandwich panels have desirable mechanical properties combining high strength and stiffness with low densities. This in combination with their flexibility in design makes them an interesting construction material. There are however some important drawbacks of sandwich panels. One of the most important being their susceptibility to incur impact damage. Because structural integrity of sandwich panels is of major concern in engineering applications, efficient nondestructive testing (NDT) methods are necessary to assure the desired level of safety. There are numerous experimental techniques to reveal structural damage in composites including the classical NDT methods [3-5] and non-classical nonlinear approaches [5-10]. This paper considers the use of three methods: ultrasonic c-scan, vibrothermography and shearography. A comparative test was performed on a sandwich panel with barely visible impact damage.

2. Test specimen

The test specimen was a light composite sandwich panel. The overall dimensions of the panel were 400×120×13.2 mm, as shown in Fig. 1. The face sheets were made of Seal Texipreg HS300/ET223 prepreg system, with [0/90]_3 ply stacking sequence. The total thickness of the face sheet laminate was 1.6 mm. The core material was a closed cell PVC foam DIAB Divinycell HP60 with the total thickness of 10 mm.

![Fig. 1. Geometrical dimensions of the test specimen.](image)

The panel was damaged in a low velocity impact event. Impact testing was performed using an instrumented drop-weight testing machine. An impact of 9.8 J energy was introduced at the central position of the panel, as shown in Figure 1, which resulted in a BVID in the upper face sheet of the panel.

3. Measurement techniques

Three measurement techniques were used to evaluate the damage caused by the impact, namely (1) ultrasonic c-scan, (2) vibrothermography and (3) shearography.

3.1. Ultrasonic C-Scan

Ultrasonic measurement in the pulse-echo mode is based on a principle that a pulse of energy is sent into the material and the reflected echoes are recorded as shown in Fig. 2a. Depending on the experimental configuration one or two ultrasonic transducers may be used to send and record the signals. At least two echoes will be present in the measured signal coming from the reflections from the front wall and back wall of the material (Fig. 2b). Internal flaws may be identified as additional echoes in measured signals. These additional echoes will be located between the two main echoes. This type of measurement is especially useful when only one side of a material is accessible.
C-scan is a two dimensional presentation of ultrasonic data displayed as a planar view of a test piece where colors represent the gated signal amplitude (Fig. 2c.). The data is acquired by performing pulse-echo ultrasonic measurements in a number of points on the test sample. Knowing the x-y coordinates of measurement locations the individual measurements are merged to create a c-scan image.

In the present study the ultrasonic c-scan technique was used to test the impacted sandwich panel. The panel was immersed in water and scanned at normal incidence in pulse-echo mode by using a focused broadband transducer (3.2 mm diameter, 18 mm focal length) with a center frequency of 22 MHz. The ultrasonic testing system consists of a 0.025 mm resolution scanning bridge, a 150 MHz Krautkramer HIS2 ultrasonic pulser/receiver, and a 500 MHz Hewlett Packard 54520A digital oscilloscope used for acquisition of the ultrasonic echo signal. A personal computer with in-house developed software controls the scanning sequence and triggers the pulser/receiver for emission of ultrasonic pulses and acquisition of reflected echoes. During scanning the complete ultrasonic waveform is digitized at each point, stored in the internal buffer of the oscilloscope and, once the buffer is filled, transferred to the computer hard disk. In this way a database representing the three-dimensional internal structure of the sample is built which allows post-processing of data for reconstruction of delaminations on an interface-by-interface basis by selecting the appropriate through-thickness depth. The ultrasonic data were acquired with a scanning resolution of 0.2 mm (both in x and y direction)

3.2. Vibrothermography

Vibrothermography is an active thermographic nondestructive testing (TNDT) technique with external excitation [11,12]. The technique is also referred to as ultrasonic thermography or thermosonics. In vibrothermography, the external energy is delivered to the structure by ultrasonic vibrations, as shown schematically in Fig. 3. Typically a burst ultrasonic signal with the duration less than a few seconds is used to excite the test sample. High frequency vibrations introduced to the volume of the material cause energy dissipation at discontinuities (i.e. cracks, delaminations) and mechanical energy is converted into heat. Thermographic camera is used to record the surface temperature distribution of the sample. Inference about the existence of damage is performed on the basis of the measured temperature distribution. Vibrothermography is a dark field method where the source of heat is the damage itself, which simplifies the data processing phase to a great extent.

In the present study the MONIT SHM vibrothermographic test system using the 35 kHz ultrasonic excitation column was used [13]. FLIR Silver 420M photon detector camera was used to acquire thermal image sequences. The transducer was exciting the plate for 500 milliseconds and thermographic camera was acquiring the signal at 100 Hz frame rate for 3 seconds.
3.3. Shearography

Shearography is the common name for the digital speckle pattern shearing interferometry (DSPSI) [14]. It is a full-field nondestructive testing technique that can be used to screen the structural components for surface irregularities and internal defects. Schematic illustration of shearography test setup is shown in Fig. 4. The structure being studied is illuminated by a coherent laser light and a stochastic interference pattern is created on its surface. The image of the test object is sheared to create two superimposed images and a digital camera is used to record the resulting shearogram. The speckle pattern changes when the object is deformed, typically due to mechanical or thermal load. The two speckle patterns (in the unloaded and loaded states) interfere to produce a fringe pattern that provides information on the first derivative of surface deformations. Shearography with thermal excitation is a noncontact measurement technique with a relatively simple hardware setup.

In the present study the Steinbichler ISIS 1100 system was used [15]. The system uses thermal excitation and consists of a sensor with attached heating lamps mounted to a tripod. The sensor has a central shearing optics unit combined with a phase shifter and an attached illumination segment with symmetrically arranged laser diodes. On either side of the laser diode segment, powerful heating lamps have been added to allow for homogeneous thermal loading of the object under investigation. The value of 5 mm vertical shear was used to test the analyzed composite plate.
4. Results and conclusions

All three test methods gave satisfactory results both in damage localization and size estimation. Results of all techniques are shown in Fig. 5. The area covered by the images corresponds to the NDT FOV area marked by a dotted rectangle in Fig. 1. The c-scan image in Fig. 5a shows the amplitude of the signal reflected by the delamination at the 90°/0° interface farthest from the impact side. The estimated size of the BVID was equal to 580 mm². The image in Fig. 5b shows temperature map on the surface of the sample 500 milliseconds after the start of ultrasonic excitation. The initial temperature distribution measured just before the start of the experiment was subtracted in order to observe only the temperature generated in the sample during the test. The estimated size of the BVID was in this case equal to 640 mm². Fig. 5c. shows the result of shearography test. The presence of damage can be clearly identified, the estimated size of BVID was equal to 590 mm². Among the three approaches the c-scan was the most time consuming and required the immersion of the panel in water during testing. However, by appropriate signal gating we can get a much more detailed information about the delamination at different depths. Vibrothermography and shearography offer much shorter testing times (less than few minutes) and can be applied the field when the panel is mounted on the structure. The drawback is that the exact shape and depth of the delamination is more difficult to evaluate.

![Fig. 5. Results of nondestructive tests performed on a sandwich panel with barely visible impact damage with use of the three analyzed test techniques: (a) ultrasonic c-scan, (b) vibrothermography and (c) shearography.](image)

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