APPLICATIONS OF INFRARED THERMOGRAPHY IN NDE OF SANDWICH COMPOSITE STRUCTURES

Viorel ANGHEL, Nicolae CONSTANTIN, Andreea BORÎTU, Mircea GĂVAN, Ștefan SOROHAN

Laboratory for Integrity Evaluation of Composite Structures, The University “Politehnica” of Bucharest
email: anghelviorel@resist.pub.ro

Composite materials are increasingly deployed in many industrial fields, into both the civilian and military sectors. Nondestructive evaluation (NDE) and damage assessment is essential for keeping high reliability of this class of materials. Several NDE/NDT methods are currently used in order to evaluate the structural integrity of different structures, in the manufacturing process or in maintenance operations. Specific problems of sandwich structures are related to water ingression and foam core-skin interface or bonding state. Other studies concern flaws as those induced by in service low velocity impact events. The Laboratory for Integrity Evaluation of Composite Structures (LEISC) currently uses ultrasonics and infrared thermography (IRT) in NDE of different type of structures. This paper presents several examples, showing the capability of IRT as a NDE method in the assessment of sandwich composite structures, for highlighting type and severity of defect.

Keywords: NDE, Infrared Thermography, Sandwich Structures.

1. INTRODUCTION

Sandwich structures are increasingly used in different applications due to their multifunctional capabilities: high stiffness/strength to weight ratios, good fatigue properties, excellent thermal/acoustic insulation, good corrosion resistances and energy absorption properties etc. There are also some disadvantages related to their sensibility to failures by localised loads (like low velocity impact loads) or due to the geometric and material discontinuities. They are also highly vulnerable to face/core delamination or debonding. For these reasons, an important issue related to the sandwich structures is the monitoring of structural integrity during the manufacturing process or along the maintenance operations. Different type of NDE methods can be used, a relatively new one being InfraRed Thermography (IRT). This is a non-contact, fast and portable method, giving good results for different type of materials and structures. There are two major variants in which the method can be used, namely the passive and active techniques. Our laboratory currently uses two active IRT inspection techniques: Pulse Thermography (PT) and Lockin Thermography (LT). In the case of composite materials, with generally small heat conductivity, the structure has to be heated with long pulses, up to several tens of seconds, and then the decay of the surface temperatures is recorded and analysed with specific techniques. In Lockin thermography, the object is heated using the same energy source with a harmonic (sinusoidal) heat flow over an even longer period of time. Basic concepts related to active Lockin and Pulse thermography are given in [1].

In the active methods, a heating source generates a thermal wave at the surface of the inspected structure, which propagates inside the material by diffusion. This wave will be reflected by flaws, such as voids, delaminations etc. altering the diffusion rate. As a consequence, the damaged areas appear as areas of different temperature with respect to the surrounding sound areas. The method is called by reflection, when the heating source and the IR camera are located on the same side of the inspected structure, and by transmission, when these are located on opposite sides with respect to the inspected sample. The appearance of a damaged zone is like a hot spot in the case of reflection configuration and a cold spot when the configuration is by transmission. Our experiments were performed using the reflection configuration setup. Generally speaking, IRT is a NDE method consisting in the monitoring of a target temperature field, by
producing visible images (thermograms) of invisible recordings (to our eyes) of the infrared light emitted by the inspected items, according to their thermal state. The key device of IRT is the infrared camera which is able to detect the thermal radiation. The obtained pictures (thermograms) are influenced by the presence of different subsurface defects. In fact, the interpretation of thermograms can contribute to detection, localization and assessment of damaged areas in a similar manner as other NDE techniques as ultrasonics or X/γ radiography, keeping some advantages, especially in the case of composite materials.

The purpose of this paper is to present several applications concerning the use of IRT in the evaluation of the integrity state of sandwich structures, highlighting some specific problems and flaws of this type of structures.

2. DESCRIPTION OF THE EXPERIMENTAL EQUIPMENT AND TECHNIQUE

The equipment able to perform NDE by using active thermography consists in an excitation source (power electronics module with a panel with 4 halogen lamps - actual power 2.6 kW). The power electronics module forms a functional unit with the IR-NDT software and the IRX-box, aimed to control the connected lamp panel. IR-NDT is advanced software containing various functions for easy, versatile use, especially for thermograms post-processing. The non-linear electrical signal for the modulation of the heat source is generated by the IRX-box. The modulation signal controls the power electronics and thus the power output of the heat source [2]. A view of the integrated equipment is presented in figure 1. It uses a Flir A 40 M infrared camera, which has an uncooled microbolometer detector with a frame rate of maximum 50 Hz and a focal plane array (FPA) pixel format of 320(H) × 240(V). The infrared detector absorbs the IR energy emitted by the inspected sample and converts it into electrical signal (current or voltage). This camera works in the so called long spectral IR range 7.5-13 μm and has a thermal sensitivity 0,08ºC [3]. The operating environmental temperature range is -15°C to +55°C and operating humidity range is 20-95%. Three standard temperature ranges can be used -10 oC to 55oC, -40ºC to +120ºC or 0ºC to +500ºC. The measurement range and settings for the noise reduction are then setup. The lowest range (-10ºC to 55ºC) allows the lowest noise level and was used in all test cases for the sandwich plates presented in this paper.

Figure 1. The setup for active infrared thermography.
3. RESULTS AND DISCUSSION

A specific application of IRT for sandwich structures is detection of water ingression, like the detection of moisture penetrated in aircraft structures. In this case, no active techniques are necessary in order to highlight the usually cold spot due to the water presence, in any form. The sample is a 15 cm x 10 cm x 5 cm sandwich type plate with faces in composite GFRP (4 layers of a total thickness 2 mm) and polyurethane foam core 46 mm thick. Some cold water was injected in the space between the upper face and core. Using the infrared camera, a live view of the plate is presented in figure 2b. The lowest temperature is in the region with the water ingression and the hot spot is due to reflexion of a heating lamp.

Another sandwich configuration is that presented in figure 3. A similar type of sandwich plate specimen was manufactured, but a frictionless thin sheet was included in order to create an artificial delamination between a face and the core. The analysis was performed using the active Lockin method.

The parameters of the Lockin analysis were: the excitation period - 25 [s], number of periods - 4, amplitude low - 0 [%], amplitude high - 100 [%], frequency image acquisition - 50 Hz, acquisition duration - 100 [s]; in total 5000 images/frames. The figure 3b shows a thermogram obtained by the harmonic approximation (frequency) analysis method and the corrected phase plot.

Figure 2. Sandwich GFRP plate with water ingression on the upper side (a – experimental setup; b - thermogram).

Figure 3. Thermograms of a GFRP sandwich plate with delamination ( a – Passive image; b- LT thermogram).
The next example concerns the LT examination of a GFRP sandwich plate subjected to a low velocity impact (LVI) test at 20 J energy level. The figure 4b shows a thermogram obtained with the harmonic approximation (time) analysis method and the second derivative of the temperature field (trend 2nd).

Figure 4. Thermograms of a GFRP sandwich plate after LVI (a – Passive image; b- LT thermogram).

Other examples concern sandwich plates with faces in CFRP (each face - 1 layer, 0.5 mm thick) and expanded polystyrene core, 9 mm thick. In figure 5, it is presented a strip of this sandwich plate, presenting a discontinuous core. The corresponding LT thermogram was obtained with the single frequency DFT analysis method and the corrected phase plot.

Figure 5. CFRP sandwich plate with damaged core (a –visual images; b- LT thermogram).

Another damage type evaluated in the case of a sandwich CFRP plate was the non-uniformity of the thin faces. The figure 6 presents a LT thermogram obtained using the harmonic approximation (time) analysis method, for a similar 150 mm ×100 mm probe.
A similar sandwich CFRP plate inspected further on had an artificial delamination between the face and core. Figure 7a presents a passive image this plate obtained with the infrared camera, while figure 7b shows a thermogram obtained using the active Lockin method, with the same test parameters and the harmonic approximation – time, offset plot analysis method, better highlighting the damage.

The last example concerns a sandwich CFRP plate inspected after LVI at 1,5 J energy level. Figure 8a presents a passive image obtained with the infrared camera and figure 7b shows a thermogram obtained with the active Lockin method, with the same test parameters and the harmonic approximation (frequency) analysis method.
Good contrast was obtained in all presented thermograms for sandwich type structures with both GFRP and CFRP faces. All the active IRT examinations were performed using LT.

4. CONCLUSIONS

The objective of this paper was to evaluate the capability of the IRT method, in LT variant, to highlight specific defects/damages related to sandwich type composite materials. For example, by exploiting phase transition of water, active IRT inspection makes possible to better detect the water ingestion in the space between the faces and core than using passive IRT. Other type of flaws, such as a damaged core (missing material), face non-uniformities (thickness variations) or core/faces delaminations can be successfully investigated using active IRT. Two type of sandwich plates have been inspected (with GFRP and CFRP faces) by LT, using as heating source a panel with 4 halogen lamps, this technique proving to be an appropriate tool in the NDE of sandwich plates. According to the face thickness and depending on the tested material, one can choose the appropriate Lockin test parameters in order to obtain a good contrast. LEISC is currently involved in the development of active IRT techniques, such as Lockin, Pulse and Transient Thermography, in order to evaluate the integrity of different materials and structures [4], [5].

ACKNOWLEDGEMENT: This research work was supported by the CEEX projects with DALEISC and CAFICMEIS acronyms, running under contracts no. 252/2006 and no. 240/2006.

REFERENCES