

A comparative investigation for the nondestructive testing of honeycomb structures by holographic interferometry and infrared thermography

S. Sfarra¹, C. Ibarra-Castanedo², N.P. Avdelidis³, M. Genest⁴, L. Bouchagier⁵, D. Kourousis⁵, A. Tsimogiannis⁵, A. Anastassopoulos⁵, A. Bendada², X. Maldague², D. Ambrosini¹, D. Paoletti¹

¹Las.E.R. Laboratory, DIMEG, University of L'Aquila, Italy

²Department of electrical engineering, Laval University, Quebec City, Canada

³Mat. Science and Eng. Section, National Technical University of Athens (NTUA)

⁴National Research Council Canada (NRC), Institute for Aerospace Research (IAR)

⁵Envirocoustics S.A., Athens, Greece

IbarraC@gel.ulaval.ca

Abstract. The nondestructive testing (NDT) of honeycomb sandwich structures has been the subject of several studies. Classical techniques such as ultrasound testing and x-rays are commonly used to inspect these structures. Holographic interferometry (HI) and infrared thermography (IT) have shown to be interesting alternatives. Holography has been successfully used to detect debonding between the skin and the honeycomb core on honeycomb panels under a controlled environment. Active thermography has proven to effectively identify the most common types of defects (water ingress, debonding, crushed core, surface impacts) normally present in aeronautical honeycomb parts while inspecting large surfaces in a fast manner. This is very attractive for both the inspection during the manufacturing process and for *in situ* regular NDT assessment. A comparative experimental investigation is discussed herein to evaluate the performance of HI and IT for the NDT on a honeycomb panel with fabricated defects. The main advantages and limitations of both techniques are enumerated and discussed.

1. Introduction

The nondestructive testing (NDT) of parts and materials is a crucial step for inspection and maintenance of honeycomb structures, especially in the aerospace industry [1]. Sandwich structures with honeycomb cores consist of two stiff skins (metallic, plastic or composite) having great mechanical strength, separated by a low-density material core spacer (honeycomb) typically made in aluminum, aramid fibers (Nomex®/Kevlar®) or (more recently) thermoplastics, providing better distribution of loading than a simple laminate and less weight.

The integrity of sandwich structures can be impaired in several ways, during the fabrication stages, subsequent machining, or during normal operation [2]. At present, several NDT techniques are used in aerospace applications [3]: optical testing (visual inspection, shearography, holography), radiographic inspection, eddy current, thermal methods (thermography) and ultrasonic testing (UT), with the latter being perhaps the most commonly used for aerospace components.

Holographic interferometry (HI) is a whole-field optical method that allows non-contact measurement of surface displacement in the micron to sub-micron range. Because of its high sensitivity, surface, subsurface and interior details of the object can be obtained [4].

Infrared thermography (IRT) is another interesting alternative presenting some advantages over other techniques: it is less time consuming, less expensive, portable, subsurface defects location can be marked on the surface, and there is no risk of water permeation during the inspection [5].

In this paper, both HI and IRT are investigated for the NDT of honeycomb parts. The following sections summarize the operation principles and experimental aspects of HI (section 2) and IRT (section 3), followed by a comparison of experimental results (section 4) and finally some conclusions (section 5) are provided.

2. Holographic interferometry (HI)

Holographic interferometry (HI) is defined as the interferometric comparison of two or more waves, one of which is holographically reconstructed. It requires the use of highly coherent light. In this paper, the double exposure (DE) HI has been used. In DE, two holograms are recorded on the same plate, with each one capturing the object in a different state separated by a fixed time interval (t_i). This technique can be used to gain meaningful information with regard to the structural characteristics of a component, by observing the surface deformation produced when the component is subjected to a mild stressing force, but, in the classical configuration, its use is limited to laboratory measurements [4]. As such it offers the potential for inspection problems wherein the defect of interest can be made manifest as an anomaly in an otherwise regular interferometric fringe pattern (see Figure 4); the stressing technique must be devised in such a way that the anomalies induce detectable perturbations in the surface deformation. In this work, the specimen has been subject to a thermal stressing induced by a welder. A detailed review of this technique and others (*e.g.* Real Time HI, sandwich holography) can be found elsewhere [6]. Figure 1 illustrates the DE configuration ($P_{laser}=250\text{ mW}$, $t_{exp}=1''$, $t_i=5''$).

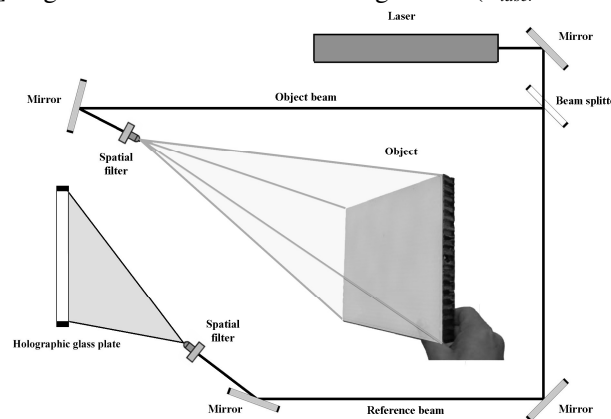


Figure 1. Experimental configuration for double exposure (DE) holographic interferometry (HI).

3. Infrared thermography (IRT)

Infrared thermography is gaining popularity in industrial environments. Although a *passive* configuration, for which no external stimulation is required, is sometimes used, *e.g.* aircraft inspection right after landing when temperature gradients are important, the *active* approach is most commonly used for aerospace applications. Active thermography requires an external source of energy to induce a temperature difference between defective and non-defective areas in the specimen under examination. There are two classical active IRT techniques that can be implemented using a wide variety of energy sources (*e.g.* optical, mechanical, or electromagnetic): pulsed thermography (PT) and lock-in thermography (LT). A detailed review of these techniques and the excitation sources can be found elsewhere [7], [8]. Figure 2 illustrates these two configurations.

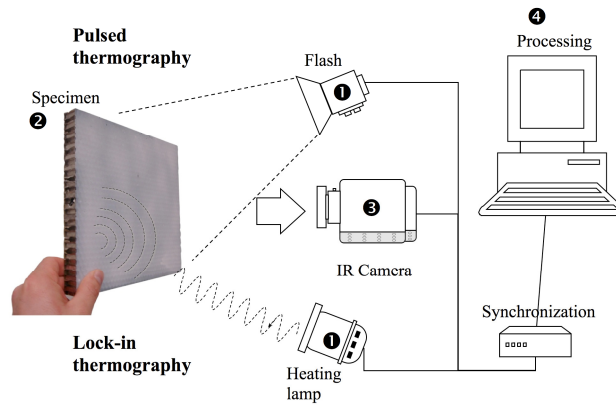


Figure 2. Experimental configurations for pulsed thermography and lock-in thermography.

4. Comparative results

The specimen, provided by Thales Alenia Space, consists of an aluminum honeycomb core (thickness=18 mm) between two CFRP three layers (0,60,-60) skins. The specimen core was pierced from three lateral sides (A, B, C as seen in Figure 3) in our laboratories to simulate collapsed cells. The produced holes (from 1. to 8. as seen in Figure 3.) have different diameters ($\phi = 4, 6$ and 8 mm), and sizes ($L = 6, 7$ and 8 cm), and were pierced at several depths ($z = 3, 4, 6, 8, 9, 12$ and 16 mm).

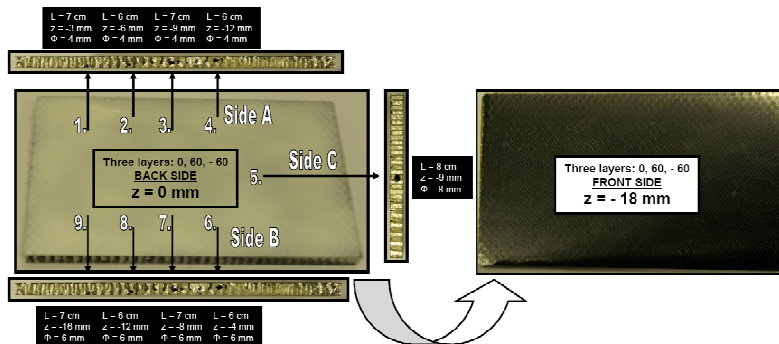


Figure 3. Sandwich honeycomb core specimen with lateral perforations through the aluminium core.

The hologram in Figure 4 shows the fringe pattern with the evidence of defects. Only the hologram for the area covering the 4 mm holes (Side A in Figure 3 – from 1 to 4) and the 8 mm hole (Side C in Figure 3 – defect 5) is presented. However, it can be assumed that the 6 mm holes in Side B (from 6 to 9) could also be detected since they are larger and are located at similar depths. Figure 5 shows two results obtained by IRT. Data was processed using two different processing techniques: thermographic signal reconstruction (TSR) and pulsed phase thermography (PPT), both described in reference [8]. The thermal properties of the combined aluminium cells and air in the core, both being highly diffusive, are very challenging for thermographic detection. Still, it is possible to detect some of the pierced holes. The effectiveness of detection depends mostly on the size and depth of the holes.

5. Conclusions

HI and IRT are well suited for the NDT of sandwich structures with honeycomb aluminium cores. Considering the gravity of a collapsed cell for composite structure, these techniques confirm the importance of the integration and the application on such materials, with the purpose to identify the greatest number of present defects. It was possible to detect perforated honeycomb cells $\phi = 4$ mm in diameter up to a depth of 12 mm by HI from the back side (from 1 to 4 in Figure 3). On the other

hand, IRT allowed detecting $\phi=4$ mm holes up to 6 mm in depth from the front side (defect 4 in Figure 3) and $\phi=6$ mm up to 10 mm in depth from the same side (defects 7, 8 and 9 in Figure 3).

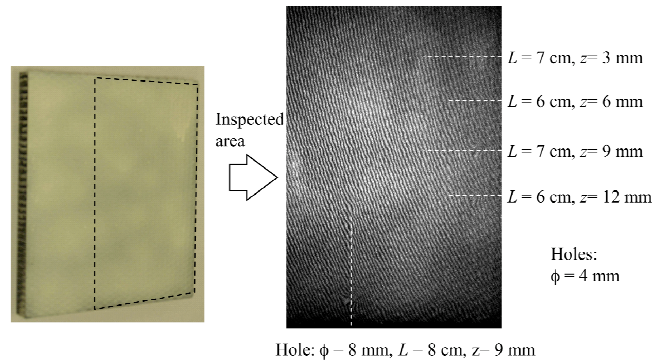


Figure 4. Results obtained by holographic interferometry by inspecting the specimen from the back side.

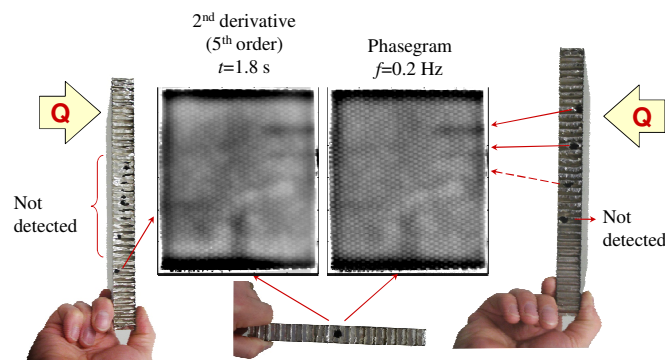


Figure 5. Results obtained by inspecting the specimen from the front side by pulsed thermography.

References

- [1] Achenbach, J.D., Quantitative nondestructive evaluation. *Int. J. Solids Struct.*, **37**: 13–27, 2000.
- [2] Marinetti, S., Muscio, A., Bison, P.G. and Grinzato, E., Modeling of thermal non-destructive evaluation techniques for composite materials. *In Proceedings SPIE, Thermosense XXII*, edited by R.B. Dinwiddie and D.H. LeMieux, **4020**: 164–173, 2000.
- [3] Taylor, J.O. and Dupont, H.M., Inspection of metallic thermal protection systems for the X-33 launch vehicle using pulsed infrared thermography. *In Proceedings SPIE, Thermosense XX*, edited by J.R. Snell and R.N. Wurzbach, **3361**: 301–310, 1998.
- [4] Di Ilio, A., Paoletti, A. and Paoletti, D., Holographic tests on ceramic coatings on metal surfaces, *Composites Science and Technology*, **57**:365-369, 1997.
- [5] Burleigh, D., Thermographic testing used on the X-33 space launch vehicle program by BFGoodrich aerospace. *In Proceedings SPIE, Thermosense XXI*, edited by D.H. LeMieux and J.R. Snell, Jr, **3700**:84–92, 1999.
- [6] Vest, C.M. *Holographic Interferometry*, Wiley, New York, 1979.
- [7] Maldague, X.P.V. *Theory and practice of infrared technology for nondestructive testing*, John Wiley-Interscience 684 p., 2001.
- [8] Ibarra-Castanedo C. Genest M., Avdelidis N., Jen C.-H., Piau J.-M., Guilbert S., Maldague X. P. and Bendada A. “Comparative study of active thermography techniques for the nondestructive evaluation of honeycomb structures,” *Research in Nondestructive Evaluation*, **20**:1-31, 2009.