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Nondestructive evaluation of aircraft components by thermography using different heat sources

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Abstract

In this paper we present the comparison of diagnostic NDT (non-destructive testing) techniques based on infrared thermography for the detection of water in composite materials used in aviation. There are different sources for thermal stimulation used in these methods. Research was performed both on a specially prepared test-sample and on a real aerospace component. The obtained results indicate the potential of IR thermography methods for the detection of water in aerospace components which is important because its presence even in small quantities may cause defects in these elements.

1. Introduction

The development of composite materials deployment in the aircraft industry results in good durability properties, corrosion resistance, low specific weight, and lower costs of production and maintenance. Tendencies of development in non-destructive testing are focused on the detection of smaller discontinuities and obtaining more detailed information about discontinuities in objects. Aviation constructions with cellular filling structures are subjected to the risk of water penetration in the case of superficial discontinuities and lack of tightness. Due to flights at high altitudes and differences of temperatures and pressures, the water may freeze and cause delamination of the cover from the cellular filling material of these structures. This may affect the safety of flight. Even microscopic discontinuities of the material can cause the penetration of the water inside composite structures. They may be difficult to detect by non-destructive testing but the presence of moisture inside the composite structure has the risk of a material defect. The fast detection of micro-defects can permit to avoid unexpected defects of aerospace elements. It means that detecting even small quantities of water inside a composite is essential.

The infrared radiation used in many investigative methods is one potentially efficient tool for composite research [1-3]. In this paper we made experiments with several methods to test their potential for the detection of water in testing samples prepared from composite materials.

2. Experimental set-up

2.1 Applied investigative methods

Usually thermographic investigations can be performed in two ways [4]:

- passive method – when the realization of the investigation does not require any special thermal stimulation ,
- active method – when the realization of the investigation requires a special thermal stimulation.

The investigation of composite materials most often demands the active method. The stimulation of heat flow for needs of the thermographic diagnostics influences the external surface (e.g. pulse heating) or immediately the internal structure (e.g. vibrations [5], microwaves [6, 7]).

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The usefulness of supervisory IR radiation methods for the detection of water in composite materials has been mentioned previously [8]. However, the investigative method used is not practical for researches of real aerospace constructions, because the sample was heated in a furnace prior to the test [8]. In the practice this is generally impossible.

We performed our investigations using methods and different sources of thermal stimulations presented below. In the methods chosen for testing we took also into account their practical aspect of the use in research.

2.1.1 Optical lock-in thermography

In optical lock-in thermography, thermal waves are stimulated by periodical illumination of the object. The idea of this investigation is based on the fact that the thermal wave is generated on the whole sample at the same time, its amplitude and phase is detected and registered separately at all pixels simultaneously. The stimulation wave has sinusoidal shape. In the stationary state the response of the sample is also sinusoidal at the same frequency but with a phase lag that depends on thermal characteristics of the sample. Also the amplitude of the response is distorted, what results from the strong suppression and scattering of the wave in the material of the sample. In fact, the phase shift is the more significant quantity for imaging [9-12].

The lock-in thermography system used in our work consists of an infrared camera AGEMA 900 LW, a lock-in module, a controller system and heating lamp (1 kW power) with an infrared filter (Fig. 1). Hardware and software of the system were delivered by FSI FLIR. Both the infrared camera and the heating lamp were located at a distance of about 1 m from the sample.

2.1.2 Reflection method

The reflection method is the most often applied in the case of composites. In the reflection method (Fig.2) we used for heating of samples the sunlamp (power 800 W) which was positioned at 0.5 m from the test sample. The lens of the camera AGEMA 900 LW had a distance of 0.7 m from the sample. The sample was heated for 60 seconds. The heating and cooling phases were both registered. Results were recorded in the sequence at the registration time of 120 seconds, and images were registered with the frequency of 10 seconds.

2.1.3 Transmission method

The transmission method is used when the back surface of the controlled object is accessible. In this method the camera and the sunlamp as the heating source are located on opposite sides of the sample (Fig.3). The lamp was positioned at 0.5 m and the camera at 0.7 m from the sample. Images were taken both during heating and cooling phases. Thermograms were registered at sequences by 300 seconds at the frequency of image registration (20 seconds).

2.1.4 The active method with microwaves source

In this method we used microwave antennas which transmit a frequency of 2 GHz at a beam width of 30 degrees to illuminate the surface of the sample with a power density of 30 mW/cm^2. Both the camera and the microwave source were located on the same side of the sample (Fig.4). The antenna was positioned at 1 m from the sample, and the camera at 0.7 m. The sample was irradiated by microwaves during 5 seconds, and then the sequence of images was registered for 20 seconds at a rate of 1Hz.

2.2 Test samples

In order to achieve a reasonable estimate and identification of areas in composite material containing water, we prepared a suitable test – sample which is a 290 x 215 mm sized sandwich panel with two 0.7 mm thickness fibredux face skins. Between covers the

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honeycomb core (hexagonal cells) with height 12.8 mm with areoweb (Fig.5) is placed. Covers with a core are joined by epoxy resin. Different quantities of water (5.0 ml, 2.5 ml, 1.2 ml and < 1 ml) were introduced in the sample to four cells.

The second sample was a piece of a propeller (Fig.6) which was also a honeycomb construction of 250x300 mm area and 38 mm thickness. The core made from aluminium foil was covered by an aluminium sheet of 0.5 mm thickness. This cover is bonded by resin to the core. 5 ml of water, which ran into several cells, was introduced to the sample.

3. Experimental results

Fig. 7 is a phase image obtained at f = 0,0146 Hz with optical lock-in thermography. This image shows clearly in which cells of honeycomb the quantity of water is larger, and in which it is smaller. Even for a minimum-quantity of water below 1 ml it is possible to get the precise location. This is perfectly visible on the graph of the profile (Fig.7) obtained along the line through the centre of cells containing water.

Results obtained with the reflection method are shown on Fig. 8. On this figure thermograms are represented which were obtained under the heating and cooling phase. The thermogram obtained under the heating phase is difficult to interpret because radiation from the heating lamp is reflected from the sample surface. The surface of the sample was not specially prepared to the experiment. Its surface is heterogeneous what determines the considerable difficulty at the estimation during the heating phase. The second thermogram was made during the cooling phase. Areas of water are well visible. However, it is very difficult to distinguish between various quantities of water. Even on the profile obtained along the line through the centre of cells with water this distinction is not possible.

The thermogram obtained by the transmission method (Fig. 9) allows for a very good location of areas with water and an approximate estimation in which cell there is more of it.

Fig. 10 represents a thermogram obtained by the use of microwaves as the stimulation source. Places with the water are well visible but we expected to get better results from this method. However, these were initial investigations where we used this kind of stimulation source. In further works we will be trying to improve this method.

From the presented results it is clear that the best interpretation can be obtained using the optical lock-in method.

Fig. 11 represents a phase image obtained with optical lock-in thermography of a propeller piece. The moisture area of this sample as a result of the introduction of 5 ml water is well visible.

4. Conclusions

All methods used in this paper are suited to detected water in composite samples, even in small quantities and both in reflection and transmission arrangement. It is difficult to qualify precisely the water content. A reason is probably the phenomenon of longitudinal heat diffusion. Only with the lock-in thermography method we can distinguish between different amounts of water.

Our results are consistent with previous results obtained also with lock-in thermography on honeycomb structures containing water [13].

In our further work we intend to give a survey on the efficiency of water detection by other non-destructive testing methods using infrared radiation and other kinds of thermal stimulation.

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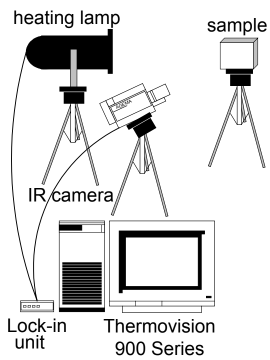

__Fig. 1.__ Experimental set-up for lock-in thermography

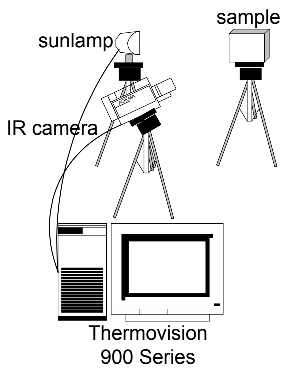

__Fig. 2.__ Experimental set-up for reflection method

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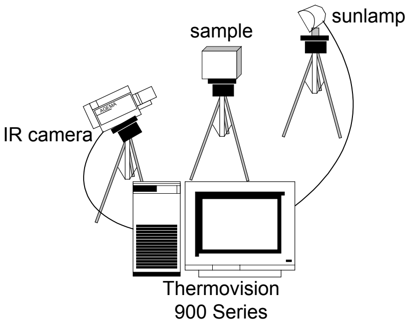

Fig. 3. Experimental set-up for transmission method

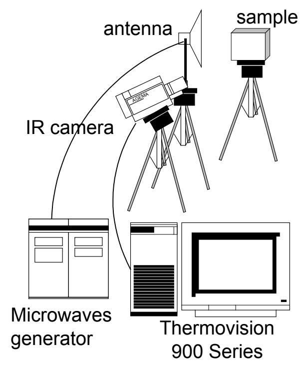

Fig. 4. Experimental set-up for microwaves stimulation

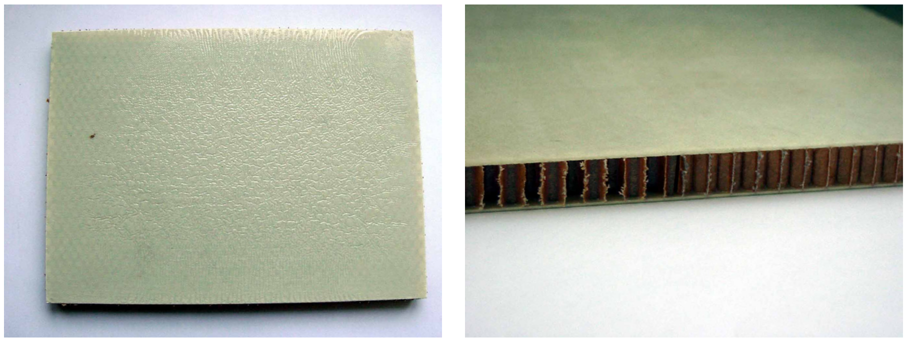

Fig. 5. *Photography of test sample*

Fig. 6. *Photography of propeller element*

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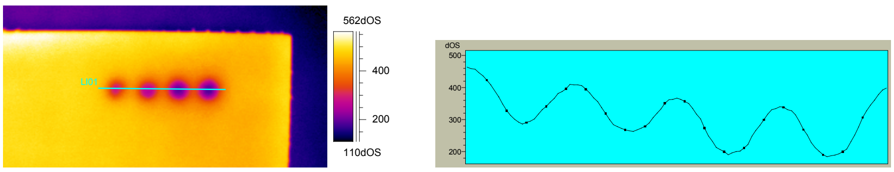
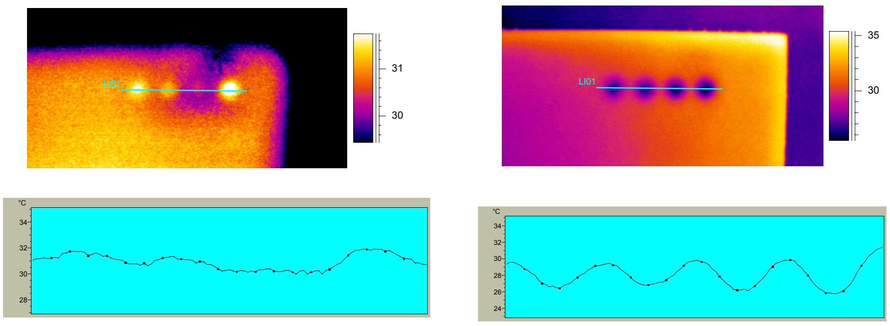


Fig. 7. *Lock-in amplitude image and profile plots of cells containing water, f = 0.039Hz*



a) *b)*

Fig. 8. *Thermograms – reflection method*

a) heating phase,

b) cooling phase and profile plots of cells containing water.

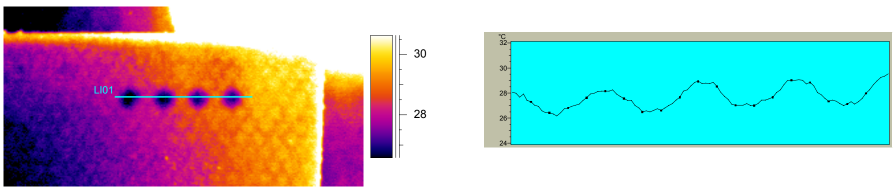


Fig. 9. *Thermogram – transmission method and profile plots of cells containing water*

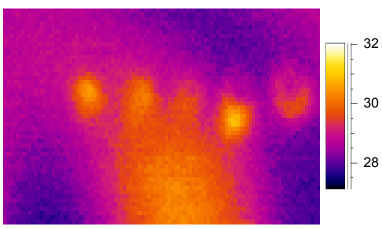


Fig. 10. *Thermogram method with microwave stimulation*

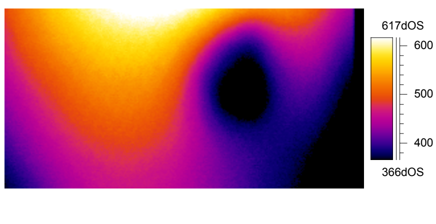


Fig. 11. *Lock-in phase image of propeller f=0.0146 Hz*