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IR THERMOGRAPHY IN NDE OF CARBON-GLASS LAMINATE

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Abstract

The article presents a comparison of the effects of using active IR Thermography technique for the tests of composite aircraft structures.

The most important question arising together with an increased use of composites in aviation industry is to work out a method, which would allow identification of the technological defects, and damages appeared in the process of the aircraft use. Non-destructive testing which has been used so far to identify defects in the aircraft structure made from metallic materials has a quite limited application in case of composite structures. With the growing use of composites in the aviation industry, a necessity appears to work out a method allowing early identification of technological defects and damages appeared in the process of the aircraft operation. It could be the active thermography techniques used for the thin walled elements tests, such as wing and fuselage skin, with the focus on fractures and delamination.

Light composite aircraft have been built for a many of years, however, the annual flight hours of these aircraft are incomparably lower than those of the aircraft used in air transport. In group of light aircraft, the less important elements were made of composites regarding the strength of the whole construction. When the newest aircraft were introduced, with most important construction elements such as the fuselage, wings, horizontal and vertical tails, doors and the interior made of composite materials, it was expected that the increased amount of the annual flight hours (more than 3000 hours) and the expected airliner lifetime (about 30 000 hours) would soon cause degradation of the mechanical properties of the composites following from the progress of ageing of the composite structures.

The obtained research results bring closer the problem of selection of the well-fitted non-destructive testing method depending on the kind of the diagnosed construction.

Keywords: *IR Thermography; NDE; non-destructive testing; composite aircraft structures; fracture; delamination*

1. Introduction

Also, the processes of advanced composite manufacture are prone to errors. Many defects cause a reduction in the mechanical properties of a composite structure. In many cases it could lower the properties the design allowable, hence the importance of detecting defects using non-destructive technologies. IR Thermography methods were developed at the few last years and practical examples of use are described at the literature [1-4].

The Nordam Repair Division has developed the concept of choosing an optimal method for inspecting and documenting results of the repair of aircraft panels [5].The concept include following points [6]:

- a method should detect defects of different types,
- a method should scan the panel surface and possibly produce an image,
- a method should not require extracting a test object out of an airplane or its considerable disassembling,
- inspection results should be evaluated on test site,
- inspection results should be well documented and archived for future reference,
- test equipment should be portable and mounted in a short time,
- test equipment should be convenient for using by Level I thermographers,
- implementation of test equipment should not cause essential re-organization of already operating inspection system.

In addition to traditional techniques, Nordam began a wider use of thermal methods, which, largely, meet the requirements above.

It was reported that the IR thermographic inspection of a Boeing-737 rudder by the area of $6.5m^2$ was performed for 3 hours and resulted in the detection of a defect in the bonding layer, which experienced thunderbolt [5]. Ultrasonic inspection would last about 7 hours in this case.

The aim of this work was to bring closer the problem of selection of the quick, well-fitted non-destructive testing method depending on the kind of the diagnosed construction. The obtained results indicate the potential of Infrared (IR) Thermography methods for the detection of flaws in aircraft components causing critical defects in these structures. This article presents the results of research with use of Pulse IR Thermography and Vibrothermography NDT techniques to identify defects like voids, fracture and change of thickness in composite aircraft structures.

In thermography, heat sensing devices are used to measure temperature variations caused by differences in heat capacity or thermal conductivity in a structure.

Generally in TNDT models differential temperature signals ΔT and their derivatives, such as running temperature contrast $C^{run} = \Delta T/T_{nd}$ (where ΔT is temperature evolution and underscript nd means non-defect) depends on time (τ, τ_h-heating time), heating parameters (Q, $\tau_{h)}$, intensity of heat exchange between a sample and the ambient (α^F, α^R where), sample thickness (L), sample thermal properties (λ- conductivity, a-diffusivity), defect size (h_x, h_y, h_z=d), defect depth (l) and defect thermal properties (λ_d, a_d). In the TNDT method, defect detectability varies significantly in time.

On a heated sample, the boundary condition is constituted by the sample external heating and its cooling with convection and radiation flux Q_{cv+rd}. The corresponding phenomena are conductive flux Q_{uds} that penetrates the sample. The heating flux Q is described as in paper [6]:

$$Q = Q_{cw+rd} + Q_{cd} \,. \tag{1}$$

The general presentation of (1) is as follows:

$$-\lambda \frac{\partial T(z=0)}{\partial z} = Q - \alpha\left[T(z=0) - T_{amb}\right], \tag{2}$$

where z=0 represent front surface of the specimen, and z=L rear surface (3). On the rear surface, there are only two flux of heat, therefore:

$$-\lambda \frac{\partial T(z=0)}{\partial z} = \alpha\left[T(z=L) - T_{amb}\right], \tag{3}$$

where:
L – sample thickness.

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2. Experimental investigations

In the paper introduced the diagnostic technique making possible the research of internal structures in composite material using in aircraft. In this experiment, Vibrothermography (Fig. 1) and Reflection Pulse IR Thermography (Fig. 2) methods were used.

To identify the areas in composite material, which contain the separator inclusion it was, used a prepared suitable test sample, which was a 300x300 mm, sized with structure configuration as below:

- topcoat,
- acrylic primer,
- glass fiber 160 g/m^2,
- 3 layers carbon fiber 168 g/m^2.

All plies of fiber were joined by an epoxy resin, defect were introduced on 5th layer of laminate as imprint of hand with separator on it.

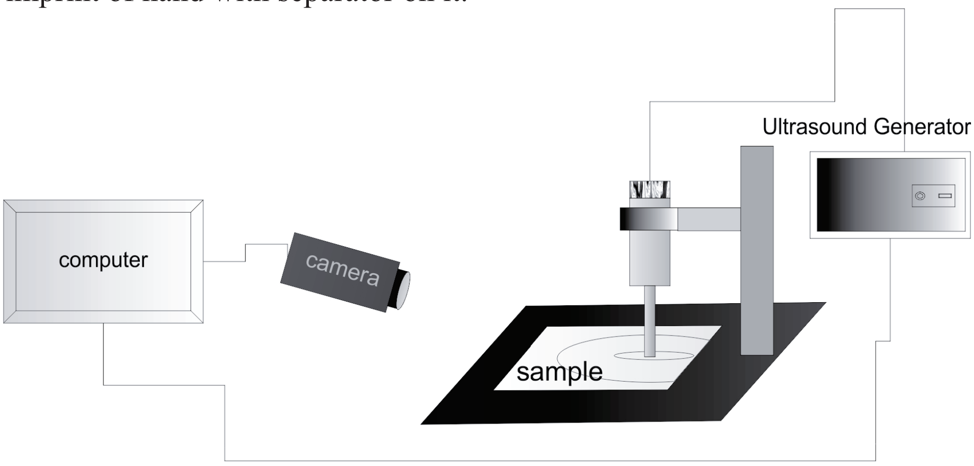

Fig. 1. Experimental setup for Vibrothermography method

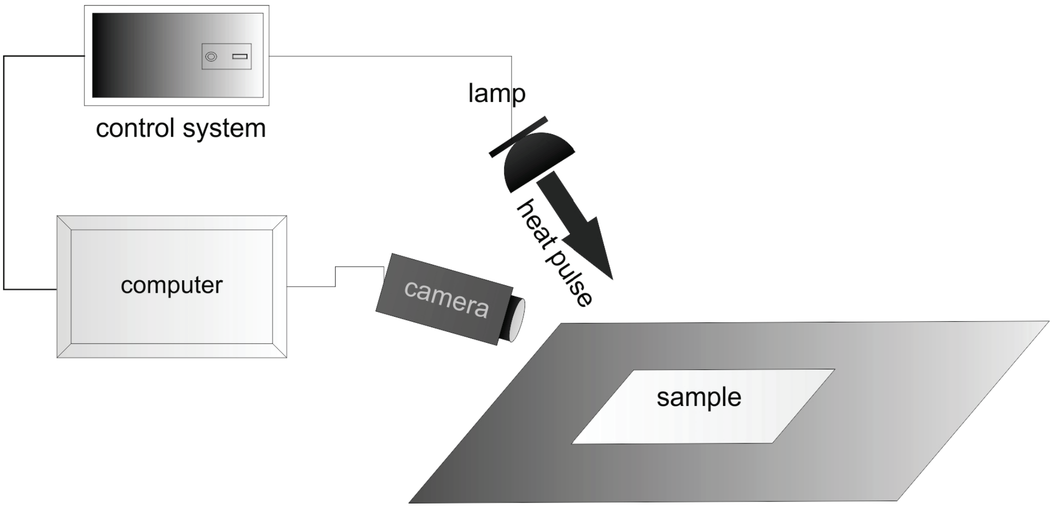

Fig. 2. Experimental setup for Reflection method in Pulse IR Thermography

In Vibrothermography, method of sample evaluation the IR camera FLIR SC655 was placed in distance of 0.7 m from the sample, and frequency modulation of ultrasound generator amount to 20 kHz.

The thermograms obtained with the IR Vibrothermography method were acquired under the heating and cooling phase. Thermographic imaging of this test detected disbonds between an 2nd and 3rd ply of fibres as shown on Fig. 3:

In this method, detected heat is directly generated by the defects themselves. Low amplitude mechanical excitations induce local heating by friction when relative motion of the flaw surface occurs. The defect indication is observed to develop gradually over time, consistent with a diffusion governed process that this technique is suited to the detection of delaminations and matrix cracking.

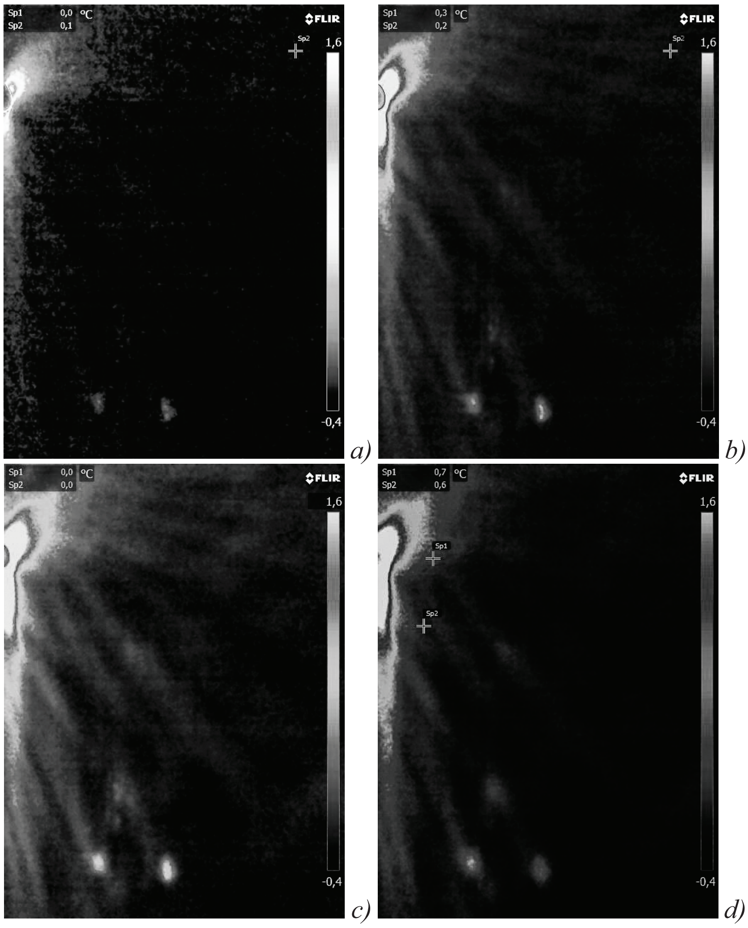

Fig. 3. IR Vibrothermography result thermogram: a) 0.5 s after start of ultrasounds application b) 2s after start of ultrasounds application c) 3 s after start of test d) cooling phase of test- 3s after stoppage of ultrasound impulse

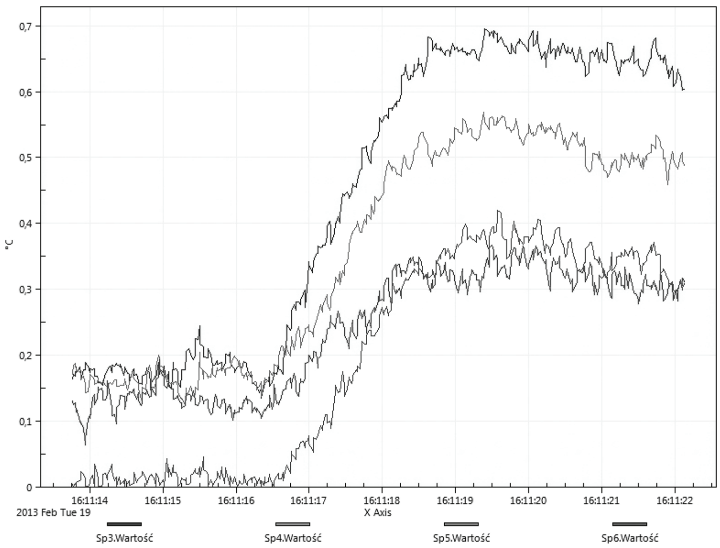

Fig. 4. Temperature of different points of tested sample

In Pulse IR Thermography test, a heating lamp (power 500 W) was positioned 0.6 m before the test sample. The camera FLIR SC655 was placed 0.7 m from the sample. Results obtained with the reflection method are shown on Fig. 3 a) and b). Both thermograms were received under the cooling phase. Thermograms from heating phase were rejected because of radiation from the heating lamp was reflected from the surface of the sample.

Figure 5 and 6. represents the results of research obtained at estimation of delamination area after inclusion of separator on 5th layer of carbon-glass laminate specimen. The area with more inclusion of separator cools down slowly then parts without defects.

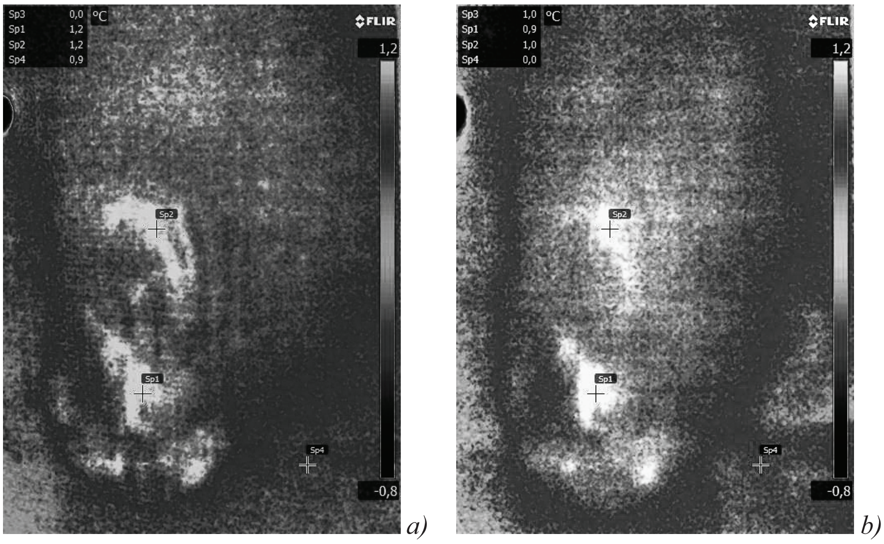

Fig. 5. IR Pulse Thermography thermograms a) 0.5 s after end of heating phase, b) 5 s after end of heating phase

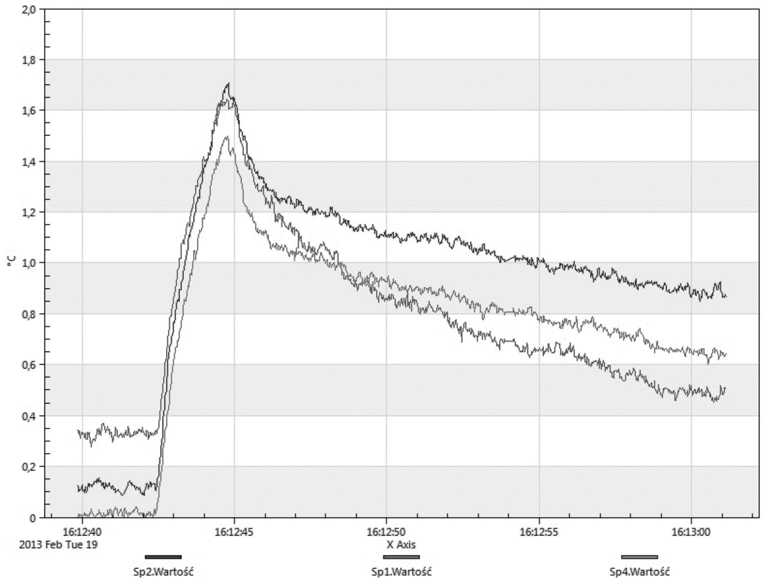

Fig. 6. Temperature in defects points graph

Comparison between two non-destructive methods of defect detecting show differences of IR images result, caused by varies phenomena, which occur into evaluated structure because of kind of heat excitement under test. Using of both IR method featured in this allow to comprehensive and fast structure health evaluating.

4. Summary

Non-destructive inspection for advanced composite aerospace structures plays a significant role in the assurance of forming high quality composite components that meet the stringent product quality demands of the aerospace industry. The current NDI technologies used in industry employ a combination of automation and hand-held labour. In many instances, these technologies are slow, and contribute significant cost to the final product. The continual development of a lower cost, simple and reliable system for detection of defects in all current and future families of advanced composite structures is a main driver in research and development activities in the aerospace industry.

In this study, some approaches to the detection of delaminations, cracks and foreign inclusions have been analysed. IR thermography is well fitted method for inspections of thin aircraft structures, but the efficiency of this technique depend on a type of materials under test and availability of proper heat sources.

The obtained research results bring closer the problem of selection of the well-fitted non-destructive testing method depending on the kind of the diagnosed construction. Therefore, the optimal conditions of testing have to be defined separately for each specific kind of material and this problem will be taken into consideration in next researches.

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