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Non-destructive evaluation of aerospace materials with lock-in thermography

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Abstract

The attention of the present study was focused on the aid provided by lock-in thermography for non-destructive evaluation of aerospace materials and structures. The experimental analysis was performed by testing several specimens, which were made of different materials employed in the fabrication of aircraft (composites, hybrid composites, sandwiches, metals) and which included the most commonly encountered kinds of damage (delamination, impact damage, fatigue failure).

Keywords: Aerospace materials; Non-destructive testing; Thermography; Composites; Damage assessment

1. Introduction

Aircraft represent the most quick and efficient mean of transport, but people are still afraid of flying. The reason probably lies in the impossibility of surviving an aircraft crash. Aircraft crashes may be due to several factors, such as materials failure (impact damage, hidden defects, corrosion and quick crack propagation), icing, adverse atmospheric conditions, human errors and so on. In the philosophy of a *safe flight* an important role is played by the material's performance. The material should have superior mechanical, chemical and physical characteristics such as fatigue, impact and damage tolerance, burn-through resistance and corrosion resistance. But, the material should also be light and so the compromise "lowest

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weight, highest strength''. By now, aircraft are almost entirely made of composites (carbon reinforced fibres composites), or hybrid composites (Fibre Reinforced Metal Laminates), or advanced aluminium alloys.

Of course, the development of new materials requires the availability of effective non-destructive techniques able to discover defects at an incipient stage during fabrication and in service. The requirements for non-destructive evaluation are driven by the need for low cost methods and instruments with great reliability, sensitivity, user friendliness and high operational speed as well for applicability to increasingly complex materials and structures. In this context, infrared thermography seems attractive because of its two-dimensionality and non-contact character, which allow for the control of full scale artefacts, or parts in service, or procedures in process.

The attention of the present study was focused on the aid provided by lock-in thermography for non-destructive evaluation of aerospace materials and structures. The experimental analysis was performed in the laboratory by considering several specimens made of materials effectively employed for aircraft fabrication (composites, hybrid composites, sandwiches, metals) and which included the kinds of damage most commonly encountered (delamination, impact damage, fatigue failure).

Glare® [1–3] is worth particular consideration. Such an innovative material has excellent fatigue, impact and damage tolerance characteristics with low density and thus it complies with the increasing safety level; at the moment, it is regarded as the best material and is being used in civil aviation (the entire top half of the A380 fuselage is made of fibre metal laminate). However, it is a difficult material for non-destructive evaluation. It seems that the ultrasonic technique, routinely used in the aeronautical field, is not at all effective for the evaluation of Glare® because glass fibres reflect back ultrasound waves and hinder the visibility of the layers underneath.

2. Theoretical remarks on lock-in thermography

The basic concepts of lock-in thermography (LT) were first described by Carlomagno and Berardi [4] and later developed by many researchers [5–9]. Basically, the thermographic system is coherently coupled to a thermal wave source which is operated in such a way that a sinusoidal temperature modulation results. The modulation is generated by a non-linear electrical signal produced by the Lock-in Module which has a waveform table for this purpose. The heat source has to be calibrated (for each frequency) to ensure that the temperature waveform is really sinusoidal.

In the lock-in analysis the system collects a series of images and compares their temperature extracting the sinusoidal wave pattern at each point of the image. The periodical transfer of heat at the surface (depth $z = 0$) results in a (time dependent) thermal wave, which in one dimension, is given by [5],

$$T(z,t) = T_0 \exp\left(-\frac{z}{\mu}\right) \exp \mathrm{i}\left(\omega t - \frac{z}{\mu}\right) = T(z) \exp \mathrm{i}[\omega t - \phi(z)], \tag{1}$$

where μ is the thermal diffusion length:

$$\mu = \sqrt{\frac{\alpha}{\pi f}} \tag{2}$$

with α thermal diffusivity and $f = \omega/2\pi$ wave frequency. The term $T(z)$ represents the decay with depth of the thermal wave amplitude, while $\phi(z)$ is the phase shift. The depth range, for the amplitude image, is given by μ while the maximum depth which can be inspected, for the phase image practically corresponds to 1.8μ [8].

In the LT technique, the behaviour of the thermal wave is driven by the material morphology. Generally, the thermal wave propagates inside the object and gets reflected when it reaches parts where the heat prop-