Science real and relevant conference 2010
Proceedings homepage://www.conference.csir.co.za/

Reliable non-destructive inspection of composite materials in use in the aviation industry

Manfred Johannes

Defence, Peace, Safety and Security, PO Box 395, Pretoria, 0001

*Corresponding author: Manfred Johannes (mjohannes@csir.co.za)

Reference: DS06

1. Introduction:

Fibre reinforced composite materials are increasingly being used in engineering applications in the aircraft industry as they display an excellent weight to strength ratio. The limitation on the use of these materials in load-bearing applications is largely brought about by the difficulties in inspecting these materials in a non-destructive manner. Also, the lack of mechanical behaviour data for these materials in general e.g. fractures toughness[1], which could provide information regarding the size of critical defects, contribute to the challenges in inspections.

Various inspection technologies have been developed for the inspection of these materials. These include amongst others ultrasonic testing (UT), mechanical impedance or resonance testing, infrared thermography and laser shearography[2]. The range of technologies and equipment are required to cope with the particular requirements of the varied composite materials and structures. No single inspection technology can cope with the variety of builds and style of construction.

Although infrared thermographic testing (IRT) has been available for a number of years, the associated costs in applying his technology was generally too high to become a frontline inspection technology out in the field. The IR cameras available were bulky and also very costly. Of late the cost associated with the cameras has been reduced significantly through the use of bolometer technology, so that at present an IRT system can be purchased at more or less the same costs as a UT system which is designed to also inspect composite materials and structures.

In order to investigate the possibilities in establishing an inspection capability for the composite manufacturing industry, funds were made available through the Advanced Manufacturing Technology Strategy (AMTS), to assess which technologies are available and to develop a capability in IRT for the country.

This paper outlines the theoretical background on which the IRT is based and discusses a number of test scenarios where IRT was successfully applied in industry.

2. Theoretical basis for IRT

The theoretical basis for IRT lies in the heat conduction equation i.e.

$$\frac{\partial T}{\partial t} = \frac{K}{\rho C_p}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right)$$

where

T = Temperature
t =Time
ρ = density
K = Thermal conductivity
C_p = Specific heat capacity

The equation can be simplified by assuming that the body in which the heat is conducted is isotropic and that the body stretches to infinity in the x- and y-directions. The thickness in the z-direction is finite and the heating at the surface (z=0) is instantaneous and uniform and the thermal pulse has a strength of Q.

The assumptions reduce the equation to:

$$\frac{\partial T}{\partial t} = \frac{K}{\rho C_p} \frac{\partial^2 T}{\partial z^2}$$

which renders the solution

$$T = \frac{Q}{2e\sqrt{\pi t}} e^{-z^2/4\kappa t}$$

where

Q = Input energy at the surface of the sample

e = thermal effusivity, $\sqrt{K\rho C_p}$

k = Thermal diffusivity, $\lambda/(\rho C_p)$

The thermal propagation time t* to the depth z of a subsurface defect is given by the approximation:

$$t^* \sim \frac{z^2}{\kappa}$$

As an example it can be stated that t^* for 2 mm of Aluminium is around 40 ms and t^* for 2 mm graphite epoxy around 30 s.

From these theoretical considerations the following assumptions can be made:

- Where materials have a high thermal diffusivity (e.g. metals), short pulse excitation must be employed together with high frame-rate cameras to assure an acceptable resolution.
- For materials with low thermal diffusivity (e.g. composite materials) the time taken by the thermal front to pass through the body of material is relatively long. As a result the temperature on the surface (at z=0) drops substantially with time and hence pulse excitation can not be used effectively. Longer excitation times are required and hence transient or lock-in IRT must be employed. Uncooled ('slower') frame-rate cameras can be employed for these applications.
- Short pulse excitation can be employed to find reflectors (discontinuities) close to the surface. For discontinuities lying deeper in the material, longer excitation times, together with either transient or lock-in IRT must be employed. [3]

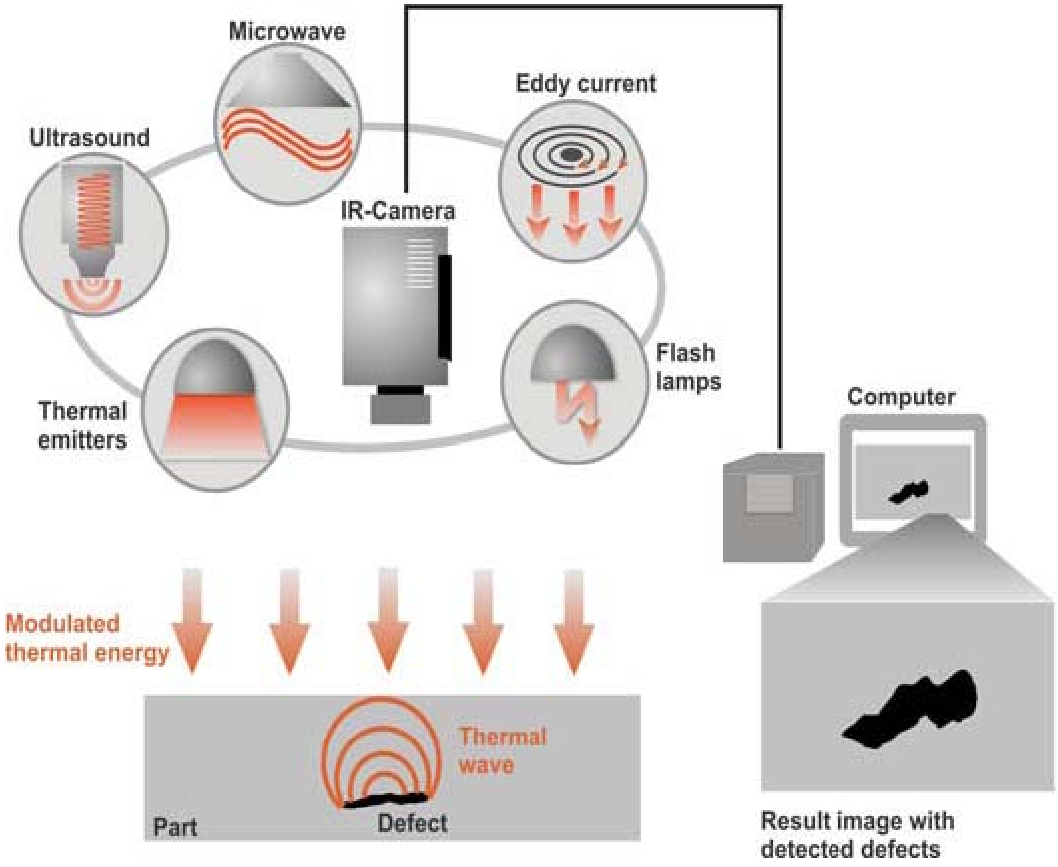
3. A short description of the system purchased [4]

Although it was initially thought to develop an in-house IRT system, using equipment (cameras) which became obsolete in other departments, the availability of a modern IRT system, specifically designed for NDT, changed the thinking. It made financial sense to purchase this system, as this would make the latest state-of-the-art IRT hard- and software available to industry, thereby assuring that the results achieved by using such a system would be accepted in industry.

The IRT system purchased is an all-purpose modular real-time infrared imaging system for all kinds of non-destructive inspections with active thermography. It supports all known measurement techniques (lock-in, pulse, transient, vibro-thermography, TSA) with all kinds of excitation sources (optical, ultrasound, eddy current, microwave, stress-strain test rig, etc.). Furthermore, a wide variety of excitation sources and expansion components are available to cover the whole range of inspection tasks on non-metal and metal parts.

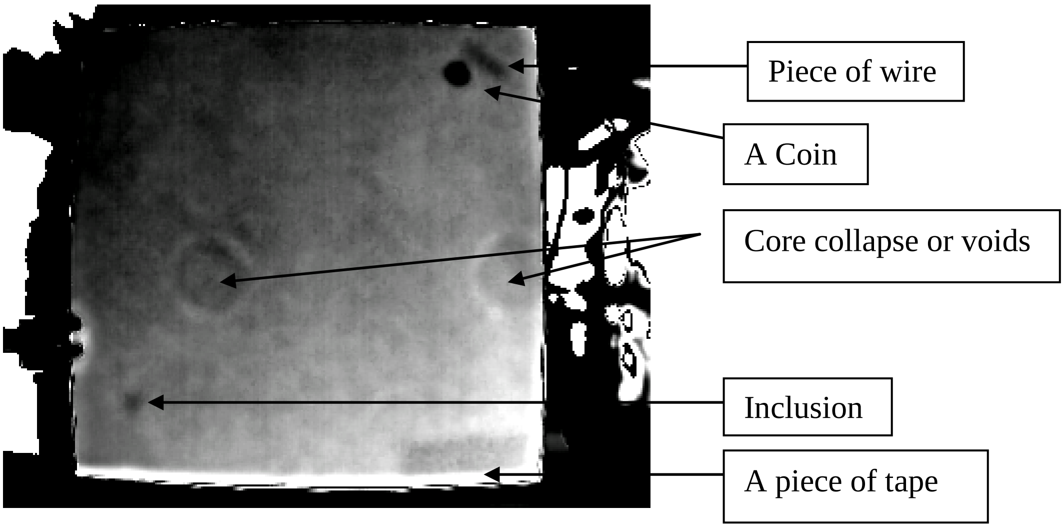
The components of the system are optimally assembled to give the highest possible sensitivity, performance and flexibility. The configuration purchased was already successfully field tested by a large number of companies, including renowned companies like Boeing and Airbus, the largest manufacturers of commercial aircrafts. Since March 2010, the FAA has approved the system for use on composite aircraft components and is currently in the process of changing the control documents for the inspection of aircraft to also include IRT.

Figure 1 below illustrates the different components of the system.

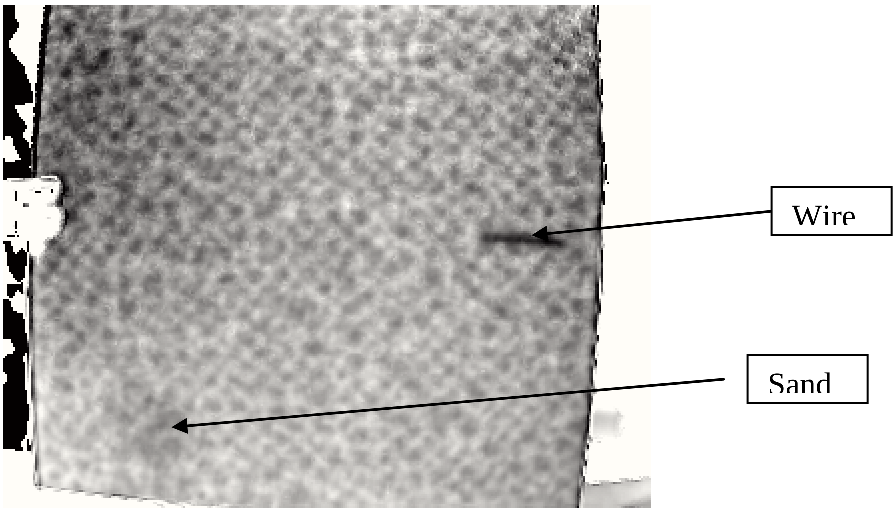


4. Results achieved on a number of different samples supplied by the composite manufacturing industry

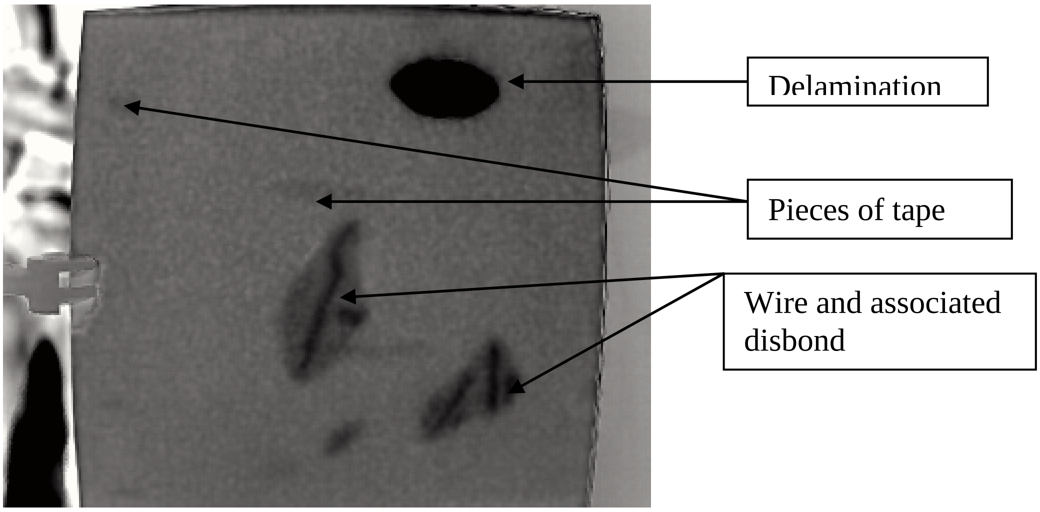
Sample 1: Carbon composite



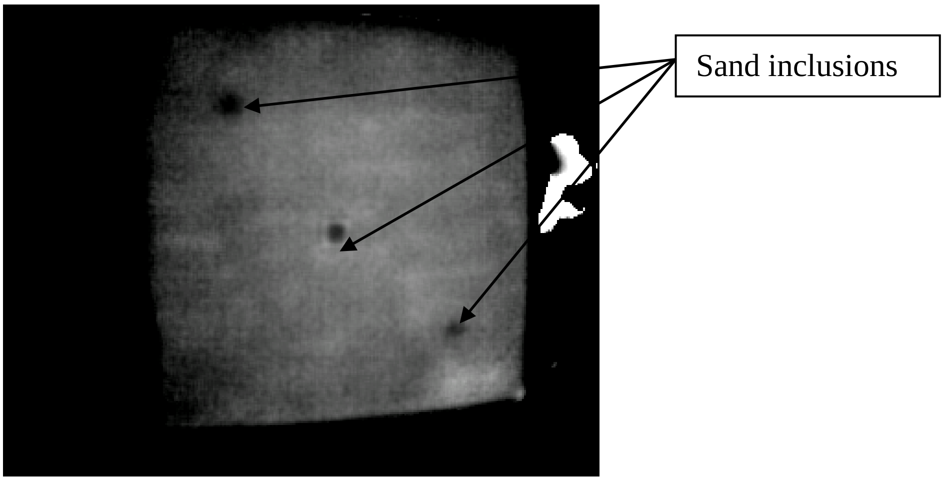
Sample 2: Piece of wire



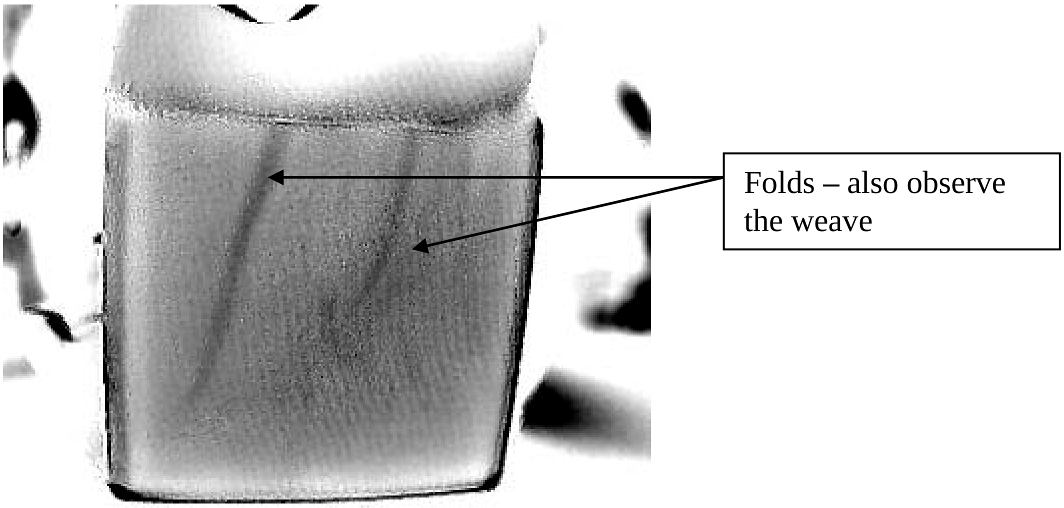
Sample 3: Carbon composite



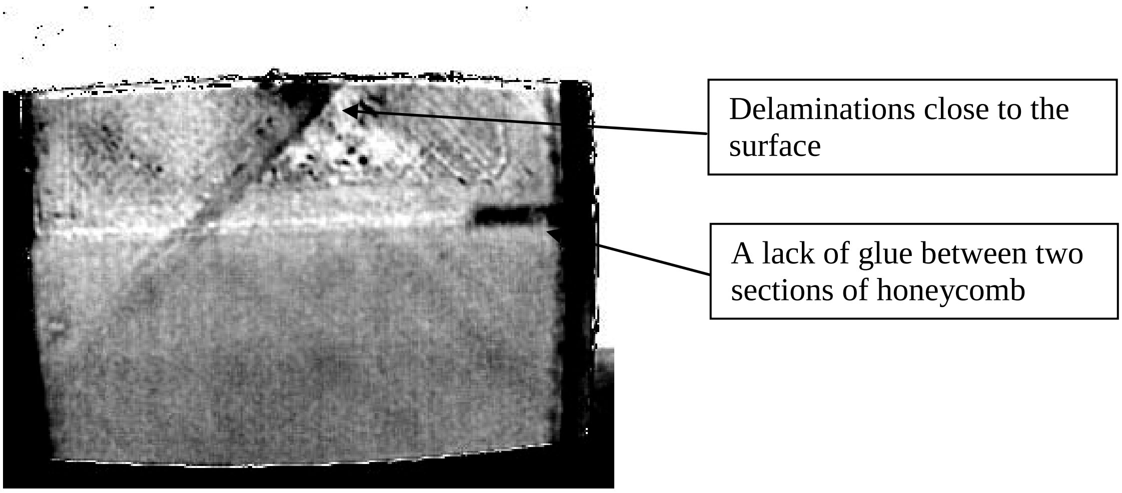
Sample 4: Through transmission

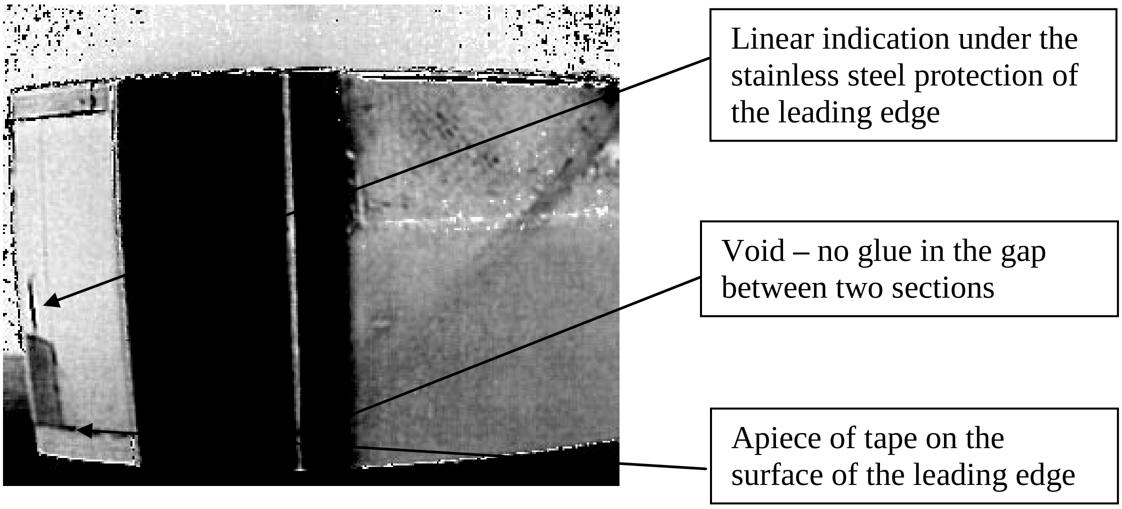


Sample 5: Carbon fibre – folds in the sample



Sample 6: Test piece - a rotor blade containing discontinuities which cannot be detected reliably by any other NDT technology





Sample 7: The frame of a racing bicycle showing interlayer delaminations

Sample 8: Site test on the Groupama around the world record-holding yacht in Cape Town

The yacht moored in Cape Town harbour

The inspection system affixed to the yacht to eliminate relative motion

5. Conclusions:

5.1 IRT was found to be capable of inspecting composite materials, which are not inspectable by any other NDT methods.

5.2 The depth resolution which the technology provides makes IRT ideally suitable for inspection of materials where access is limited to one side of the component only.

5.3 The perturbation of the surfaces affects the test result significantly and has to be established for every test scenario before conducting the test.

6. Acknowledgements

6.1 This paper is the result of a research effort funded by the DRDB in terms of contract KT 470001 and funding from the DST via AMTS funding.

6.2 The assistance from Automation Technology, Bad-Oldersloe, Germany, in the technology transfer is acknowledged and appreciated.

7. References

1. Gillespie, Jr., J. W., “Damage Tolerance of Composite Structures”, *Journal of Offshore Mechanics and Arctic Engineering,* 247-252 (1991)
2. Schnars, U., Heinrich, R., “Applications of NDT Methods on Composite Structures in Aerospace Industry”, Airbus, Bremen, Germany
3. NDT Handbook, Vol 5. ISBN-978-5-904270-03-2
4. Wandelt, M., User guide for the AT IRT Inspection system, Bad-Oldersloe, Germany