A study of active thermography approaches for the non-destructive testing and evaluation of aerospace structures

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ABSTRACT

The prerequisite for more competent and cost effective aircraft has led to the evolution of innovative testing and evaluation procedures. Non-destructive testing and evaluation (NDT & E) techniques for assessing the integrity of an aircraft structure are essential to both reduce manufacturing costs and out of service time of aircraft due to maintenance. Nowadays, active – transient thermal NDT & E (i.e. thermography) is commonly used for assessing aircraft composites. This research work evaluates the potential of pulsed thermography (PT) and/or pulsed phase thermography (PPT) for assessing defects (i.e. impact damage and inclusions for delaminations) on GLARE and GLARE type composites. Finally, in the case of the detection of inserts – delaminations C-Scan ultrasonic testing was also used with the intention of providing supplementary results.

Keywords: active thermography, composites, GLARE, inspection, and defects.

1. INTRODUCTION

The main approach for developing GLARE composites includes the placement of layers from aluminium alloy(s) and the prepregs between them in a specific base. After this, the mutli-layer structure is placed in an autoclave for approximately 2 hours at a temperature of 120°C and 6 bar pressure. The aluminium layers have a thickness of 0.3 to 0.4 mm and up to a maximum of 1.65 m of wideness. This results to a problem as far as the manufacturing of large structures of the aircraft is concerned (i.e. > 2 m). To overcome this, the development of consecutive aluminium alloy layers (next to each other) leaving a very small gap - void in between them (~ 1mm) has been used. This approach is also known as GLARE splicing method. Nonetheless, rapid delamination was observed, especially during the loading of technique, due to the pressure that is applied at the doublers (i.e. placed aluminium alloy sheets) in the autoclave and because of the use of the adhesive for the preparation of the prepregs, the voids – gaps are filled from the material itself. The composite has now improved strength and the filled gaps are no longer the weak spots of the material. Several NDT & E techniques, such as ultasonics [1], x-rays radiography [2], eddy current testing [3], as well as infrared thermography [4], can find use in the inspection of GLARE composites. In literature, one can find A–Scan and C–Scan ultrasonics inspection on composite structures from GLARE. Furthermore, radiography has been used in the inspection of GLARE in specific situations, such as preliminary detection of cracks in the aluminium part of the material. Eddy Current testing has also been applied, providing good results for detection on the surface and near surface defects. The main limitation of this approach is detecting defects at the greater depths within the material. Furthermore, infrared thermography has also found use in the inspection of joints from GLARE composites.

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2. EXPERIMENTAL PROCEDURES & TECHNIQUES

Firstly, GLARE type composites were prepared with different inserts for simulating delamination in the samples (table 1). These samples were prepared using aluminium 2024-T3 of 0.4 mm thickness and using BR-127 chromic anodising as surface preparation on the material. Secondly, GLARE composites, using s-Glass instead of e-Glass, were also prepared; this time for impact damage testing. 12 samples were prepared; 6 with Al/FM-94/s-Glass/FM-94/Al and the other 6 with Al/FM-94/s-Glass/FM-94/Al/FM-94/s-Glass/FM-94/Al.

Sample	GLARE type	Composite Orientation	Lay-up	Dimensions	
				Length (mm)	Width (mm)
DT1	G.e-g/w-2/1-0.4	e-Glass MMR–002/w	Al/FM-73/e-Glass/FM-73/Al	150	50
DP2	G.e-g/w-2/1-0.4	e-Glass MMR–002/w	Al/FM-73/e-Glass/FM-73/Al	150	50
DT3	G.Bor-2/1-0.4	Boron 5521/un	Al/FM-73/Boron/FM-73/Al	150	50
DP4	G.Bor-2/1-0.4	Boron 5521/un	Al/FM-73/Boron/FM-73/Al	150	50
DT5	G.e-g/w-3/2-0.4	e-Glass MMR–002/w	Al/FM-73/e-Glass/FM-73/Al/ FM-73/e-Glass/FM-73/Al	150	50
DP6	G.e-g/w-3/2-0.4	e-Glass MMR–002/w	Al/FM-73/e-Glass/FM-73/Al/ FM-73/e-Glass/FM-73/Al	150	50
DT7	G.Bor-3/2-0.4	Boron 5521/un-un	Al/FM-73/Boron/FM-73/Al/ FM-73/Boron/FM-73/Al	150	50
DP8	G.Bor-3/2-0.4	Boron 5521/un-un	Al/FM-73/Boron/FM-73/Al/ FM-73/Boron/FM-73/Al	150	50

Table 1: Description of GLARE type composites

In the instance of the inserts – simulated delamination [5], the dimensions - specifications of all investigated samples can be seen in the schematic of figure 1. The defects were either from Teflon or polyamide. In the instance of the impact damage testing [5], a falling weight impact tester was used. A lead filled tube with a standard hemispherical 8mm diameter steel ball was used as the impacter. A sliding plate at the base of the guiding tower allows the impacter tube to be caught after impact to prevent secondary impact of the sample.

Impact energy was calculated using the standard equation:

$$E = m * g * h$$

where: m is the mass of the impacter, g is the acceleration due to gravity (9.81m/s) and h is the height from which the weigh was dropped. The following impact energies were calculated: 2 Joules, 4 Joules and 8 Joules.

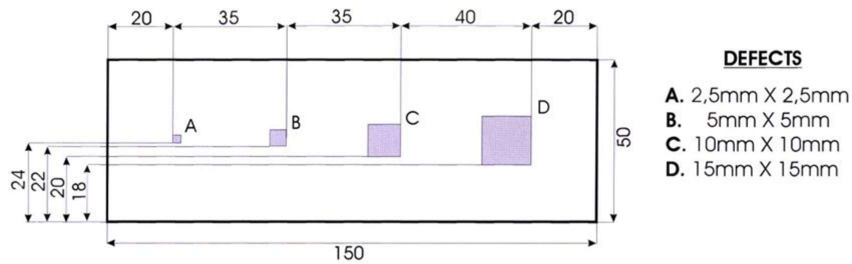

Figure 1: Schematic of investigated samples containing inserts.

Two different experimental set-ups were used for the inspection of the GLARE and GLARE type composites. In the investigation of the inserts, acquisition was carried out using a focal plane array infrared camera (Santa Barbara Focal Plane SBF125, 3 to 5 μm) on a 320x256 pixel array. Two high power flashes (Balcar FX 60), giving 6.4 KJ for 15 ms each, were used as heating sources. Thermographic data was analyzed with a PC (Pentium 4, 2 GB RAM) using MatLab® language from The MathWorks, Inc.

Furthermore, C-Scan ultrasonic immersion testing was used with the intention of providing supplementary information about the defects. In the investigation of the impact damaged samples, a pulsed thermographic system (Echotherm) employing a medium wave (3 – 5 μm) infrared camera (Phoenix) was used for the imaging and analysis of the panels. Echotherm, a portable state-of-the-art non-destructive testing and evaluation system, has an attached integrated flash heating system (giving ~10 KJ for variable duration of the flash heating - up to 25 ms). The Phoenix mid-wave infrared camera (also attached to the system) uses a cooled InSb detector with a maximum frame rate of 60 Hz and a focal plane array pixel format of 320x256.

3. RESULTS & DISCUSSION

In the investigation of composites with transient – active thermographic approaches, since the thermal diffusivity mainly affects the time of maximum thermal contrast, the clearest images (high thermal contrast between defect and sound area) are acquired at relatively long periods during the cooling down thermal transient process.

In the instance of the inserts, detection of the simulated delamination can be seen in the representative figures (Figures 2 and 3) presented in this work. Furthermore, supplementary C-Scan results can also be seen for the same samples in figure 4.

In the case of the assessment of the impact-damaged samples, it was possible to view the impact damage on the surface of the investigated samples. Especially in the case of the thinner composite panels (i.e. Al/FM-94/s-Glass/FM-94/Al) the impact damage was further noticeable (see figures 5 and 6). Furthermore, even in the case of the thicker GLARE samples (i.e. Al/FM-94/s-Glass/FM-94/Al/FM-94/s-Glass/FM-94/Al) the defected areas, created by the impact damage testing, were able to be picked up by pulsed thermography. A representative image for this case can be seen in figure 7.

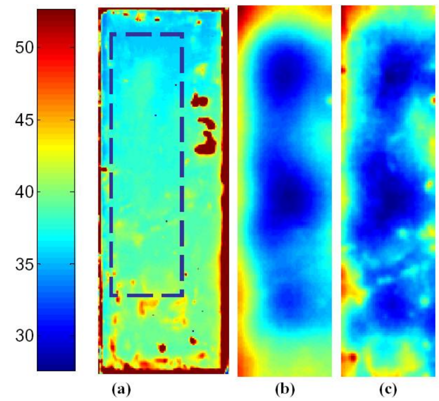

Figure 2: Thermography result after investigating sample DT1: (a) raw thermogram, (b) 2nd time derivative image of selected area at a time of 0.5512 s, (c) pulsed phase thermogram at f=0.7907 Hz.

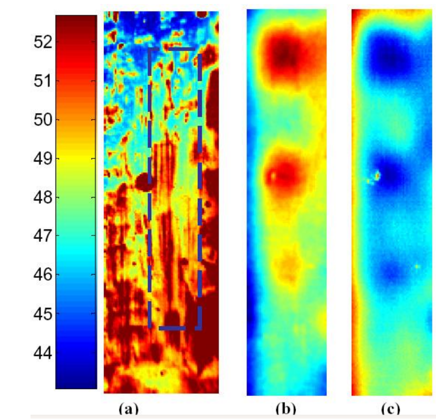

Figure 3: Thermography result after investigating sample DP2: (a) raw thermogram at 0.02 s, (b) 2nd time derivative image of selected area at a time of 0.0634 s, (c) pulsed phase thermogram at f=0.9624 Hz.

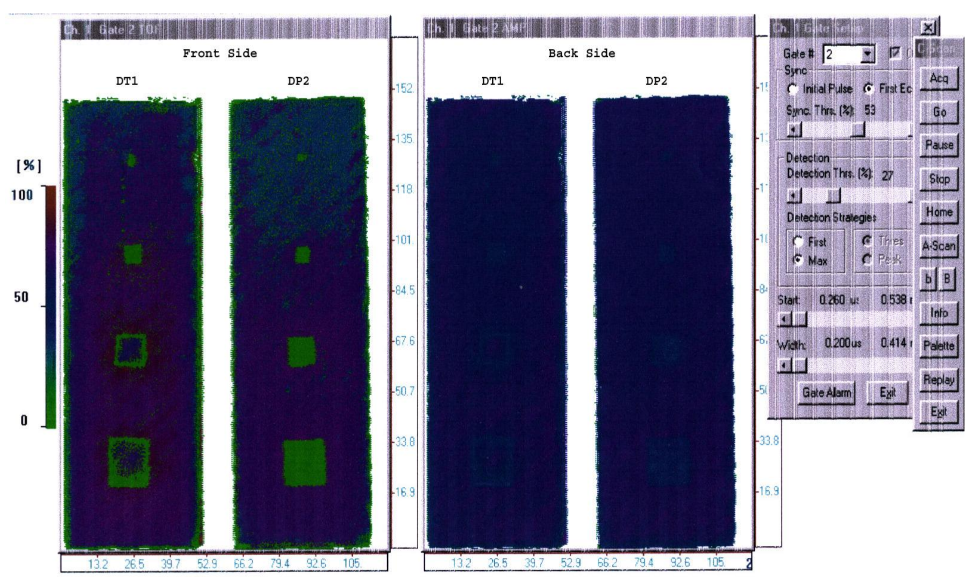

Figure 4: C – Scan results after investigating samples DT1 & DP2.

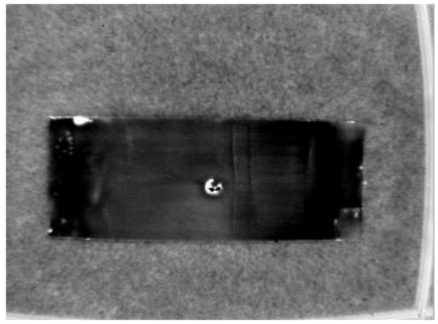

Figure 5: Thermogram of GLARE sample (Al/FM-94/s-Glass/FM-94/Al) after impact damage testing (8 Joules).

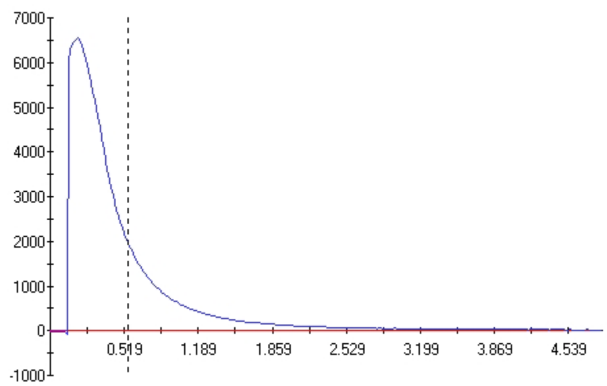

Figure 6: Temperature – time plot of sample presented in figure 5.

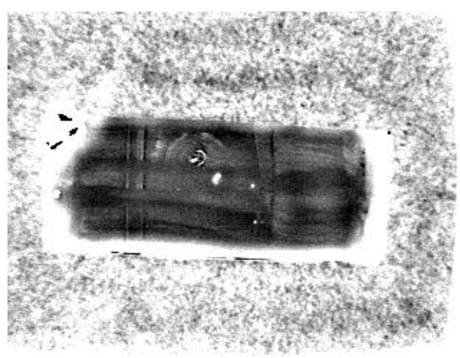

Figure 7: Thermogram of GLARE sample (Al/FM-94/s-Glass/FM-94/Al/FM-94/s-Glass/FM-94/Al) after impact damage testing (4 Joules).

From the obtained results it was realised that thermography (using both experimental set-ups) was possible to detect the defected areas in the GLARE and/or GLARE type composite panels that were investigated in this work. Nonetheless, quantitative analysis, especially in the case of the inserts – simulated delamination was not possible, due to the noise within the obtained thermograms. It is however the authors' intention to accomplish this in GLARE composites, at a later stage.

4. CONCLUSIONS

The main objective of this work was to employ active – transient thermography approaches such as pulsed thermography and pulsed phase thermography in order to detect simulated delamination (inserts), as well as impact damage on GLARE composite panels. Both approaches were mostly used [6] in qualitative terms (i.e. defect detection). However, some analysis (i.e. temperature – time plots), was also attained. The acquisition of the thermograms was completed taking into consideration the thermal characteristics – properties of the composites under investigation, as well as the defect type (i.e. impact damage or delamination). In both situations thermography proved to be an appropriate means of revealing-detecting the defects at the investigated composite panels. It is therefore concluded that thermography could be used in the rapid investigation of GLARE composites, producing interpretable results.

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