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NDT thermographic techniques on CFRP structural components for aeronautical application

V. Dattoma[a], R. Nobile[a], F.W. Panella[a], A. Saponaro[a]*

[a]*Department of Engineering for Innovation, University of Salento, Lecce 73100, Italy*

Abstract

This paper describes the application of active pulsed Thermography (PT) as a Non-Destructive Test (NDT) method for the investigation of CFRP aeronautical components. The analyzed specimens include T-shaped stringers, previously monitored by ultrasonic analysis, and laminated flat plates with internal production defects. Several set-up tests allowed to identify optimal configurations for the defect detection, according to specimen geometry and defect location. A custom post-processing algorithm has been developed to improve thermographic data for more precise defect characterization, whilst a successive full-field contrast mapping allows to achieve a reliable defect distribution map and a better definition on larger areas. Detection of defects was studied with a specific thermal contrast evaluation, with a suitable choice of undamaged reference area during the transient cooling phase. The influence of heating time and experimental set-up on the thermal contrast results has also been studied; moreover, the ability of thermographic technique to detect real small production defects with accuracy and reliability is verified for CFRP aeronautical components.

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Keywords: NDT; pulsed thermography; thermal contrast; real defects; CFRP aeronautical components.

1. Introduction

Defects can be introduced in composite materials during the manufacturing process or are developed during normal service life. The most common defects can be porosity, the presence of voids and cracks in the matrix and mostly delaminations (Bolotin, 1996; Mallick, 2008; Ghobadi, 2017). For these reasons, defect detection becomes a

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* Corresponding author. Tel.: +39 (0)832 297786; fax: +39 (0)832 297768.
E-mail address: andrea.saponaro@unisalento.it

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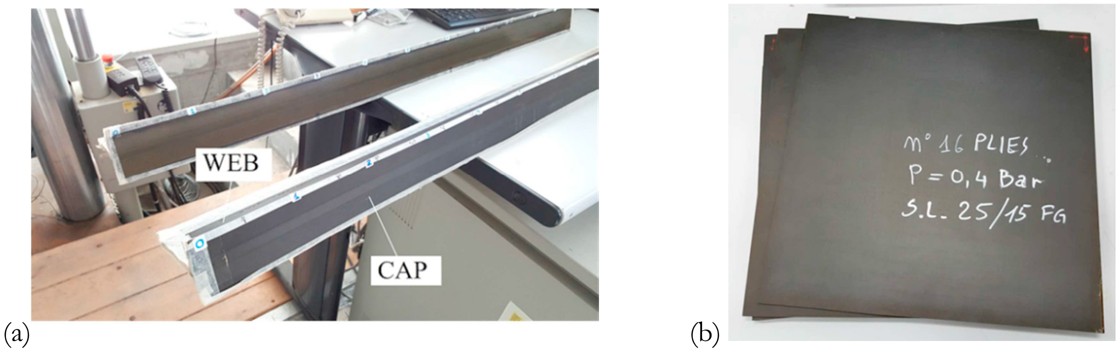
critical activity to verify integrity of structural parts (Roth et al., 1997; Hendorfer et al., 2007; Almond et al., 2012). Active thermographic methods are now a promising technique to check the structural integrity of CFRP aeronautical components (Avdelidis et al., 2003; Mayr et al., 2010; Almond and Pickering, 2014); the methods differ in the type of excitation source and thermal response processing; transient thermography techniques analyze the thermal maps during the cooling phase, as recorded on component surface after it has been exposed to various types of thermal pulses. For pulsed thermography (Maldague, 2003; Ibarra-Castanedo, 2005; Sun, 2006), adopted in particular in this work by the authors, halogen lamps are used to stimulate the inspected material with an unique intense thermal input. Unlike flash thermography (Maldague, 1993), thermal energy is applied for a longer time period and the presence of defects and their characteristics are analyzed by means of thermal contrast evaluation between non-defective zones and damaged areas (Maldague, 2003; Maldague et al., 2002).

The present work applies pulsed thermography (PT) to CFRP aeronautical components in the form of stringers and flat plates containing real defects, whilst in previous papers the authors applied similar techniques to detect artificial defects (Carofalo et al., 2012-2014) in composites. In addition, an extensive experimental campaign is needed to define the optimal set-up and optimization of parameters for a better detection and characterization of defects.

A matlab routine is developed by implementing Source Distribution Image methods (Susa et al., 2010), based typically on the analysis of isothermals to select a defect-free reference zone, supposing it receives the same heat flux of the damaged zone. In this paper a new method, based on algorithm named LBC *(Local Boundary Contrast)*, has been introduced by the authors; it is based on a new contrast mapping methodology, which allowed to achieve a better identification and more accurate distribution maps of dangerous defects.

2. Materials and specimens

The CFRP components investigated in this work include 2 T-shaped stringers (here denoted A and B) and 3 laminated flat plates. All specimens present different real defect typologies, such as slight and diffused delaminations with localized small voids in the first case and elevated porosity values in the latter case. The length of both stringers is 970 mm and their analysis has been performed inspecting the CAP areas, manufactured with Automated Tape Lay-up, with 15 plies and a thin protective tape on it for a thickness of 2.76 mm; the WEB zone is built with 30 plies and a total thickness of 5.20 mm, without protective tape (Fig.1a).



(a) (b)

Fig. 1. (a) stringers parts inspected (CAP and WEB); (b) laminate flat plate specimens.

The flat plates (400 x 400 mm^2) have been manufactured in a vacuum bag in an autoclave (Fig. 1b), inducing porosity through pressure variation during curing cycles. The stacking sequence, number of plies and cure pressure for each plate are indicated in Tab. 1.

Tab. 1. Stacking sequence, number of plies and cure parameters of laminated plates.

Specimen	Thickness [mm]	No. of plies	Pressure [bar]	Stacking sequence
Panel 1	3.023	16	0.4	[0, +45, -45, 90, 0, +45, -45, 90]s
Panel 2	5.568	24	0.1	[0, +45, -45, 90, 0, +45, -45, 90, 0, +45, -45, 90]s
Panel 3	13.267	64	0,75	[0, +45, -45, 90, 0, +45, -45, 90]4s