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Lock-in Thermography Inspection for Characterizing and Quantifying Material Defects Resulting from Parameter Deviations within the Manufacturing Process Chain of CFRP Composites

by T. Ullmann[1], T. Schmidt[2] and S. Dutta[2]

[1)] German Aerospace Center, Institute of Structures and Design, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany, *thomas.ullmann@dlr.de*

[2)] German Aerospace Center, Institute of Structures and Design, Am Technologiezentrum 4, 86159 Augsburg, Germany, *t.schmidt@dlr.de and somen.dutta@dlr.de*

Abstract

Due to upcoming requirements of reduced weight and significant savings in fuel consumption of future aircraft types, lightweight composite materials such as carbon fiber reinforced polymers (CFRP) are playing a key role in modern aircraft design concepts. With new aircraft models like as for example the 787 from Boeing and the A350 XWB from Airbus, manufacturers have just begun to establish a new generation of so called black airframes which are mainly composed of carbon fiber reinforced composites. The use of such a new material class does not only mean to exchange structure components but to revise the whole structure design, component manufacturing and joining techniques as well as the material's machining procedures, maintenance procedures and quality assurance concept. In order to reduce manufacturing costs and at the same time ensure high quality standards, it is inevitable to establish a reliable monitoring system which is integrated into the production process. For example a CFRP pre-form structure which shows anomalies in the fiber layup after draping, will be removed from the process chain immediately in order to avoid ongoing expensive process steps and therefore to minimize the manufacturing costs. However, quality assurance is not only a question of identifying and separating structure components with material flaws but to understand which kind of parameter deviation is responsible for the rejection of CFRP parts in order to improve reliability of each step of the process chain. First of all it is necessary to understand what kind of microstructural anomaly in the composite material is critical and which is not and how it can be distinguished and quantified with non-destructive inspection techniques. While establishing new manufacturing techniques for CFRP structure components, aircraft industry is also searching for non-destructive techniques that are capable to fulfill a bunch of specific key criteria such as a high scanning/measurement speed, a large coverage area per measurement cycle, high defect selectivity or the ability of single-side inspection. However, lock-in thermography is one of the promising inspection methods that become more and more important for this field of application.

This work is focussing the capabilities of optically enhanced lock-in thermography (OLT) for identification and categorization of manufacturing related failure critical defects in CFRP composites. The material investigated here was manufactured by using different processing routes and is contaminated with artificial flaws of varying size and density (e.g. porosity or out of plane undulations). In order to obtain quantifiable information from the phase images of OLT inspection, other non-destructive methods such as air-coupled ultrasound and X-ray based computed tomography (CT) are used as reference. As an example, Figure 1 and 2 are showing the phase shift signature of OLT from different thermal penetration depths of a CFRP sample plate. In comparison, Figure 3 shows the same material area as a C-mode scan from air coupled ultrasound inspection. The varying colours of the ultrasound image are representing different attenuation values caused by the inhomogeneous distribution of pores. Although both OLT phase images (Fig.

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1 & 2) were undergoing post-processing by means of colour distribution and enhanced contrast, it is very difficult to compare the visual signatures obtained with OLT and air-coupled ultrasound directly. There might be two main reasons: first the C-mode ultrasound image is a projection of all details through the thickness of the CFRP fibre layup while OLT images of different attenuation frequencies (Figure 1: f = 0.3 Hz and Figure 2: f = 0.06 Hz) are always focused on certain thermal penetration depths (Figure 1/2: $\mu \approx 0.7/1.5$ mm). Second, it is basically quite challenging to compare the interactions between material microstructural patterns and acoustic waves with those of thermal waves which behave quite different from their physical nature. Visual comparability is certainly a question of fibre layup type, defect size and defect density as well.

However, in order obtain comparability it is inevitable to analyze and compare numerical values from the measurement image data files. Due to the variation of defect parameters in one and the same sample plate it is necessary to define certain regions of interest (ROI) of approx. 20 x 20 mm with quasi constant defect density. Referring to the exact position of each ROI, reference measurement with CT and destructive analysis methods (e.g. chemical analysis) are compared with the numerical data from non-destructive air-coupled ultrasound and OLT inspection for certain penetration depths. The objective of this work is to make analysis procedures of OLT measurements more precisely in terms of providing reliable data for material quality assurance and manufacturing process control.

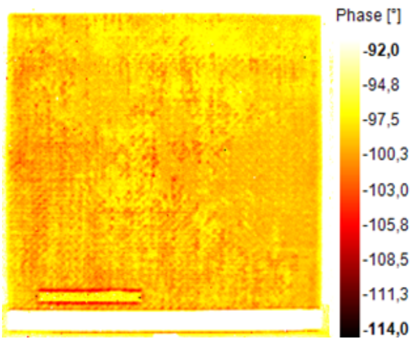

Fig. 1: OLT phase image at f = 0.3 Hz attenuation frequency

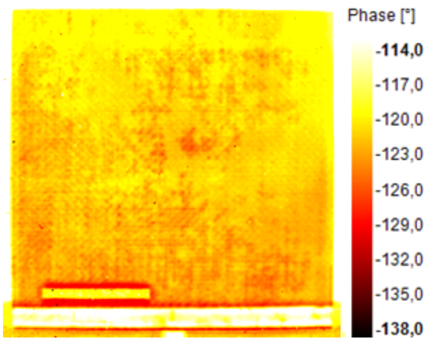

Fig. 2: OLT phase image at f = 0.06 Hz attenuation frequency

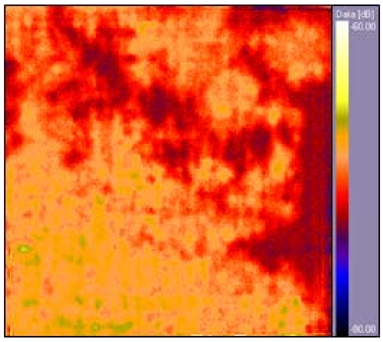

Fig. 3: C-mode image of air coupled ultrasound inspection