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Identification of lightning strike damage using Pulse Thermography through integration of thermal data

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ABSTRACT

A novel process is investigated, which evaluates the use of pulse thermography data to assess lightning strike induced damage in composite materials. A new damage identification approach is proposed that numerically integrates the difference in thermal decay between each image pixel and the thermal decay from a selected reference pixel that corresponds to no visible damage. The resulting integration provides a metric for the thermal decay pixel-by-pixel relative to a non-damaged region, which provides a quantitative damage severity parameter.

Keywords: lightning strike damage, wind turbine blades, CFRP composites, pulse thermography, active infrared thermography.

INTRODUCTION

Lightning protection of wind turbine blades has gained attention over the past few years. The problem has become acute and serious with regards to damage due to the increasing use of electrically conductive Carbon Fiber Reinforced Polymer (CFRP) composite materials for large wind blades, rather than Glass Fiber Reinforced Polymer (GFRP) composite materials, that have been traditionally used. Significant research has been conducted to understand the problems involved where efforts to a large extent have turned to experimental methods such as simulated lightning strike on CFRP panels to understand the resulting damage. The damage is typically identified and assessed by CFRP ultrasonic techniques (UT) [1], [2]. An appealing alternative to UT would be Pulsed Thermography (PT), which takes minutes to conduct rather than hours and does not require a couplant. PT is an NDE method based on the use of infrared imaging systems to detect subsurface damage. The IR images show a thermal decay from a pulsed energy source as it passes through a component or sample. Methods developed to detect subsurface damage for thermography are either purely utilizing the temperature map from the IR readings or using FFTs to convert the data to the frequency domain and extracting the phase of the thermal response, known as pulse phase thermography [3]–[5]. In the paper, a new damage identification approach for composite materials is proposed based on numerical integration so that the difference in thermal decay between each IR data pixel is identified by comparison with the thermal decay from a reference pixel that corresponds with no visible damage.

MATERIALS

The proposed data processing method is evaluated using calibrated plate samples made from Glass Fiber Reinforced Polymer (GFRP) composite material with known defects, and it is also used to investigate CFRP samples damaged by simulated lightning strikes. The calibrated GFRP plates are 4-ply contacting stitched bi-axial E-glass fiber reinforcement and epoxy resin with a total laminate thickness of 2.4 mm. The known defects are 20 mm square PTFE inserts placed between plies to simulate a delamination. The second test was conducted using CFRP pultruded samples. The CFRP samples were made with Zoltek Panex 35 fibre system with vinyl ester resin. The dimensions of the samples were 400 mm long x 200 mm wide x 5 mm thick. The samples were struck with oscillating currents up to 150 kA.

INTEGRATION METHOD

The thermal data is captured in the same way as a typical PT inspection. The key feature of the new approach for damage detection is the way the results are post-processed. The integration method is carried out in three steps. The first step is data gathering from the IR camera. The data gathering takes the temperature data from the IR camera and assemblies it into a 3D matrix. The 3D matrix is made up of a 2D array of temperature measurements from the IR image for each pixel, with the third dimension being a stack of these 2D temperature measurement arrays at different times based on the recording of the camera. The second step is to normalize the temperature data. As the flash does not provide a uniform temperature field over the surface of the sample, the temperatures of each pixel need to be normalized. Each pixel is normalized by taking an average of the temperature readings from a point in time where the temperature on all the pixels are the at ambient temperature to the end of the data. Then, the pixels are corrected to a reference pixel by moving the full temperature set of each pixel up or down by an addition operation. The third step is to numerically integrate the data. This method uses a Matlab script to integrate using a trapezoidal rule. The integration runs from the time of the flash point (or when the active thermography is started) until the pixels return to ambient temperature. The result of this is a 2D array of data indicating where heat had to accumulate before diffusing through the sample, thus providing a clear indication of where damage has occurred.

EXPERIMENTAL PROCEDURE

The setup used for thermography includes are 4 components: (1) IR camera, (2) flash/heat source, (3) sample, and (4) computer as shown in Figure 1. The heat source chosen for this method is a Nikon flash. The IR camera used for this research is a FLIR SC5000.

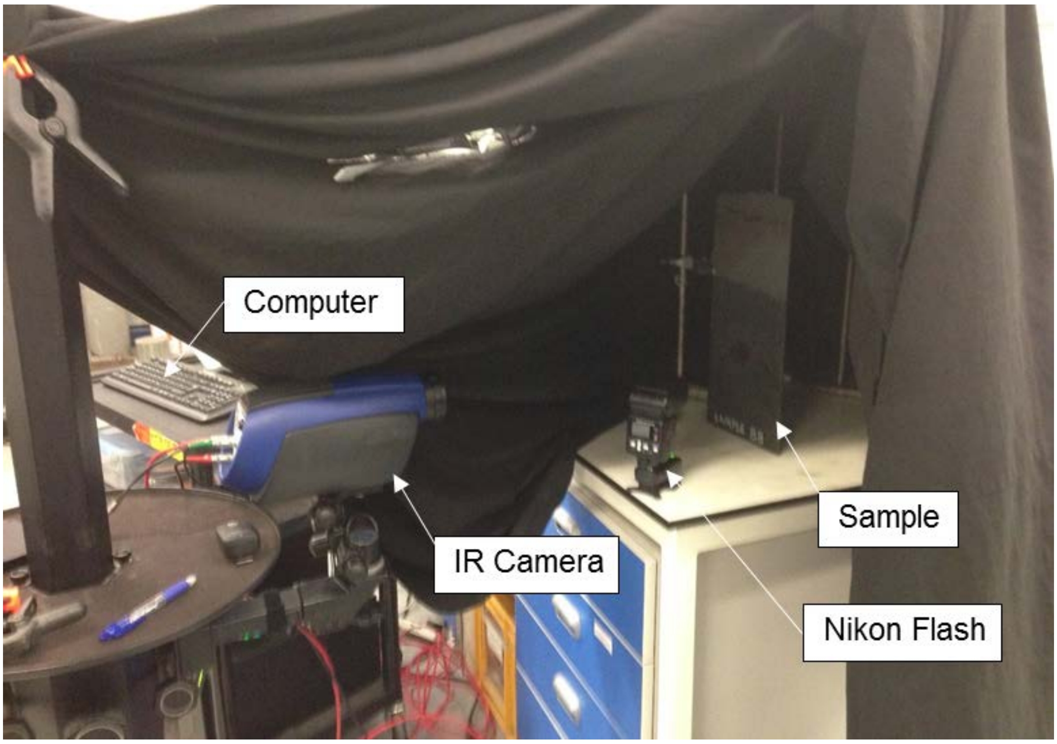

Fig.1 *Thermography setup*

RESULTS

The resulting integration over the samples provides a value for the thermal decay pixel-by-pixel relative to a non-damaged region, thus providing a quantitative damage severity parameter. The resulting colormap correctly identifies the known defects and displays constant severity over the PTFE insert region. The same method was applied to the lightning damaged CFRP samples made of 5-ply stitched dry fabric. Figure 2 and 3 show the integration for the GFRP calibration plate and the CFRP lightning strike damaged sample, respectively. The resulting integration reveals the full extent of the damage, which cannot be identified by pure visual inspection.

CONCLUSIONS

The results show a new post processing method with PT that can indicate damage severity and sub-surface damage in composite materials. This method gives a quantifiable measure of difference in damage across the inspected material, and the new method takes far less time (minutes instead of hours) to setup and evaluate compared to UT.

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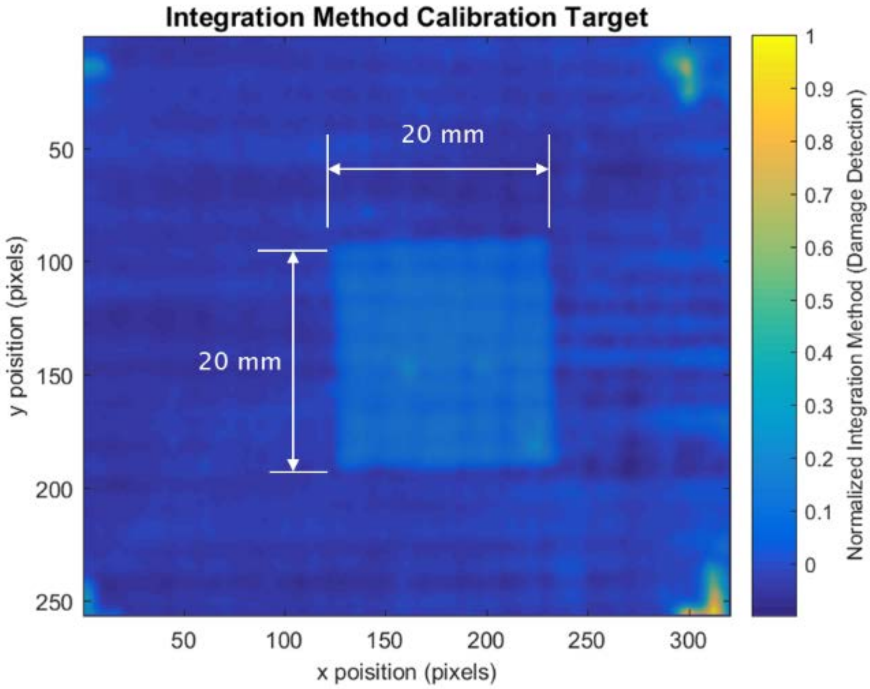

Fig.2 *Integration method of GFRP calibration plate sample*

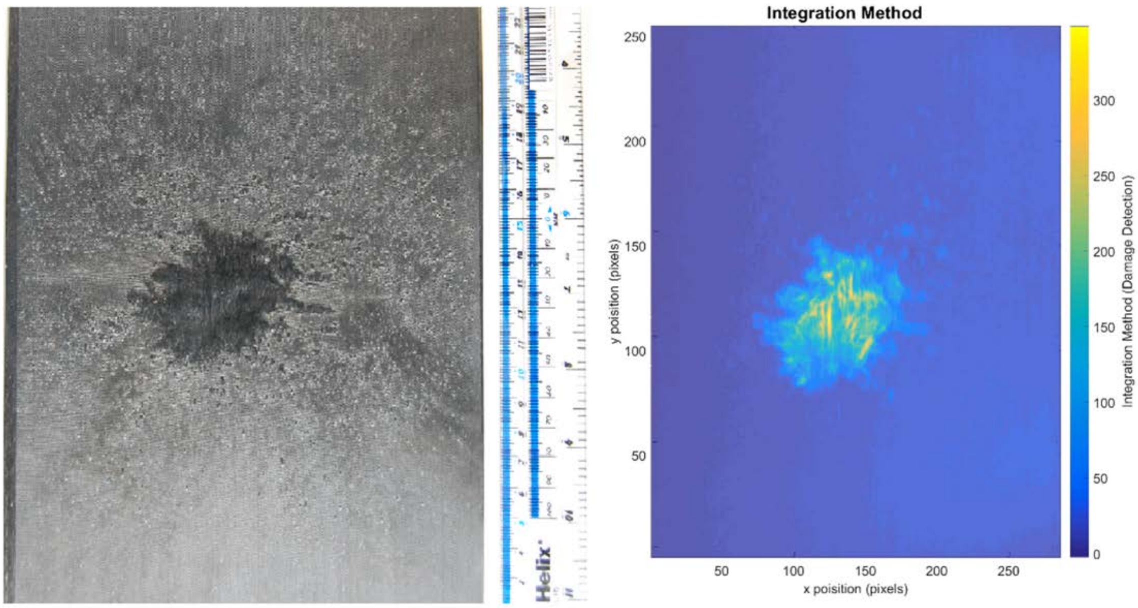

Fig.3 *PT Integration method of CFRP sample damaged by simulated lightning strike*

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