Active Thermography Method for Delamination Detection and Localisation in Composite Structures

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ABSTRACT

This paper presents an application of active thermography method for delamination detection in CFRP composite panel. The panel is a part of a AW-139 helicopter fuselage. For this purpose a optical excitation was used. This method based on exciting the composite surface with a single pulse from halogen lamps. Transmission method was investigated that was based on excitation of one face of the specimen and observing the infrared response on the second face of the specimen. The surface temperature distribution highly depends on the structure of the investigated composite specimen. This allows to determinate location of stiffeners, changes in thickness, internal composite structure as well as different types of damage (crack, delamination) occurrence.

During the investigation a whole composite sample face was excited by optical source. A back face infrared response was being continuously monitored using infrared camera SC-5600 FLIR. The monitoring was begun just before the excitation pulse started and finished when the sample cooled down. Three cases were investigated. Firstly, sample with one delamination due to impact damage and the next with two and three delaminations were investigated.

INTRODUCTION

Infrared thermography is very useful method widely used in diagnosis of many types of structures. Infrared thermographic methods are divided into passive and active ones [1]. In the passive methods natural heat distribution in structure due to its normal operation is utilized. It means that additional heat excitation is not used. In the active methods external thermal excitation is applied to the structure. Active methods are more often used in NDT (*None*

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Destructive Testing) of structures in comparison to passive methods. In active methods various types of thermal excitation are used: ultrasound exciter [2], halogen lamps [3], xenon flash lamps [4], eddy current transducers [5]. Optical based excitation method have such advantages that allow to avoid modifications of temperature field of structures due to the contact of exciting transducer (ultrasound based methods).

Active methods utilizing thermal excitation can be divided into two groups according to form of implemented thermal excitation: pulse [1],[4] or continuous (*lock-in* methods) [1],[2],[6]. In the case of pulse method choice of proper thermal pulse parameters is a key issue. In the [7],[8] two types of excitation pulse shapes are investigated: rectangular and exponential. In [9] very interesting approach based on frequency modulated thermal excitation is used. Such approach allow to detect discontinuities located deeper as well as allow to avoid problems with non-uniform distribution of thermal reflection coefficient.

In active infrared thermography two approach can be distinguished according to the [1]. First is based on heat reflection (thermal excitation source and infrared camera on the same side of sample) and second on heat transmission (thermal excitation source and infrared camera on opposite side of sample).

Active infrared techniques are widely utilized for damage detection in metallic structural elements especially in aerial structures [1], [10] as well as parts made out of CFRP (*Carbon Fibre Reinforced Polymer*) [11] and GFRP (*Glass Fibre Reinforced Polymer*) composites [12]. In composite materials infrared active thermography allow to detect delamination, matrix cracking or thermal degradation [13] Infrared thermography is increasingly utilized for composite bonds evaluation, for example kissing bonds are detected [10].

A problem of signal processing in the field of active thermography methods is very important. Thanks to especially developed algorithms of image and signal processing algorithms it is possible to detect small discontinuities existing inside of many types of structures.

The state of art shows that problem of composite material inspection is very important. It is caused by fact that composite elements are more and more used as a part of new developed structures. The motivation of conducted research was a lack of papers related to the thermal transmission method using optical heating source. Moreover signal processing method is more straightforward than in the case of thermal reflection method.

This paper presents a delamination detection in composite sample using active thermography method – transmission method. The investigated sample was excited using optical source (halogen lamps), while the infrared response on the second face of the specimen was measured using infrared camera. One, two and finally three defects in one specimen were investigated. The results of analysis performed in a purpose of damage detection and localisation are presented and discussed.

EXPERIMENT

The experimental investigation was performed on a CFRP (*Carbon Fibre Reinforced Polymer*) sample cut off from an AW-139 helicopter panel. The sample is presented in Figure 1. The sample was examined using active thermography method – transmission method. The experimental set up is presented in Figure 2. It consists of infrared camera SC-5600 FLIR (1), halogen lamps (2) and PC computer (4) used for infrared camera software operation.

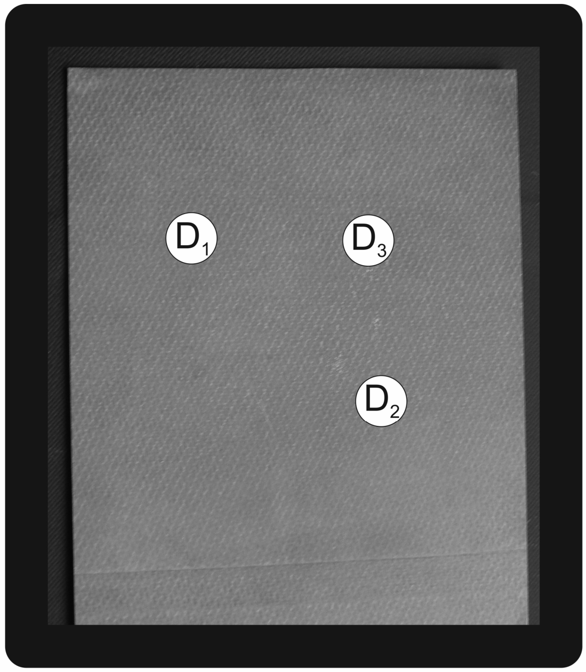

Figure 1. Composite sample with delamination locations denoted as D1 to D3.

During the experiment one face of the specimen was excited using optical source (three halogen lamps, 150 W each) while the infrared response was observed on the second face of the specimen using infrared camera. The sampling frequency of the infrared camera was equal to 100 Hz. The monitoring was begun just before the excitation pulse started and finished when the sample cooled down.

Figure 2. Experimental set-up: 1 – infrared camera, 2 - halogen lamps, 3 – composite sample, 4 – PC

The excitation was concentrated on the centre part of the sample. The Figure 3 presents the normalized infrared image of temperature distribution on second face of the examined sample. As it is visible the highest value of energy from the optical source was located in the middle of the sample.

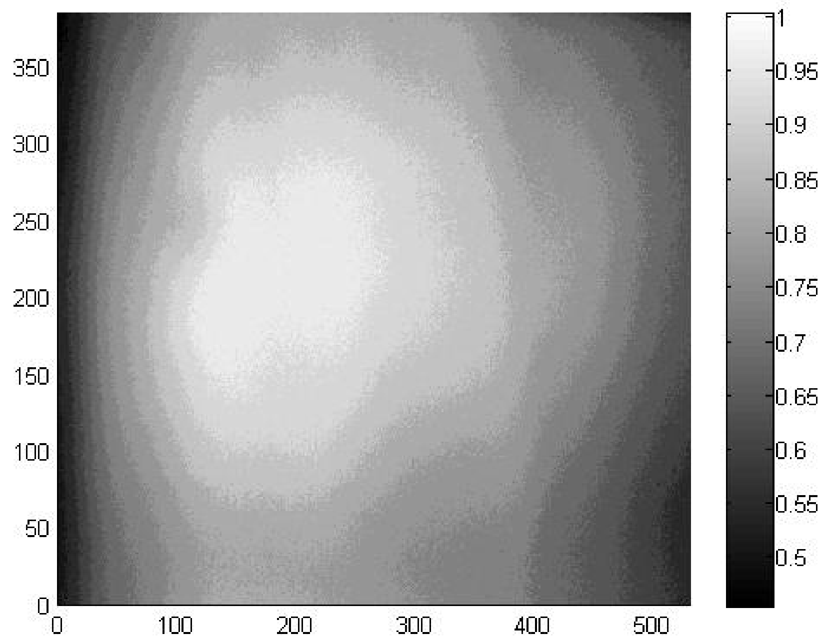

Figure 3. Temperature distribution during heating process.

The experiment was divided into three steps. In the first step one delamination (denoted as D_1) was made in the specimen, in the second step the next one (denoted as D_2) was added. Finally in the last step the specimen had three delaminations (denoted as $D_1 - D_3$) – see Figure 1 for more details. The delaminations location on maps presented in the paper are described as areas containing pixels in a range of (81-125, 242-278) for delamination D_1, (349-390, 94-121) for delamination D_2 and (349-390, 94-121) for the third one denoted as D_3. In every step of the experiment the specimen was examined using transmission thermography method.

RESULTS AND DISCUSSION

The damage detection was performed using following procedure based on division of the whole range of registered values *M(k,i,j)* of termogram (called digital level) into subsets according to its rising values. These values *M(k,i,j)* are measured in every pixel *(i,j)* of the termogram at time instant *k*.

Each subset represented 25 values of *M(k,i,j)*. In this way the number of data to process was reduced. The smaller values were put in the first subset, then the higher values to the second one. The procedure was continued as long as all digital levels were assigned to appropriate subsets. The number of subsets depends strongly of delamination location and its level. Then for every subset element one number was assigned equal for all subset elements. The procedure can be described as follows for a chosen time instant *k*:

$$M'(k,i,j) = \begin{cases} 1 & 0 < M(k,i,j) \le 25 \\ 2 & 25 < M(k,i,j) \le 50 \\ \vdots & \vdots \end{cases} \qquad (2)$$

This allows to create maps divided into parts equal to subsets and consists only few values. Maps of that kind are presented in the next part of the paper, although in a purpose of better reading all values presented on maps are normalised.

Then the processed frames were divided in a purpose of creating maps containing of few values showing similar pattern to fingerprints or rings of a tree. For every step of the experiment one example of differences map is presented shows divisions difference between 600th and 650th frame (50 frames). The idea of the procedure is to achieve the damage location using as small subsets number as it is possible.

All maps presented in the paper consists only the IR response from the composite sample surface. The surrounding holder and environmental background was removed.

One delamination

In the first step of the experiment one delamination (denoted as D_1 - Figure 1) was made. Figure 4 presents map of differences between two maps containing processed signals from infrared camera. The optical source location is visible in the map. Unfortunately the delamination slightly influenced the heat distribution process. A curvature of gradient lines is visible in its location, but similar curvature can be notice in other parts of the sample. The problem with detection of the particular delamination was strongly related to heating source location. A part of the delamination was located on a part of a sample that was not heated at the instant of turning on the heating source (halogen lamp). So, the delamination part hided in a shadow in a border part of the investigated sample, while the second half of it was located in the hotter part of the sample.

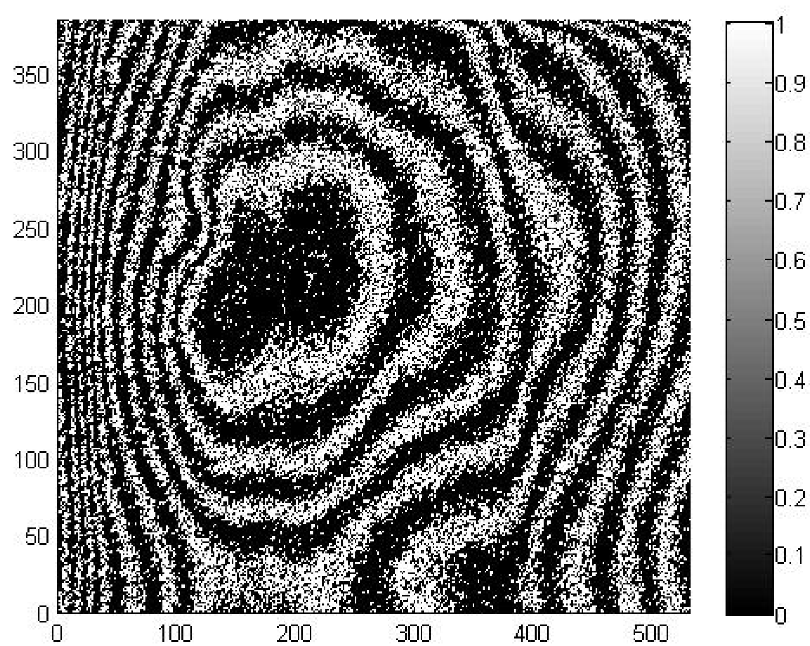

Figure 4. Maps of differences between two processed frames M' from the infrared camera for one delamination.

Two delaminations

In the next step in the investigated sample second delamination (D_2) was made, so the investigated sample contained two delaminations. Figure 5 shows a map presents differences between two maps containing processed signals from infrared camera. The second delamination (denoted as D_2) is better visible, than the previous one (denoted as D_1). It is due to its localisation on a part of the sample that is heated uniformly. The delamination denoted as D_1 is poorly visible, because in its location only small disturbance is occurred. The location of the delamination D_2 is visible as a circle area of a smaller value of processed digital level surrounded by a circle ring of a higher value of processed digital level.

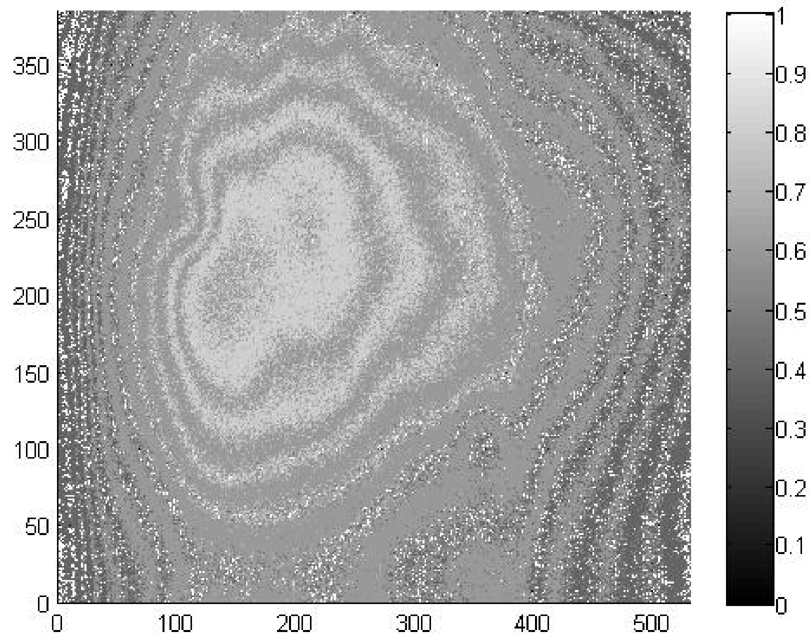

Figure 5. Maps of differences between two processed frames M' from the infrared camera for two delaminations.

Three delaminations

In the last step in the investigated sample the third delamination (denoted as D_3) was added. This newly created delamination was located on a hotter part of the sample than delaminations made previously and surrounded by area of similar digital level values. In Figure 6 a map of differences between two frames in a distance of 50 frames is presented. The locations of two delaminations D_2 and D_3 are easily visible as a circles surrounded by a circle rings or curves passing by the damaged region.

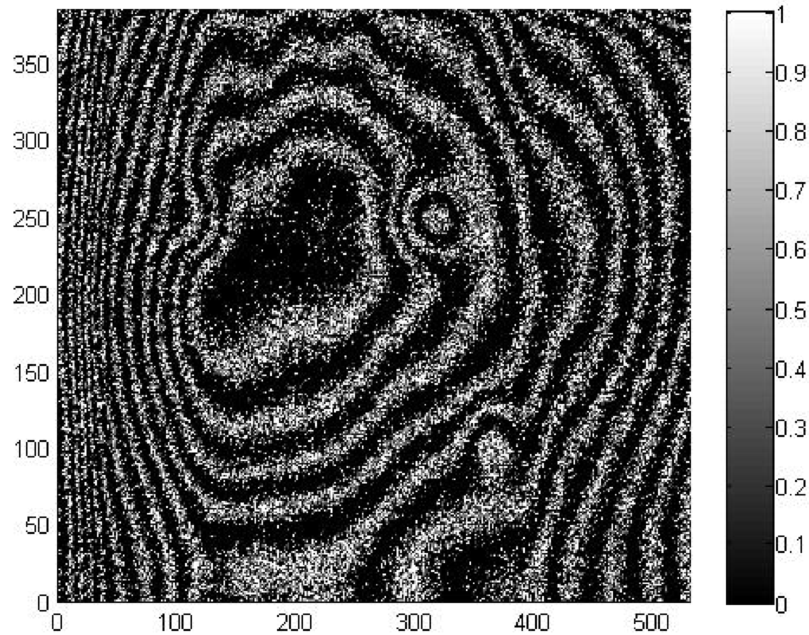

Figure 6. Maps of differences between two processed frames M' form the infrared camera for three delaminations.

CONCLUSION

In the paper an application of active thermography method for delamination detection in CFRP (*Carbon Fibre Reinforced Polymer*) composite panel being a part of AW-139 helicopter is presented and discussed. During the investigation a transmission method was used, while excitation was made using optical source (halogen lamps). The experimental tests were divided into three steps, according to consecutive delamination creation. The received raw signals from infrared camera were analysed and processed. A method of signal processing based on division the measured signals into subsets and then determining maps presenting differences between processed frames is presented and discussed in the paper. The method allows to determine the location of delaminations that are not well visible in raw signal from the infrared camera. Also the achieved maps features showing the similarity to fingerprints or rings of a tree present good possibility for automation of the damage localization process.

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