ANALYSE D'IMAGES THERMOGRAPHIQUES DE STRUCTURES EN MATÉRIAU COMPOSITE

ANALYSIS OF THERMOGRAPHIC IMAGES OF COMPOSITE PARTS

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Résumé

Dans cet article sont présentés les résultats de mesures thermographiques de défauts situés dans différentes pièces d'avion en matériau composite. Pour ce faire, deux méthodes de thermographie infrarouge ont été mises en œuvre : la thermographie induite par ultrasons et la méthode LockIn. Dans un premier temps, ces deux méthodes sont présentées.
Pour cette étude, différentes pièces aéronautiques, tel qu'un panneau autoraidi en composite carbone-epoxy (CFRP), ont été testées. Dans le cas de la thermographie induite par ultrasons, les paramètres d'excitation comme le temps et la puissance de l'impulsion ainsi que la distance de la source au défaut ont été étudiés. Dans le cas de la thermographie LockIn, différentes fréquences de modulations ont été utilisées. Les délaminages dus aux impacts furent détectés avec succès avec ces deux méthodes.
Par la suite, des méthodes de traitements d'images sont appliquées afin d'analyser les images et séquences d'images obtenues. Les paramètres de défauts (taille, forme) sont déterminés de façon automatique. Puis, les images obtenues avec les deux méthodes sont superposées à des fins comparatives.

Abstract

In this paper, we present results of active thermographic measurements at different composite components that were performed with Ultrasound Induced Thermography (UIT) and Optical LockIn Thermography (OLT). First, the principles of both active thermographic methods are explained.
For this study several composite components like Carbon Fibres Reinforced Plastics (CFRP) stiffened panels were tested. The samples were inspected with OLT and UIT. The parameters like ultrasonic excitation time and power as well as the distances between excitation point and defect for UIT were investigated. In addition, OLT measurements with different modulation frequencies were performed. Delaminations of impact damages could be detected successfully with both methods. Then image processing methods are used to analyse the images and sequences. The defect parameters (size and shape) are determined automatically. At the end of this study, the results obtained with both methods are overlaid and compared.

INTRODUCTION

Thermography [1-2] is a method that is mostly known for its application in the field of detection of heat loss of buildings. But in the field of non-destructive testing and aeronautics, infrared thermography is applied and investigated since more than 20 years [3-10] and found recent applications for the detection of subsurface defects (for example impacts, delaminations, fibre break or resin crack) [5-8].
In this study, we show the results obtained with two active thermographic techniques: ultrasound induced thermography [9] and optical LockIn thermography [7-8].

ACTIVE THERMOGRAPHY

Active thermography implies – in contrast to passive thermography – to introduce external energy into the material. Optical lamps or ultrasound energy are generally used (but also acoustic [10] or microwaves [11] are possible excitation sources). The techniques differentiate in the kind of excitation and the analysis of the thermographic sequence.
In this study, we utilised two techniques: ultrasound induced thermography (UIT) and optically excited LockIn thermography (OLT) (figure1). The resulting images of these both methods contain completely different information: With optical excitation a thermal wave is generated at the surface and reflected at boundaries within the component (for example at a defect boundary). Using ultrasound excitation, a hysteresis effect on thermal boundaries generates heat. This allows the distinction between different defects.

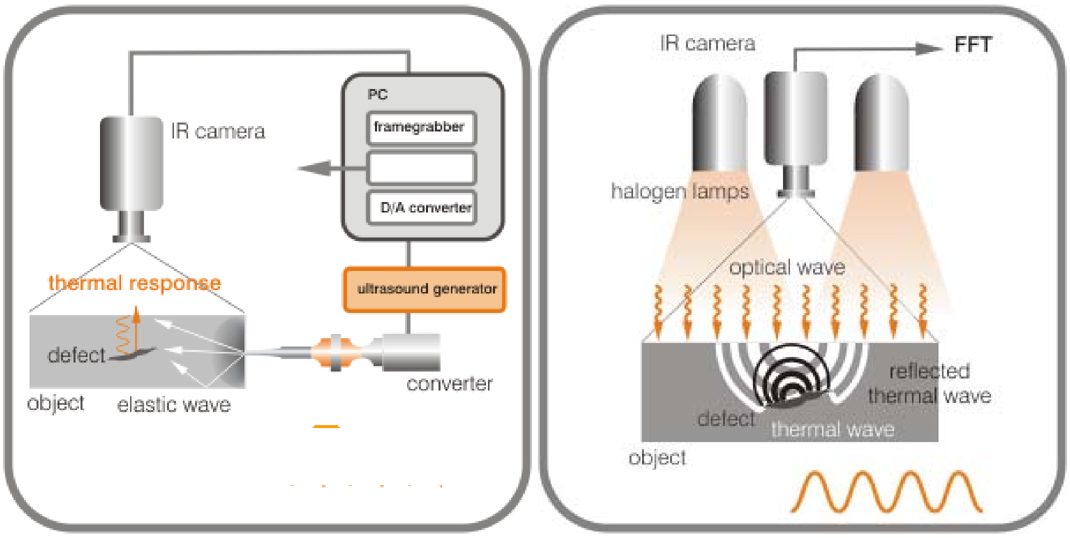


Figure 1: Ultrasound induced thermography (left) and optically excited LockIn thermography (right) [12].

Ultrasound Induced Thermography (UIT)

For this technique, the difference in the mechanical properties of defects is used to generate heat (friction). The physical mechanism of this is the increase of the mechanical loss angle (hysteresis) in the defect area. Therefore, ultrasound is injected into the component, which is preferably damped in the defect area and is thereby generating heat. The heat highlights the defect in a selective way (figure 2).

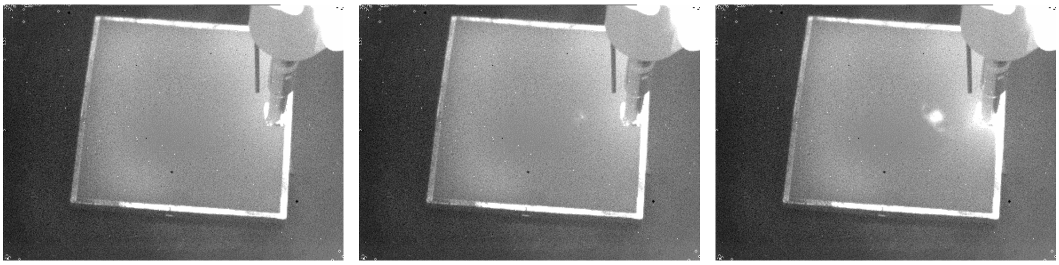


Figure 2: Detection of an impact damage in a composite part (UIT at times 0, 0.22 and 0.93 seconds after the start of ultrasound)

With an ultrasound sonotrode (here a hand-held gun, figure 3), ultrasound is injected into the material. The time and power of the induced ultrasound can be varied.

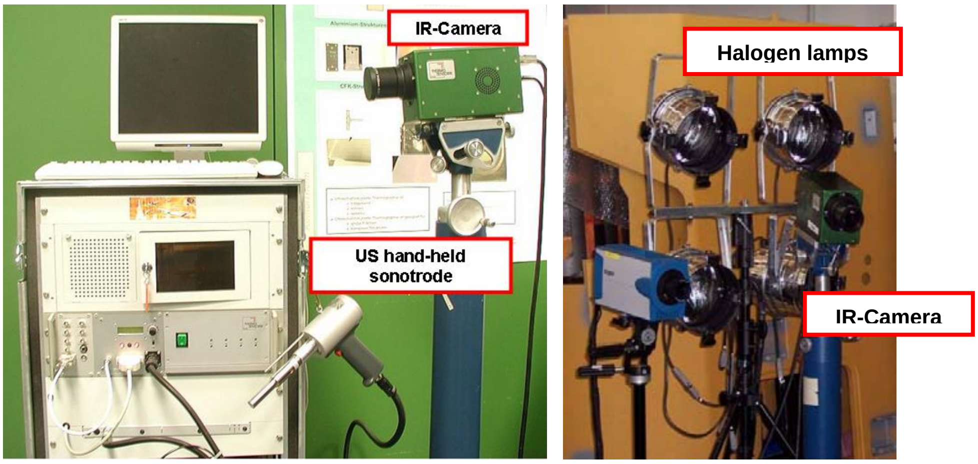


Figure 3: Thermography system with ultrasound gun (left) and with lamps for OLT (right).

Optically excited LockIn Thermography (OLT)

LockIn thermography is a dynamic measurement method (thermal wave analysis). A sinusoidal thermal wave is generated with halogen lamps, laser, or hot-air gun on the surface of the tested component (in our case halogen lamps see figure 3). The wave propagates into the part and is reflected at boundaries because of the different temperature conductivity and thermal impedance of the material (thermal boundaries).
Additionally to common thermography, a Fourier transform is performed on the time sequence and the temperature changes are analysed only at the excitation frequency. The phase images represent the time delays of the reflected wave in contrast to the initial wave.
Phase images suppress the artefact of inhomogeneous light illumination which is difficult to realise. The thermal depth penetration depends on the modulation frequency and is twice as big as the depth penetration in amplitude images. The method is therefore adjustable to different materials and testing conditions. With the help of frequency variations one can find out the depth of thermal structures (thermal tomography).

QUALITATIVE EVALUATION OF THE DETECTED DEFECTS

Figure 4: Image of the CFRP stiffened panel: Part 1

In order to investigate the performance of thermography in the detection of defect in composite material, a CFRP stiffened panel of approximately 1m*1,5m with delaminations was used (figure 4).
UIT and OLT allow both the successful detection of impact damages (delamination). For UIT, an effect of steady wave patterns might appear in stiffened panels (figure 5). In fact, the ultrasound waves are reflected between the two boundaries and standing waves are generated. Maybe by overlaying different energy frequencies, this phenomenon could be avoided. It has not been experimented yet. Nevertheless damages could be clearly detected.
Figure 6 and 7 demonstrate the successful detection of delaminations with both techniques. Figure 7 shows the effect of OLT: by varying the modulation frequency, it is possible to detect deeper defects.
A delamination observed from the rear side can be detected with ULT (figure 8). OLT could not find this defect in the direct illumination mode whereas the transillumination mode (the camera is placed on the front side and the lamps on the back side of the part so that the transmitted infrared beams are recorded) showed good results. A phenomenon of heat diffusion can be observed that let the image appear blurred.

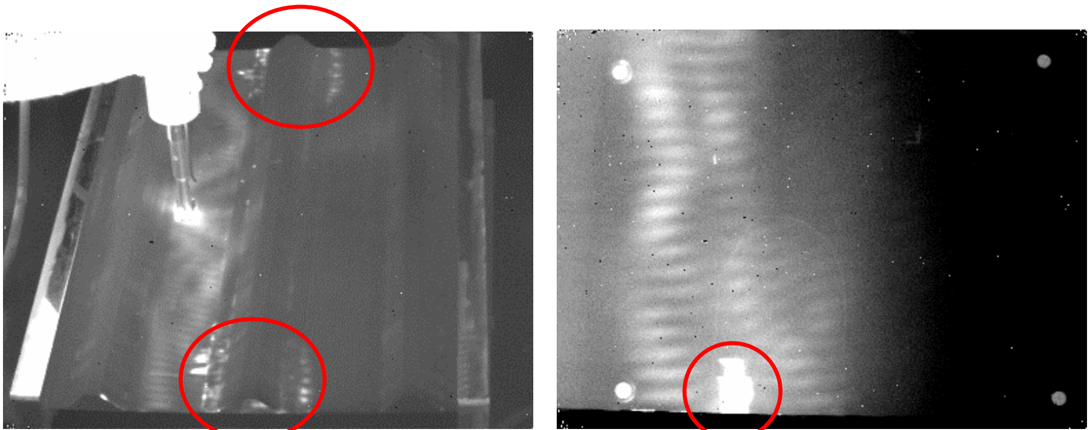


Figure 5: Detection of delaminations on the rear side (left) and static wave on the front side (right) with UIT.

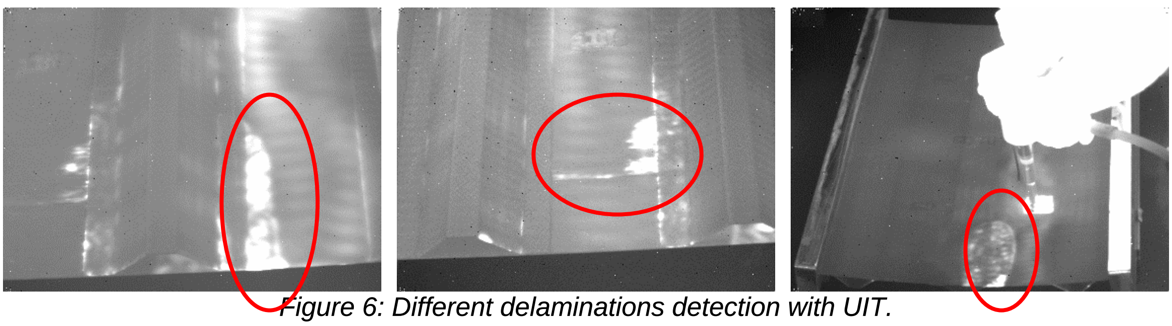


Figure 6: Different delaminations detection with UIT.

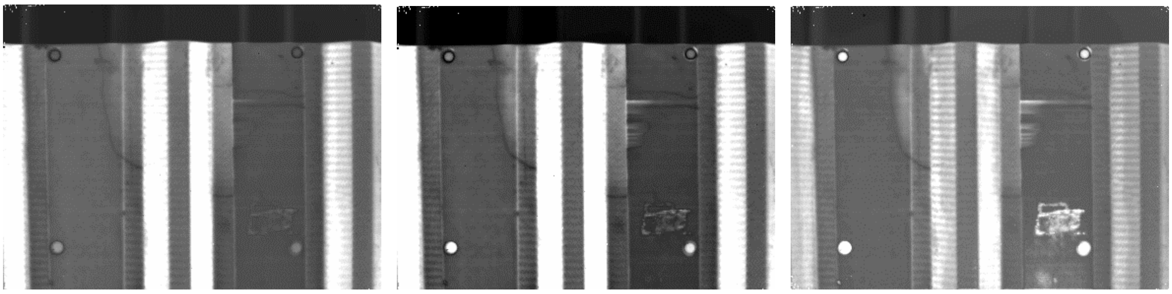


Figure 7: LockIn thermography phase images with different excitation frequencies (from left to right: 0,03 Hz 0,06 Hz and 0,1 Hz).

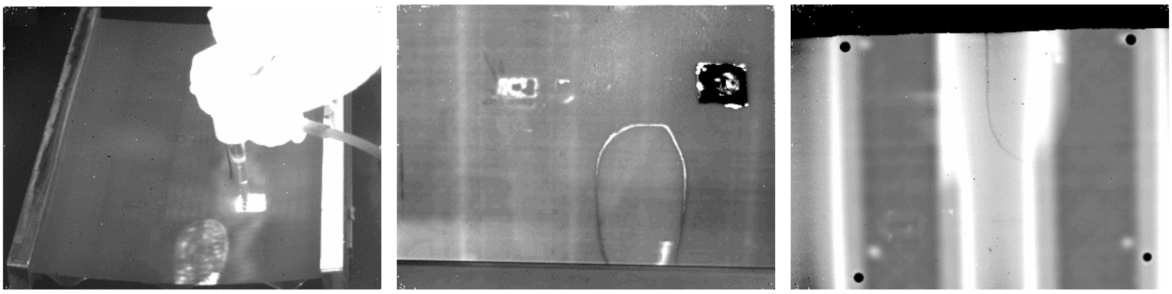


Figure 8: Comparison between UIT (left), OLT in the direct (middle) and transmitted (right) illumination mode.

STUDY OF THE EXCITATION PARAMETER FOR UIT

In order to find out the robustness of ultrasound thermography to the excitation parameters, some tests were performed by varying the excitation pulse time and the distance between the excitation point and the damage. The duration and amplitude of the excitation pulse were also varied according to the distance. For this task, a panel of CFRP of approximately 3.5 m length with artificial impact damage was used (figure 9). The C-Scan shows the impact damage: the damage area has 160 mm2 which correspond to a diameter of 14 mm.

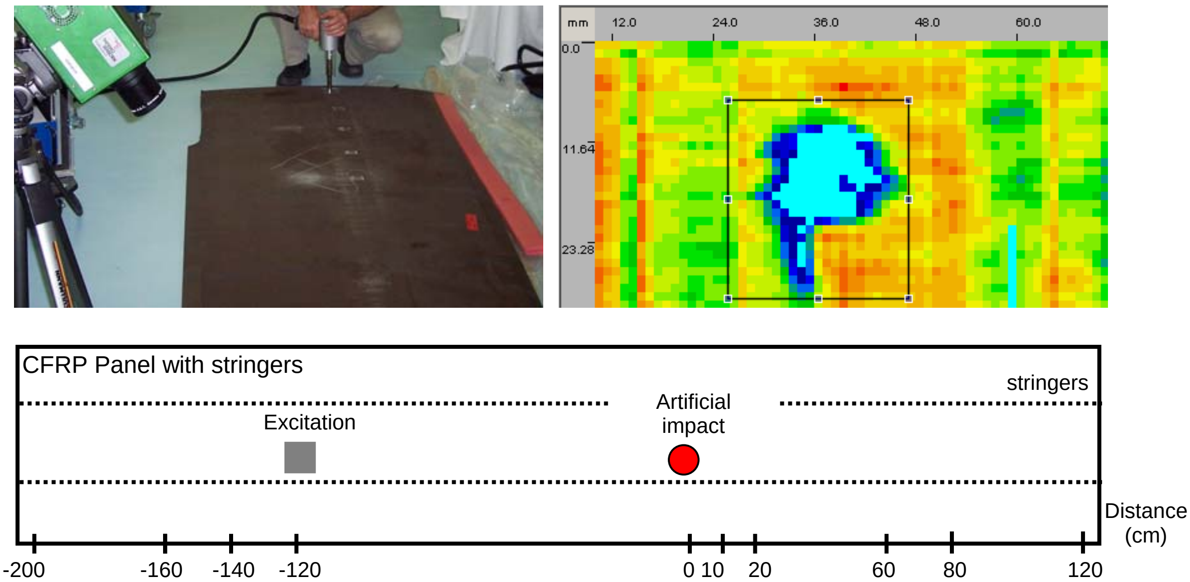


Figure 9: CFRP panel (part 2) with an artificial impact damage (top left), C-scan of the impact damage (top right) and scheme of the CFRP panel showing the different positions of the excitation source.

Time parameter

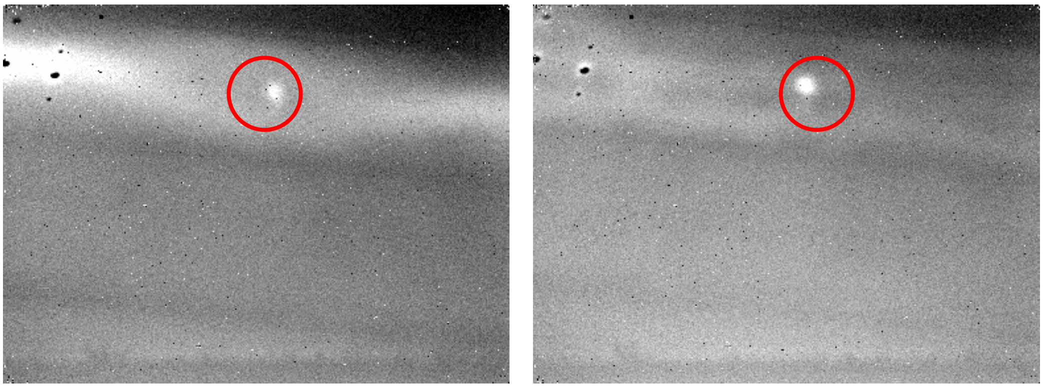


Figure 10: Infrared images of the impact damage with 1.2 s (left) and 2 s (right) excitation times (200 cm distance between excitation point and damage and 1000 W power amplitude).

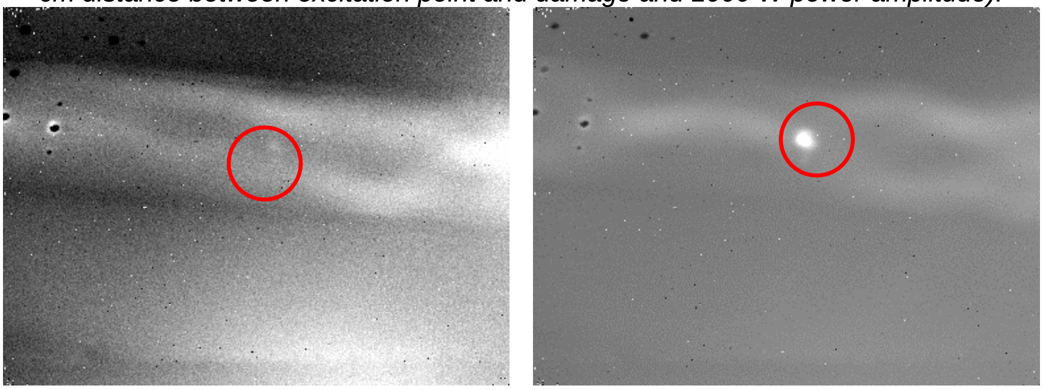
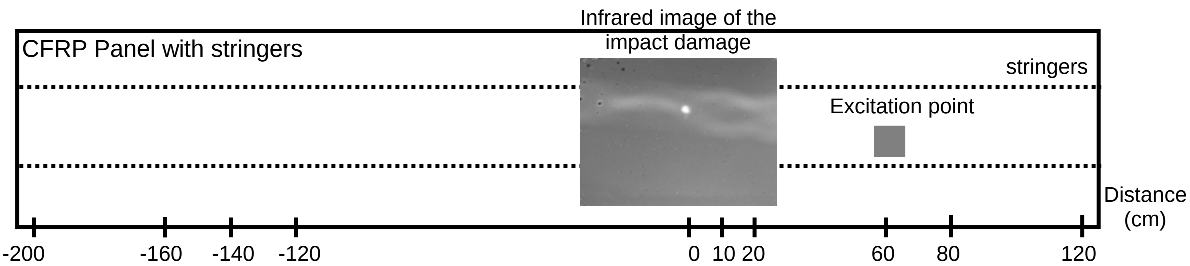


Figure 11: Infrared images with an excitation of power 800 W and 0.8 s duration (left) and of power 1000 W and 1.2 s duration (right) (distance of 80 cm between source and damage).

In figure 10, it is shown that at a distance of 200 cm between excitation and impact, the impact can be detected more clearly with 2 s of excitation than 1.2 s at constant power. In figure 11, the defect could be better detected with a higher power and a longer excitation time.

Distance between excitation point and defect

The distance between the impact damage and the excitation source was increased until 2 m in order to test the expanse of detection. The damage could be successfully detected for all chosen distances. The power and pulse duration were increased with the move of the excitation source. Figure 12 representatively shows the infrared images obtained with a distance of 60 cm, 120 cm and 200 cm between excitation point and impact.



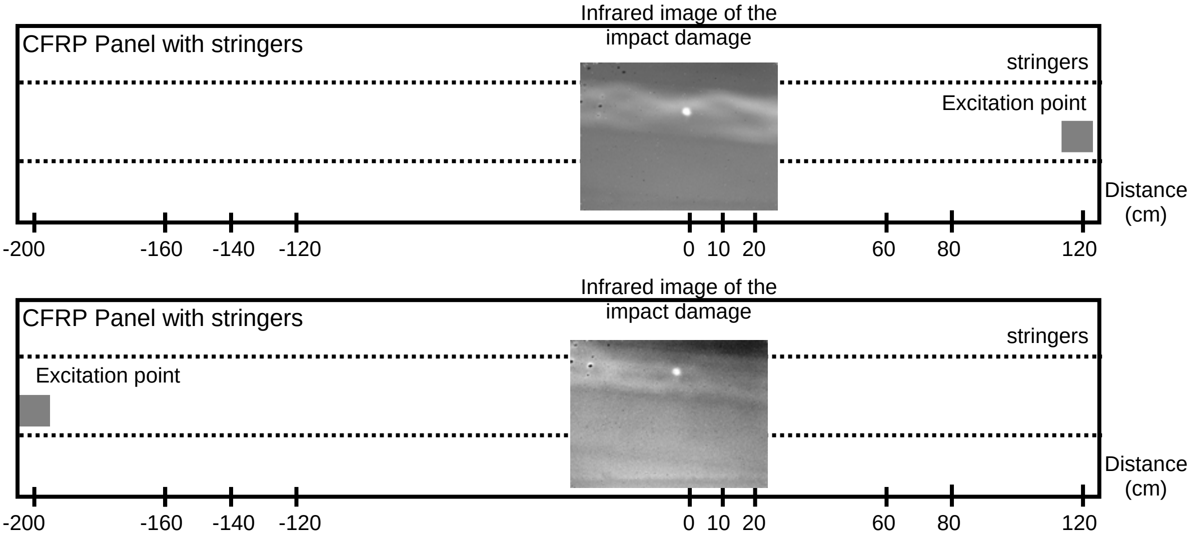


Figure 12: Some results of the detection of the impact damage with distances of 60 cm, 120 cm and 200 cm.

IMPROVEMENT OF THE ANALYSIS WITH IMAGE PROCESSING METHODS

The goal of this section is to introduce image processing methods for the quantitative and automatic analysis of thermal images. Image processing methods like the use of neural networks were introduced to improve the analysis of thermal images [13-15]. Here, we are going to use data fusion [16] in order to combine the information of both infrared techniques. Data fusion allowed in a recent task to fusion ultrasonic and radiographic data to improve the detection of defects in welds [17]. Then, as the images of the different NDT techniques have different resolution, reference points in each image are needed to compute the transformation between both images. In [18], a CAD model was utilised to detect the common features. Here, special retrospective labels that are detectable in both images are used. The labels allow also the introduction of a scale in the images and to get quantitative information about the defect size. Then, the images are segmented to localise the defect area.

Introduction of a scale

To allow quantitative evaluation, a scale has to be introduced in the images. Therefore, special retrospective labels are stitched on the components to delimit the zone of interest (ZOI) and they are automatically detected. For this, an edge extraction is performed and ellipses are fitted on the extracted closed edges (figure 13). The centres of the ellipses are computed and when the positions of the labels are known, the dimensions of the scale can be projected on the part by using photogrammetric methods [19]. In the same manner, the image can be rectified for example when the parts are tilted.

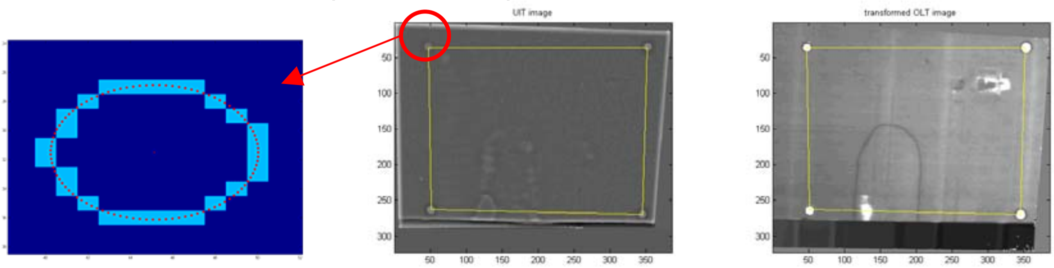


Figure 13: edge detection and ellipse fitting (left), rectified coordinates of the UIT and OLT images (middle and right).

Quantitative evaluation of defects

Defects areas are characterised by a high signal to noise ratio. The images were segmented by considering regions with a SNR greater than 6dB as defects. This criterion is commonly applied in ultrasonic testing [20]. Therefore, a gauss function is fitted to the histogram of the phase image and the mean and standard deviation of the gauss function allows the determination of the detection threshold (6 dB).
This criterion is applied to the results obtained on part 1.

Data fusion

After the UIT and OLT images are rectified and segmented, they are overlaid. For the segmentation, only the area of interest situated between the labels was analysed.
With data fusion, the defect information of multiple non-destructive evaluation methods is combined (figure 14) and we get better precision about the defect area. For better visualisation, the defect area is overlaid on a live image taken with a basic digital camera (figure 15).
It can be notice that the defect area detected with UIT is bigger than this of OLT. The red region of figure 14 representing the common defect region is quite little. The difference might be due to the physical difference for detecting defects: UIT creates a friction at closed cracks it means that the borders of a delamination are better highlighted. In OLT, the thermal wave is reflected at thermal boundaries. A big change of the reflection coefficient is needed to detect the defect so that the centre of the delamination is well detected while the border not.
Consequently, both thermographic methods appear to be complementary. But also a lot of noisy areas are detected and should be eliminated in a next step.
The data fusion can also be applied to other NDT techniques.

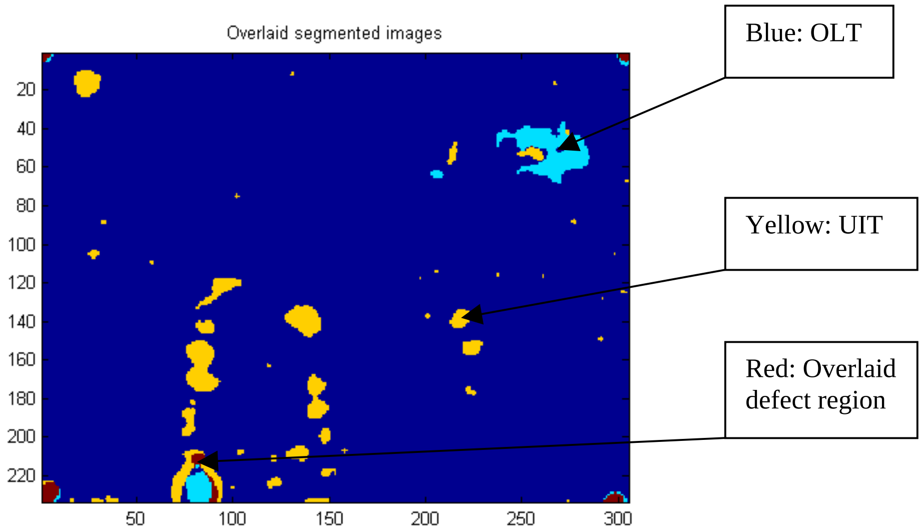


Figure 14: Overlay of segmented UIT and OLT images. The colour areas represent the defect region blue: from the segmented OLT image, yellow: from the segmented UIT data and red the defect area detected in UIT and OLT.

Figure 15: Representation of the defect area on the live image taken with a basic camera (rectified).

DISCUSSION

In this article, we presented two techniques in the field of non-destructive investigation: ultrasound excited thermography and optical excited thermography. Both methods allow the successful detection of delaminations and impact damages. By increasing the power and duration of the ultrasound excitation, it was possible to detect defects up to 2 m from the excitation point.

The resulting images showing the defect areas where analysed and compared. Image processing methods allowed the overlay of the images in order to fusion the defect information and to compare the defect area of both methods. The defect areas were then overlaid on the live image to highlight the defect area.

The UIT and OLT techniques are complementary because they provide both incomplete and different information. The data fusion improves the detection of the defect area. This tool should allow half-automatic detection. The data fusion technique should improve the characterisation of defects.

In future, images of other NDT techniques (CT-images or C-scans) will be compared and fusion. A work has to be done on the defect area classification: in figure 15, defect free areas were classified into a defect area. The combination of more than two methods and the use of wavelets [29] might reduce the number of false detection.

REFERENCES

[1] Maldague X., Nondestructive evaluation of materials by infrared thermography, London, Springer-Verlag, 224 p., 1993 (new revised edition, John Wiley & Sons Pub., exp. in 2001).

[2] Maldague X. ed., Infrared Methodology and Technology, Gordon and Breach, NY, 525 p., 1994.

[3] Spicer J.W.M., Kerns W.D., Aamodt L.C., Murphy J.C., "Time-resolved infrared radiometry (TRIR) of multilayer organic coatings using surface and subsurface heating" in Thermosense XIII, Proc. SPIE, G. S. Baird ed., 1467: 311-321, 1991.

[4] Busse G., "Nondestructive evaluation of polymer materials," NDT &E Int'l, 27[5]: 253-262, 1994.

[5] Revel, G.M., Rocchi, S., "Defect detection in ceramic materials by quantitative infrared thermography", proceedings of the conference of quantitative infrared thermography QIRT, 2006.

[6] Wu, D., Salerno A., Malter U., Aoki R., Kochendörfer R., Kächele P.K., Woithe K., Pfister K., Busse G., "Inspection of aircraft structural components using lockin-thermography," QIRT-96 (Quantitative Infrared Thermography), Eurotherm Seminar 50, D. Balageas, G. Busse, C. Carlomagno eds., Edizioni ETS (Pisa, Italy) , pp 251-256, 1996.

[7] C. Santulli, "Measurement of impact-damaged areas in commingled E-glass/polypropylene laminates via thermographic image analysis", proceedings of the conference of quantitative infrared thermography QIRT, 2006.

[8] A. Gleiter, C. Spießberger, Th. Zweschper, G. Busse, "Improved ultrasound activated Lockin-Thermography by frequency analysis of material defects", proceedings of the conference of quantitative infrared thermography QIRT, 2006.

[9] Salerno A., Wu D., Busse G., Rantala J., "Thermographic inspection with ultrasonic excitation" in Proc. of Rev. Progresses in Quantitat. NDE, D.O. Thompson, D.E. Chimenti eds., NY: Plenum press, 16A: 345-352, 1996.

[10] Acoustic thermography using an un-cooled high speed camera and low power ultrasonic excitation: test system and its application to impact flaw detection in CFRP, L. Haupt, U. Hoffmann, H. Budzier, N. Meyendorf, B. Köhler.

[11] d'Ambrosio G., Massa R., Migliore M.D. et al. "Microwave excitation for thermographic NDE: An experimental study and some theoretical evaluations Materials Evaluation, 53[4]: 502-508, Apr. 1995.

[12] e/de/vis, http://www.edevis.de/
[13] Trétout H., David D., Marin J.Y., Dessendre M., "An evaluation of artificial neural networks applied to infrared thermography inspection of composite aerospace structures", Review of Progress in Quantitative NDE, D.O. Thompson, D.E. Chimenti eds, 14: 827-834, (Plenum Press, 1995).
[14] Maldague X., Largouët Y., "Depth study in pulsed phase thermography using neural networks: Modeling, noise, experiments," Revue Générale de Thermique, 37[8]: 704-708, Sept. 1998.
[15] Foucher B., "Infrared machine vision," in Thermosense XXI, Proc. SPIE, R.N. Wurzbach, D.D. Burleigh eds., 3700: 210-213, 1999.
[16] Gros, X.E., "NDT Data fusion", John Wiley and Sons, New York, 1997, 205p.
[17] Dupuis, O., Kaftandjian, V., Babot, D. Zhu, Y.M, "Automatic detection and characterisation of weld defects: determination of confidence levels for data fusion of radioscopic and ultrasonic images", Non Destructive testing and Condition Monitoring, vol. 41, n°3, 1999, pp.170-172
[18] Matuszewski, B.J., Shark, Lik-Kwan, Varley, Martin R., Smith, J., "UK Region-based wavelet fusion of ultrasonic, radiographic and shearographyc non-destructive testing images", proceedings of 15th World Conference on Non-Destructive Testing, October 2000.
[19] Luhmann, T., Nahbereichsphotogrammetrie: Grundlagen, Methoden und Anwendung, Wichmann, 2003
[20] Pitkänen, J., SAFT- is it a tool for improved sizing in ultrasonic testing, ECNDT 2006 Poster211