International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:7, No:8, 2013

Development of an Infrared Thermography Method with CO_2 Laser Excitation, Applied to Defect Detection in CFRP

Sam-Ang Keo, Franck Brachelet, Florin Breaban, and Didier Defer

***Abstract*—**This paper presents a NDT by infrared thermography with excitation CO_2 Laser, wavelength of 10.6 µm. This excitation is the controllable heating beam, confirmed by a preliminary test on a wooden plate 1.2 m x 0.9 m x 1 cm. As the first practice, this method is applied to detecting the defect in CFRP heated by the Laser 300 W during 40 s. Two samples 40 cm x 40 cm x 4.5 cm are prepared, one with defect, another one without defect. The laser beam passes through the lens of a deviation device, and heats the samples placed at a determinate position and area. As a result, the absence of adhesive can be detected. This method displays prominently its application as NDT with the composite materials. This work gives a good perspective to characterize the laser beam, which is very useful for the next detection campaigns.

***Keywords*—**CO_2 LASER, Infrared Thermography, NDT, CFRP, Defect Detection.

I. Introduction

THE defects such as delamination or absence of adhesive eventually occurred in the application can be detected by nondestructive testing NDT techniques such as ultrasound, x-ray and infrared thermography methods [1]-[2]. Due to their simple set-up and rapidity of investigation with the more accessible results, infrared thermography methods have been widely used for detecting the near surface defects as passive or active methods [3]-[7]. The active methods can be frequently pulse thermography PT, pulsed phase thermography PPT, or lock-in thermography [7]-[9]. The development of these methods has been made by thermogram interpretation methods and by different kinds of heating source such as halogen lamps, microwave, and induction [4], [7], [10]. The Laser, which is monochromatic and unidirectional, has been also used as the heating source for the infrared thermography, especially for the small defects only such as the cracks [11]-[14]. The uncontrollable beam of the excitation in infrared thermography has caused the inhomogeneous heat and other eventually phenomena bringing the errors to the detections.

Sam-Ang Keo is with the Universtié d'Artois, Faculté des Sciences Appliquées, Technoparc Futura, 62400 Béthune, France (phone: +33677301305;e-mail: anggci@yahoo.com/sam-ang_keo@ens.univ-artois.fr).
Franck Brachelet is with Université d'Artois, Faculté des Sciences Appliquées, Technoparc Futura, 62400 Béthune, France (phone : +33321637116; e-mail : franck.brachelet@univ-artois.fr).
Didier Defer is with the Université d'Artois, Faculté des Sciences Appliquées, Technoparc Futura, 62400 Béthune, France (phone: +33321637155; e-mail: didier.defer@univ-artois.fr).
Florin Breaban is with the Université d'Artois, Institut Universitaire de Technologie Béthune, France (phone : +33678003458; e-mail : florin.breaban@univ-artois.fr).

In this work, CO_2 Laser is used as the new excitation system applied for the infrared thermography method. This kind of laser, which is more powerful than the fiber laser, enables to have a bigger heating area. As the Carbone Fiber Reinforced Polymer CFRP is increasingly used in strengthening and repairing methods on the civil engineering structures such as beams, columns, slabs, walls and other infrastructures in different environmental conditions [15], [16], this CO_2 Laser infrared thermography is firstly put into practice with the defect detection in CFRP sample.

II. CO_2 Laser Excitation System

The laser excitation is provided by a powerful CO_2 laser system used for cutting (Fig. 1). This type of laser has a wavelength of 10.6 µm, and it is equipped with a focus system and shaped of the adapted infrared beam.

Fig. 1 CO2 Laser system

The deviation device is used to change the direction of the laser beam. The principle of the laser beam deviation towards the sample is shown in Fig. 2.

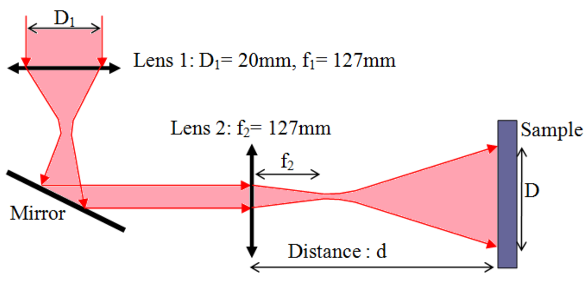

Fig. 2 Schema of Laser beam operation onto the sample

The laser beam passes through the lens 1 and arrives a mirror situated in the deviation device. Due to the mirror, the beam changes its direction and continues its path until the lens

2. By passing through the lens 2, the beam gets out of the device and goes towards the sample. The lens 2 enlarges the beam diameter in function of the distance d, which allows heating the samples in a large surface area as expected. The unidirectional criteria of the laser beam leads to heat any samples with an accurate position. From Fig. 2, the diameter of the heating area D can be determined by a simple relation:

$$(D_1/f_1) = (D/d) \quad (1)$$

which deduces $D = d\cdot(D_1/f_1)=0.1575\cdot d$

Or, the distance d to place the sample from the lens 2 can be obtained, by using (1), in function of the desired diameter of the sample to be heated ($d=6.35\cdot D$). We observe that the further distance the samples are placed from the lens, the bigger surface area can be heated. Another remark is that the distance is always much longer than the beam diameter on the samples (6 times).

III. CFRP Samples

Two samples of the same dimensions are prepared, one is without defect, and another one is with defect. On a small concrete slab 40 cm x 40 cm x 4.5 cm, is reinforced by the carbon fiber reinforced polymer CFRP 22cm x 40cm (Fig. 3).

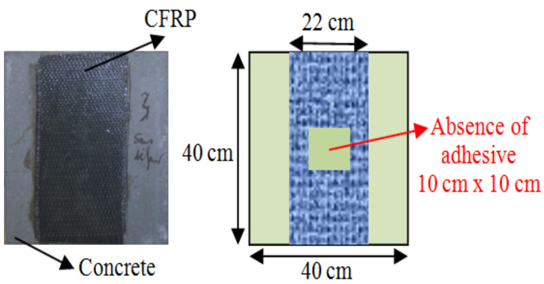

Fig. 3 Details of the CFRP samples

The CFRP consists of the Sikadur adhesive and the bidirectional carbon fiber. The defect is the bonding failure made by the absence of adhesive 10 cm x 10 cm at the middle of a sample.

IV. Test Set-Up

In order to respect to the safety instructions and the protection against the laser beam, a protective mirror is used to prevent the operator from the beam. The details of the test set-up are shown in Fig. 4 and Fig. 5.

Separating the test area into two parts by the protective mirror, the specimen and the camera are placed at the same side with the laser lens; otherwise the acquisitions and operator are at another side. The laser shot start-up is controlled from the same side as the acquisitions too.

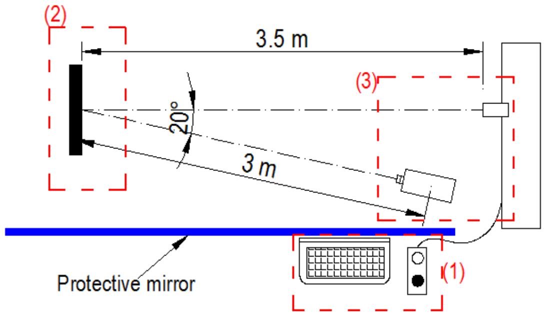

Fig. 4 Schema of experimental test set-up

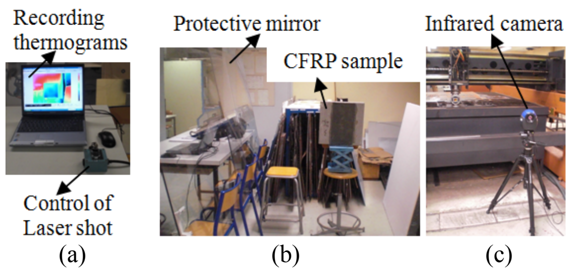

Fig. 5 Details of the test areas (a) Acquisition and laser shot control (b) Sample (c) Detector

The position of the specimen is marked; at 3.5 m from the lens (this distance is far enough to have the bigger diameter of the laser beam on the sample than the dimension of the sample surface area). An infrared camera sensitive to medium waves in range of 3-5 µm (different from the laser beam wavelength), with a detector of 320 x 256 matrix detector in InSb (Indium Antimonide), is placed at 3 m from the sample in 20° direction (angle between the axis of the camera and the laser beam path) so as to detect the whole area heated by the laser (Fig. 4).

The thermograms are recorded at regular intervals (1 image per second) by the computer using the ALTAIR software. The specimen is heated with a power of 300 W for 40 s. After the thermogram record ends, the same procedure (the position of the sample, the camera, and the lens remain the same) is repeated with another specimen.

V. Results and Discussions

A. Verification of the Determinate Area Heated by Laser Beam

In order to verify the control of the laser beam used as a new excitation system, a preliminary test is carried out with a wooden plate, 1.2 m x 0.9 m x 1 cm, without defect. The plate is placed at the distance of 3.5 m from the lens. The power of 300 W is used to heat the plate during 10s. The thermogram at the instant of 5 s and the surface temperature evolution are shown in Fig. 6. The small wavelength of this CO_2 laser, 10.6 µm, which limits its penetration depth into the materials, provide an efficiency of surface heating; the surface temperature of the wood increase from 18 °C to 26 °C after 10 s of heating.

The thermogram displays the heating area as the circular

International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:7, No:8, 2013

one with the diameter of 0.58 m. This diameter determined by using the relation (1) is 0.55 m (D = 0.1575 × 3.5 m). This concordance confirms that the laser is the excitation, for infrared thermography method, which can be controlled by its optical properties to assure the heating on the precisely detected area.

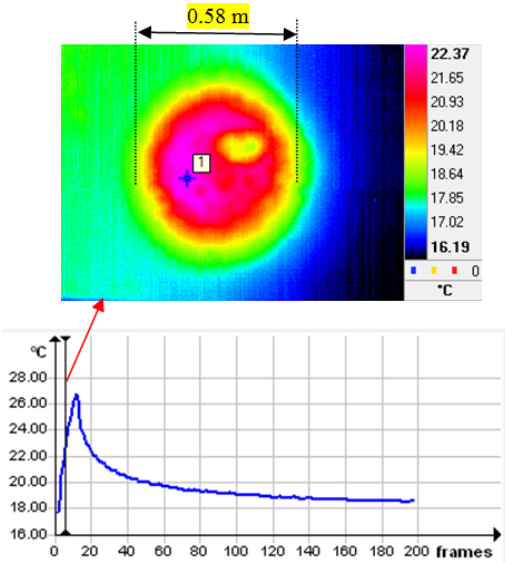

Fig. 6 Temperature evolution and thermogram of wooden plate at the instant 5 s

B. Results of the Test on CFRP

The sequence of thermograms is analyzed with the contrast algorithm in Matlab program. The nonuniformity of the beam (Gaussian) after passing through the lens in the deviation device, produces an inhomogeneous heat generated on the surface of the sample and may lead to misinterpretation. Thus, the tests are conducted in two stages.

Applying the previous algorithm to all points of the specimens' surface (37 cm x 35 cm area is observed), the thermograms at the instant 41 s is obtained as shown in the Fig. 7.

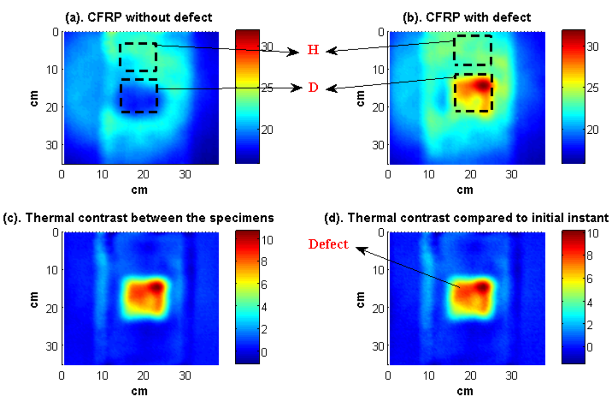

Fig. 7 Thermograms at the instant 41 s

Fig. 7 (a) shows the thermogram of the sample without defect. This thermogram lets us see the circular form and the nonuniformity of the laser beam on the specimen, which proves the need of the sample without defect in the evaluation of the sample with defect. It is noticed that the CFRP area is more heated than the concrete area.

Fig. 7 (b) is the thermogram of the sample with defect at the same instant 41 s, which shows also the inhomogeneous heat in other areas apart from the defected one.

Fig. 7 (c) is the thermogram obtained by the subtraction between the thermogram of the sample with the defect in

Fig. 7 (b), and the thermogram of the sample without defect

Fig. 7 (a) at the instant 41 s. As both samples can have the a bit different initial temperature before the test, this thermal contrast thermogram take into account not only the defect (absence of adhesive), but also the contrast of initial temperatures. Therefore, the thermal contrast in

Fig. 7 (d) is needed. This thermal contrast thermogram subtracts the initial temperatures of the samples in order to consider only the defect as the difference between both samples. It shows clearly the defect at the middle of the sample. The absence of adhesive makes it hotter than other areas having no defect.

Fig. 8 shows a temporal contrast curve. It is the contrast between the defected area and the healthy area (no defect) in the thermogram presented in

Fig. 7 (d). This curve allows to set a time for which the thermogram has a maximum contrast between the defected and healthy area.

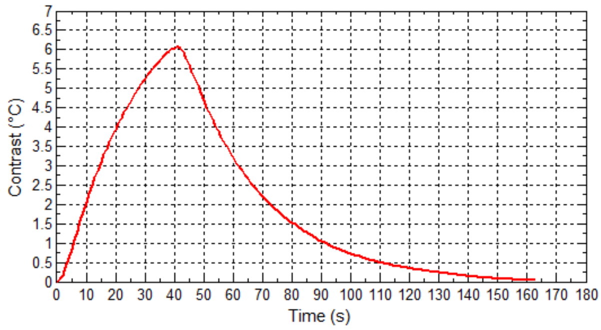

Fig. 8 Thermal contrast between the defected area and the healthy area

It is observed from this thermal contrast curve that at the instant *41 s*, the maximum contrast of *6 °C* is obtained. This high contrast value enables to visualize clearly the defect.

Suppose H an area without defect (healthy area), and D a defected area, situated at the same position of both specimens as shown in

Fig. 7 (a), and

Fig. 7 (b). Fig. 9 shows the evolution of average surface temperature of those two areas on both specimens.

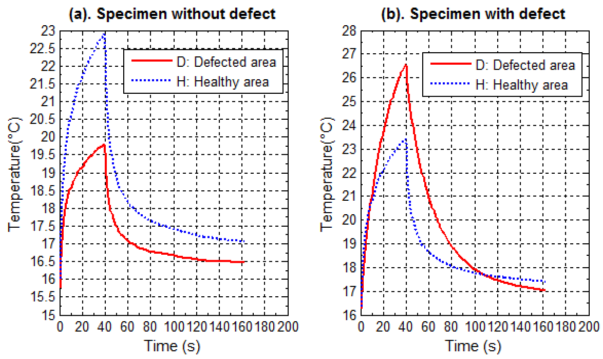

Fig. 9 Temperature evolution of the defected and healthy area

In Fig. 9 (a), two curves of average temperature evolution of the areas on specimen without defect are shown. The initial surface temperature of the specimen is 15.75 °C for both areas. Then, it increases rapidly after the laser beam arrives on the surface of the sample. On the healthy area H, the temperature rises till 23 °C; *higher* than the defected area D which increases till 19.75 °C only. The difference in temperature increase of these two areas is caused by the form of the laser beam.

Fig. 9 (b) is for the case of specimen with defect. The temperature increases from the initial instant 16.25 °C to 26.5 °C in the defected area D, and 23.5 °C in the healthy area. In this case, the defected area has higher temperature raise than the healthy area because of the bonding failure in the defected area of this specimen.

After the heating period 40 s, the temperature relaxation phase occurs for all the cases.

VI. Conclusion

The application of CO_2 Laser infrared thermography with the CFRP displays prominently the accessibility of this method in nondestructive testing NDT for composite materials as other conventional infrared thermography. The dimension of the laser beam shown on the thermogram of the wooden plate confirms the advantage of the unidirectional characteristic of the Laser allowing heating the samples with the determinated position and area as expected. The perspective of this work is to characterize the laser beam (Gaussian) or increase the uniformity of the beam by using the lens. The high power of the laser leads to a high performance detection compared to other conventional surface heating excitation.

Acknowledgment

The authors would like to acknowledge Nord-Pas-Calais regional council and Université d'Artois for financial support. The authors also wish to thank the Centre d'Application Laser Flandre-Artois (CALFA) for the CO_2 Laser system for the tests.

References

[1] Ch. Maierhofer, A. Brink, M. Röllig, H. Wiggenhauser, "Transient thermography for structural investigation of concrete and composites in the near surface region," *Infrared Physics & Technology,* vol. 43, pp. 271-278, 2002.
[2] Jeff R. Brown, H. R. Hamilton, "Quantitative infrared thermography inspection for FRP applied to concrete using single pixel analysis," *Construction and Building Materials,* 2010.
[3] Akbar Darabi, Xavier Maldague, "Neural network based defect detection and depth estimation in TNDE," *NDT & E International,* vol. 35, pp. 165-175, 2002.
[4] C. Ibarra-Castanedo, F. Galmiche, A. Darabi, M. Pilla, M. Klein, A. Ziadi, S. Vallerand, J.-F. Pelletier, X. Maldague, "Thermographic nondestructive evaluation: overview of recent progress," in *SPIE-Society of Photo-Optical Instrumentation Engineers, Procedures Thermosense XXV*, 2003.
[5] Hernán D. Benítez, Humberto Loaiza,Eduardo Caicedo,Clemente Ibarra-Castanedo,AbdelHakim Bendada,Xavier Maldague, "Defect characterization in infrared non-destructive testing with learning machines," *NDT & E International,* vol. 42, pp. 630-643, 2009.
[6] M. R. Clark, D. M. McCann, M. C. Forde, "Application of infrared thermography to the non-destructive testing of concrete and masonry bridges," *NDT & E International,* vol. 36, pp. 265-275, 2003.
[7] XAVIER P.V. MALDAGUE, *Theory and Practice of Infrared Technology for Nondestructive Testing*. Canada, 2001.
[8] Manyong Choi, Kisoo Kang, Jeonghak Park, Wontae Kim, Koungsuk Kim, "Quantitative determination of a subsurface defect of reference specimen by lock-in infrared thermography," *NDT & E International,* vol. 41, pp. 119-124, 2008.
[9] S. Vallerand, X. Maldague "Defect characterization in pulsed thermography: a statistical method compared with Kohonen and Perceptron neural networks," *NDT & E International,* vol. 33, pp. 307-315, 2000.
[10] U. Galietti, D. Palumbo, G. Calia and F. Ancona, "New data analysis to evaluate defects in composite materials using microwaves thermography," presented at the 11th International Conference on Quantitative InfraRed Thermography, University of Naples Federico II, Naples, Italy, 2012.
[11] Hongjoon Kim, Kyungyoung Jhang, Minjea Shin, Jaeyeol Kim "A noncontact NDE method using a laser generated focused-Lamb wave with enhanced defect-detection ability and spatial resolution," *NDT & E International,* vol. 39, pp. 312-319, 2006.
[12] J. Schlichting, Ch. Maierhofer, M. Kreutzbruck, "Crack sizing by laser excited thermography," *NDT & E International,* vol. 45, pp. 133-140, 2012.
[13] S. E. Burrows, S. Dixon, S.G. Pickering, T. Li, D.P. Almond, "Thermographic detection of surface breaking defects using a scanning laser source," *NDT & E International,* vol. 44, pp. 589-596, 2011.
[14] Teng Li, Darryl P. Almond, D.Andrew S. Rees, "Crack imaging by scanning pulsed laser spot thermography," *NDT & E International,* vol. 44, pp. 216-225, 2011.
[15] L. De Lorenzis and J. G. Teng, "Near-surface mounted FRP reinforcement: An emerging technique for strengthening structures," *Composites Part B: Engineering,* vol. 38, pp. 119-143, 2007.
[16] M. J. Chajes, *et al.*, "Durability of concrete beams externally reinforced with composite fabrics," *Construction and Building Materials,* vol. 9, pp. 141-148, 1995.

Sam-Ang Keo received his Dip. Ing. in civil engineering from the Institute of Technology of Cambodia, Phnom Penh, Cambodia, in 2008, the M. Eng. degree in mechanical and civil engineering from INSA Rennes, France, in 2009. He is pursuing his PhD degree at the Laboratoire de Génie Civil et GéoEnvironnement (LGCgE), Lille Nord de France, Université d'Artois, France, since 2010. He is currently working on the infrared thermography method with CO_2 LASER and microwave excitation, applying to NDT on reinforced concrete structures and CFRP. His research interests include also modeling on steel structures and fire with finite element method.

Franck Brachelet is a research engineer at the Laboratoire de Génie Civil et GéoEnvironnement (LGCgE), Lille Nord de France, Université d'Artois, France. He is working also as an Assistant Professor at Factulté des Sciences Appliquées (FSA) and Institut Universitaire de Technologies Béthune (IUT Béthune). His research interests include the NDT methods by infrared thermography, the multiscale thermophysical characterization of materials, the instrumentation in building for evaluation of energy performance, physics and metrology.

Florin Breaban is working at the Laboratoire de Génie Civil et GéoEnvironnement (LGCgE), Lille Nord de France, Université d'Artois, France.He is a Professor at the department of mechanical and production engineering of Institut Universitaire de Technologies Béthune (IUT Béthune). He is also responsible for cooperation of LGCgE Université d'Artois/IUT Béthune for the international relations with Romania, CRITTM2A for the LASER instrumentation (LASER vibrometry, holography), and the initiation of optical measurement and infrared thermography team. His research interests include diagnostic-material inspection, infrared thermography with laser and microwave excitation, spectral emissivity measurement, radiometric, photometric and energy measures, characterization of materials' parameters.

Didier Defer is Deputy Director of the Laboratoire de Génie Civil et GéoEnvironnement (LGCgE), Lille Nord de France, Université d'Artois, France. He is also Director on Artois site of LGCgE, member of the board of directors of Université d'Artois. He is a Professor at the department of civil engineering of Faculté des Sciences Appliqués (FSA) Béthune. His research interests include applied heat, acoustics and lighting in building, thermophysical characterization of materials and structure auscultation by thermal methods.