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A Study on the Non-Destructive Test Characterization of Carbon Fiber Reinforced Plastics Using Thermo-Graphic Camera

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***Abstract*—**Non-destructive testing and evaluation techniques for assessing the integrity of composite structures are essential to both reduce manufacturing costs and out of service time of transport means due to maintenance. In this study, Analyze into non-destructive test characterization of carbon fiber reinforced plastics (CFRP) internal and external defects using thermo-graphic camera and transient thermography method. non-destructive testing were characterized by defect size (Ø8, Ø10, Ø12, Ø14) and depth (1.2mm, 2.4mm).

***Keywords*—**Non Destructive test (NDT), Thermal characteristic, Thermo graphic Camera, Carbon Fiber Reinforced Plastics (CFRP).

I. INTRODUCTION

IN recent years the development and optimization of NDT procedures for the health monitoring of primary structures is gaining the attention of a growing research community. This trend is constantly fostered by technological progresses in equipment and processing tools, providing instruments with ever enhanced performances and/or lower prices. Another driving factor is the strong demand for developing further improved robust techniques, which could be in-situ implemented at low costs, deployable also in not carefully controlled environments and providing fast analyses over large surface structures. In this scenario Infrared Thermography (IRT) and related IR-NDT techniques have shown strong potentials and flexibility, becoming a competitive alternative to other NDT techniques in many applications [1]-[4]. This is in particular the case for those industrial sectors where peculiar economic constraints require the adoption of full-field, fast, non-contact and low-cost techniques [4].

The preferred approach to perform thermal NDT is by Active IR Thermography which in general consists on monitoring temperature evolution after or during the deposition of an external thermal/mechanical stimulus [1]-[4]. In fact sub-surface defects usually disturb the surface distribution of temperature through different and opportunely activated mechanisms: heat conduction perturbation, heat sinks, local heat production e.g. by frictional or thermo/viscoelastic/plastic effects, etc... Enhanced defect signatures are then retrieved through different signal processing analyses which, together with the nature of the external perturbing stimulus, characterize the various proposed IR-NDT techniques [4].

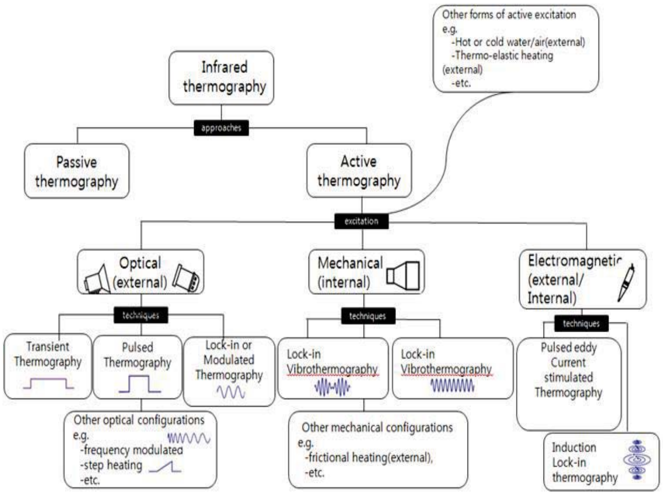

Fig. 1 Infrared thermography approaches [6]

Infrared thermography is a nondestructive testing and evaluation technique allowing fast inspection of large surfaces. Fig. 1 illustrates the different approaches to infrared thermography. As it is well-known, in the passive approach the features of interest are naturally at a higher or lower temperature than the background. This is the case, for instance, of surveillance of people on a scene and a number of medical and veterinarian applications. The active approach, on the contrary, requires an external energy source to produce a thermal contrast between the feature of interest and the background. This is the most suitable configuration for composites NDT&E since such parts are normally at thermal equilibrium during the inspection and is the subject of this investigation. Practically any energy source can be used to stimulate the specimen being inspected, from cold or hot air to water jets, or frequency and amplitude modulated acoustic waves. Of course, the choice of one or the other source will

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affect the results. The final decision on the energy source should be made depending on the application [5],[6].

The transient thermography is a method that measures the momentary heat variations occurred on the surface of a specimen using an infrared camera after applying external heat sources on the surface. The thermal variation is determined depending on the thermal characteristics and physical properties. As the internal defects are weakened by the heat-flow and present a thermal contrast, a thermo-graphic camera is used to capture such contrast. When the data measured by using a thermo-graphic camera are much mixed with noises, the depths of its defects appear deep, and its sizes appear small; therefore, it is not easy to find out such defects in carbon-carbon composite materials from thermo-graphic images as the differences of its temperature are minor [7].

In this study, Analyze into non-destructive test characterization of carbon fiber reinforced plastic (CFRP) internal and external defects using thermo-graphic camera, and detect defected CFRP specimens according to transient thermography.

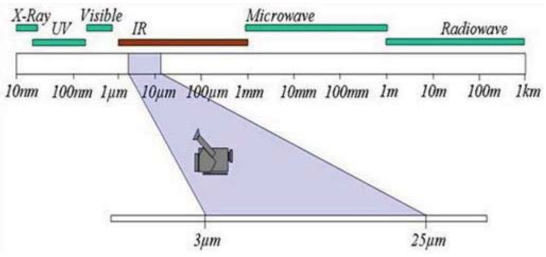


Fig. 2 Infrared band in electromagnetic spectrum of light

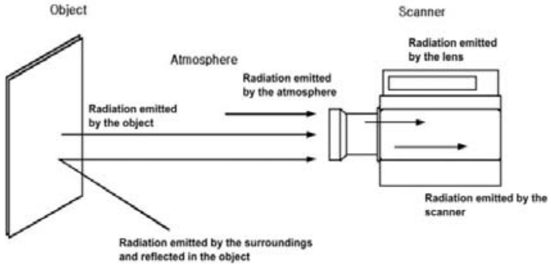


Fig. 3 Principle of infrared thermography in the surroundings

II. HEAT MEASUREMENT THEORY [8]

As shown in Fig. 2, infrared light is a part of the electromagnetic spectrum and has a longer wavelength than visible light. Electromagnetic light can be grouped by frequency or wavelength. The range of the infrared detector or system is dependent on the wavelengths it defects or handles. The system that detects radiation in the range of 8µm - 12µm and 3µm - 5µm is referred to as a “long wavelength” and “short wavelength” system, respectively. The visible region of the electromagnetic spectrum is located between wavelengths of 0.4µm and 0.75µm.

The underlying principle of infrared thermography of an object and its temperature profile is depicted in Fig 2. The high-temperature spot is denoted in red, which indicates long wavelengths, whereas the low-temperature spot is denoted in blue, which indicates short wavelengths. Accordingly, when the heated materials are imaged, the infrared camera identifies the surface temperature profile of the structure and measures the object’s temperature distribution.

As illustrated in Fig. 3, the radiant energy incident on an object is displayed as three shapes depending on the properties of light. Irradiated energy can be partially absorbed reflected, or transmitted by the object. The following formula can be deduced.

$$W = \alpha W + \rho W + \tau W \tag{1}$$

where,

$$1 = \alpha + \rho + \tau \tag{2}$$

α, ρ and τ are absorptivity, reflectivity and transmissivity, respectively. Equation (2) is Kirchhoff's radiation law. According to Planck’s law, which describes the radiation strength of a black body that fully absorbs the radiant heat, the total radiant energy emitted from an object can be calculated for a black body with the Stefan-Boltzmann's law as follows:

$$\text{For black body, } W = \delta T^4 \quad W/m^2 \tag{3}$$

σ is the Steffan-Boltzman’s constant ($5.67 \times 10^{-8}\ \mathrm{W/m^2K^4}$)

The energy radiated from the black body is W_{bb}. If the actual energy radiation is W_{obj}, then the radiation ratio ε of an object is as follows.

$$\varepsilon = \frac{W_{ab1}}{W_{bb}}, 0 \le \varepsilon \le 1 \tag{4}$$

Equation (4), the radiation ratio employed for infrared thermography is the average ϵ_λ that is generated by the infrared wavelength interval used in the infrared camera. It is thus important to predict the correct radiation ratio according to the temperature of each object.

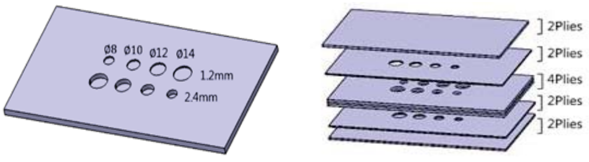
III. EXPERIMENTAL IMPLEMENTATION

A. Description of Test Specimen

The composite material used carbon fiber 12k woven prepreg (hankuk carbon LTD). This prepreg was laminated in 12plies, and was formed at 125℃(00 /cm^{2}) in hot-press method for 90min. As shown in Fig. 4 (a), external defected specimen is processed by size ($8, \emptyset 10, \emptyset 12, \emptyset 14$) and depth (1.2mm, 2.4mm) after CFRP forming. And shown in Fig. 4 (b), internal defected specimen is processed carbon fiber prepreg by size ($\emptyset 8, \emptyset 10, \emptyset 12, \emptyset 14$) and depth (1.2mm - 4plies, 2.4mm - 8plies).

B. Test Method

A matte black spray paint was used on the surface of the black body. Fig. 5 shows the experimental device used. Test specimen is between halogen lamp and infrared thermo-graphic camera. infrared camera used in this experiment is a product of the FLIR Company, type SC640, and its specifications are listed in Table I. Halogen lamp is 2kW(500W×4), heating time is 150sec and cooling time is 120sec. infrared camera was measured in 30Hz.



(a) External (b) Internal

Fig. 4 Defected specimen geometry shape

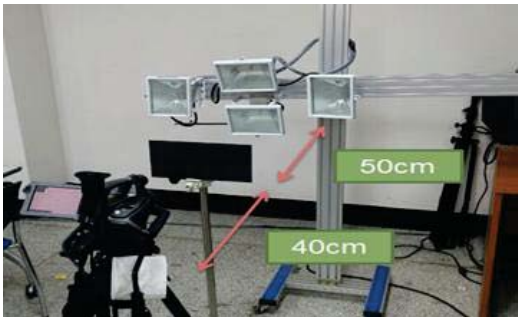


Fig. 5 Experiment NDT of CFRP

TABLE I
SPECIFICATIONS OF SC640

Specification	Scale
Temperature Range	-40°C ~+2000°C
Temperature Accuracy	±0.2°C
Frame Rate	30 Hz
Pixel Resolution	640×480 pixels
Spectral Range	30μm at 30°C

IV. EXPERIMENT RESULTS AND DISCUSSION

A. External Defected Specimen

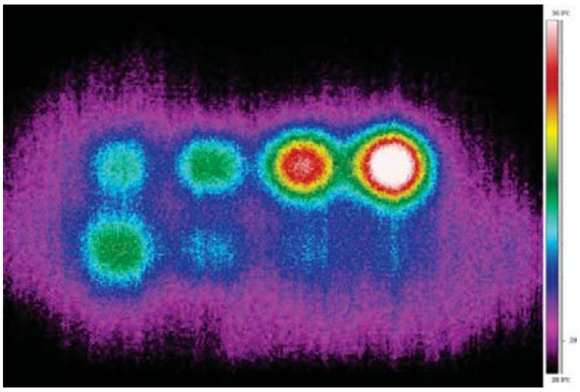
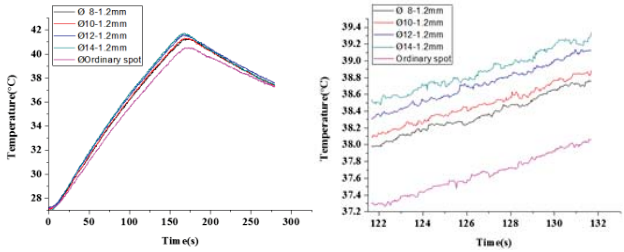


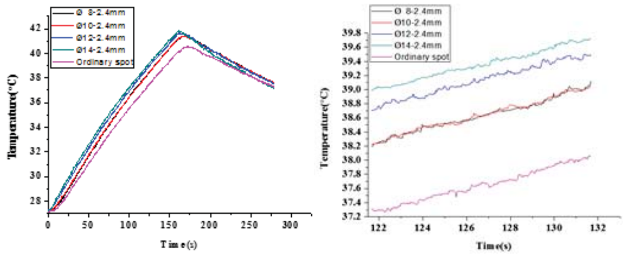
Fig. 6 External defected specimen thermo-graphic image

As shown in Fig. 7, defective part temperature is displayed higher than the ambient temperature.

At the same depth, the temperature of the defected area is higher when it is bigger. At the same size, the temperature is higher when it is deeper. This is because the defect makes the specimen thinner and thermally more conductive, which results in a higher temperature than the ambient temperature. In addition, a larger size involves less thermal conduction to the surrounding area, and leads to a higher temperature.

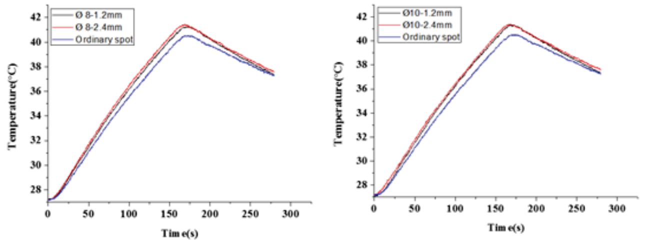


(a) Temperature of defected specimen at depth 1.2mm

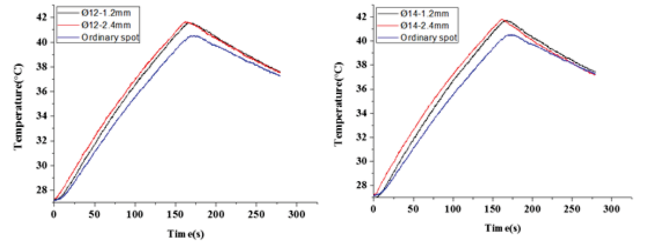


(b) Temperature of defected specimen at depth 2.4mm

Fig. 7 Temperature of External defected specimen



(a) Ø8 (b) Ø10



(c) Ø12 (d) Ø14

Fig. 8 Time-temperature graph of external defected specimen by depth and size

B. Internal Defected Specimen

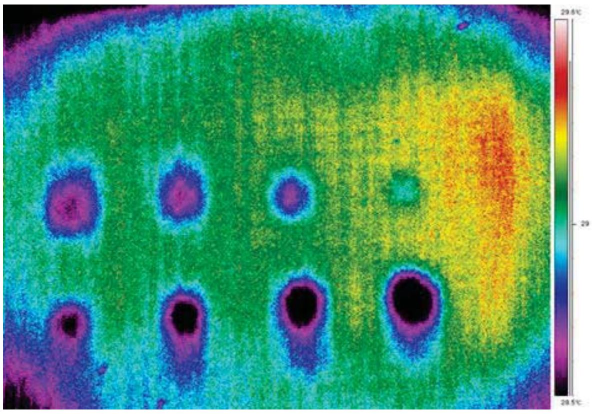
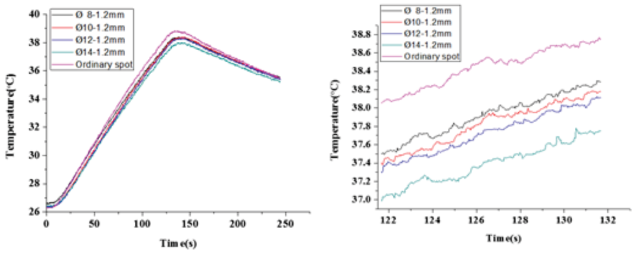
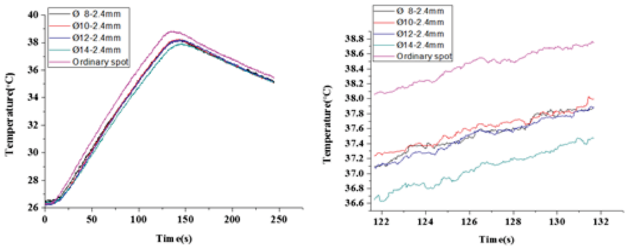


Fig. 9 Internal defected specimen thermo-graphic image

In Fig. 10, defective part temperature is displayed lower than the ambient temperature.



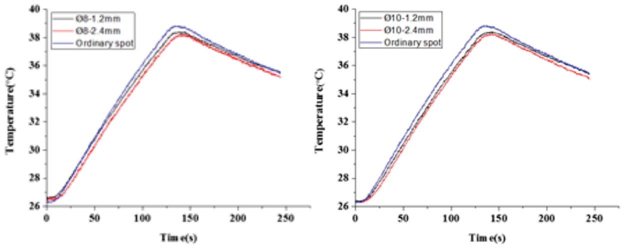
(a) Temperature of defected specimen at depth 1.2mm



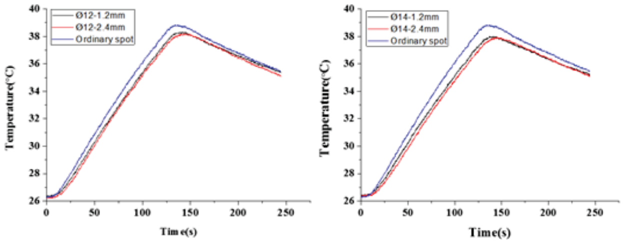
(b) Temperature of defected specimen at depth 2.4mm

Fig. 10 Temperature of internal defected specimen

At the same depth, the temperature of the defected area is lower when it is bigger. At the same size, the temperature of the defected area is lower when it is deeper. This is because the air of the inner defected area has insulation effect, and the thermal conduction is more difficult at a deeper point, resulting in a lower temperature than the ambient temperature. A larger size involves less thermal conduction to the surrounding area, and leads to an even lower temperature.



(a) Ø8 (b) Ø10



(c) Ø12 (d) Ø14

Fig. 11 Time-temperature graph of internal defected specimen by depth and size

TABLE II
MAX TEMPERATURE OF DEFECTED SPECIMEN

	Max Internal Temp(℃)	Max external temp(℃)	Ordinary spot(℃)	
			Internal	External
Ø 8-1.2mm	38.403	41.260	38.831	40.545
Ø10-1.2mm	38.389	41.337		
Ø12-1.2mm	38.329	41.645		
Ø14-1.2mm	38.025	41.745		
Ø 8–2.4mm	38.249	41.432		
Ø10–2.4mm	38.231	41.410		
Ø12–2.4mm	38.217	41.668		
Ø14–2.4mm	37.950	41.826		

V. CONCLUSION

In this study, we analyzed non-destructive test characterization of carbon fiber reinforced plastics (CFRP) internal and external defects using thermo-graphic camera and transient thermography method. The detailed experiment data are as follows:

(1) Temperature of external specimen is which results in a higher temperature than the ambient temperature. This because the defect makes the specimen thinner and thermally more conductive and a larger size involves less thermal conduction to the surrounding area.
(2) Internal specimen is which results in a lower temperature than the ambient temperature. This because is the air of the inner defected area has insulation effect, and the thermal conduction is more difficult at a deeper point.
(3) A thermal imaging camera was used for the non-destructive evaluation and the analysis of the thermal characteristics. Thus, CFRP defects can be analyzed according to the depth in the thermal imaging non-destructive evaluation.

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