TENSILE FRACTURE BEHAVIOR OF CARBON/CARBON COMPOSITE HEAT DISTRIBUTION ANALYSIS

T.H Kim[1], H.G Kim[2*], L.K Kwac[3], S. G Oh[1], H. J Shin[1], B.P Sorn[1], H. J Hong[4]

[1]Graduate school Departmetn of Mechanical Engineering Jeon-Ju University, 1200 3-ga Hyoja-dong Wansan-gu JeonJu, Korea
[2]Departmetn of Mechanical & Automotive Engineering Jeon-Ju University, 1200 3-ga Hyoja-dong Wansan-gu JeonJu, Korea
[3]Departmetn of Carbon and Nano Engineering Jeon-Ju University, 1200 3-ga Hyoja-dong Wansan-gu JeonJu, Korea
[4]Graduate school Departmetn of Carbon and Nano Engineering Jeon-Ju University, 1200 3-ga Hyoja-dong Wansan-gu JeonJu, Korea

***Corresponding author(hkim@jj.ac.kr)**

Abstract

Carbon/carbon composites, which maintain superior mechanical properties even at high temperature and have high specific strength, are utilized in many fields of car light-weighting and aerospace engineering. However, the structure of carbon/carbon composites is so complex that the defects from the manufacturing process may affect their mechanical properties. In this study, carbon/carbon composite heat distribution of the fracture in the tensile test was observed using an infrared camera, which is a sort of nondestructive test, and the correlation between stress and temperature was analyzed to identify the mechanical behaviors.

Keywords: *Carbon/Carbon composite, Infrared Thermography, Tensile test*

1. Introduction

Carbon/carbon composites have high specific strength, superior stability at high temperature, high thermal shock resistance, low thermal expansion, and superior abrasion and facture behavior. Due to these properties, carbon/carbon composites are utilized in the field of aerospace engineering industry such as rocket nozzles and airplane brakes. With the advance of manufacturing technology, Carbon/carbon composites are being more extensively employed by medical and general industries for its characteristics of biocompatibility and chemical inactivation[1].

However, carbon/carbon composites have the problem that its properties are easily damaged by the complex manufacturing process, carbon fibers' orientation state, content, angle, and so on. Also, defects may appear in the process of manufacturing and using the materials, thereby affect its life. To address the problems, studies that focus on identifying the mechanical behaviors of the materials are being conducted using ultrasonic images, a peak-delay measurement method, ablative behaviors, a mechanical strength experiment, etc. Nondestructive tests that detect and correct the error are being used as well[2-4].

Among the methods, Infrared Thermography technique, one of the representative nondestructive tests, was employed for the experiment. The infrared thermography technique is used for defect test and thermal property evaluation by detecting the surface radiation energy of the object, converting it to temperature, and providing the real-time images[5].

To analyze the correlation between the stress and temperature of carbon/carbon composites, temperature variation of the test piece over time, heat distribution on facture, and the spot of maximum stress, etc. were observed in the tensile strength test using an infrared camera.

2. Heat measurement theory [6]

As shown in the figure 1, infrared ray is a shape of electromagnetic radiation which has longer wave length than visible lay. Among the other electromagnetic radiant waves are x-rays, ultraviolet rays, and radio waves. Electromagnetic radiation is ranged by its frequency or wavelength. The range of infrared detector or system is decided by the wavelength. The system that detects radiation in the range of 8 to 12 ㎛ is referred to as "long wavelength," and in the range of 3 to 5, as "short wavelength." The visible region of the electromagnetic spectrum is located between 0.4 and 0.75 ㎛.

As in the figure 2, the measuring principle for infrared thermography is detecting the infrared ray from the surface of an object and displaying its temperature profile: the spot with high temperature is marked as red color meaning long wavelength, while the spot with low temperature as blue color meaning short wavelength. Accordingly, when the heated materials are seen, the infrared camera can not only identify the surface temperature profile of the structure in images but also measure the temperature distribution of each point of the object.

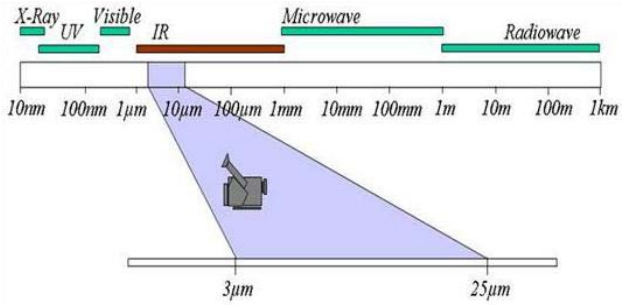


Fig. 1 Infrared band in electromagnetic spectrum of light

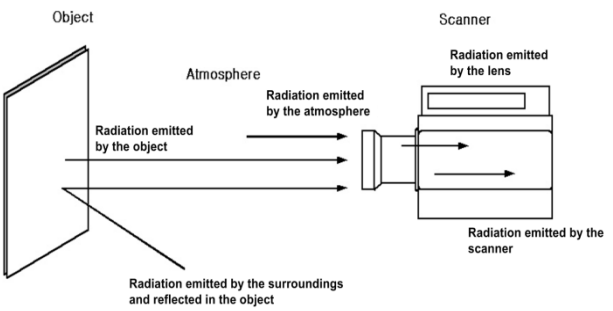


Fig. 2 Principle of Infrared Thergraphy in surroundings

As illustrated in figure 2, the radiant energy falling on an object is displayed as three shapes by the properties of the light. The irradiated energy can be partially absorbed or reflected by the object. Part of it can transmit the object. Based on this, the following formula can be induced.

$$W = \alpha W + \rho W + \tau W \quad (1)$$

That is $1 = \alpha + \rho + \tau$ (2)

In this formula, α, ρ, τ denotes absorptivity, reflectivity, and transmissivity respectively. Formula (2) is Kirchhoff's radiation law. By Planck's law that describes the radiation strength of black body fully absorbing the radiant heat, the total radiant energy emitted from an object can be calculated with Stefan-Boltzmann's law as follows:

For black body, $W = \sigma T^4 \ \ W/m^2$ (3)

In the formula (3), σ indicates Steffan-Boltzman's constant (5.67 $\times 10^{-8}$ W/m^2K^2).

The energy radiated from black body is W_{bb}. An ideal black body radiator actually does not exist. If the actual energy radiation is W_{obj}, the radiation ratio of an object ε is as follows.

$$\varepsilon = \frac{W_{obj}}{W_{bb}}, \quad (0 \le \varepsilon \le 1) \quad (4)$$

From the formula (4), the radiation ratio employed for infrared thermography is the average of ϵ_λ generated from infrared wavelength interval used in the infrared camera, and it is very important to predict the right radiation ratio according to the temperature of each different object.

3. Infrared Thermography Method

In this experiment, Shimadzu's AG-IS Trapezium UTM was used for tensile test of the test piece. For measuring the heat from the tensile test, an infrared camera was used. The infrared camera selected for the experiment is Flir's Silver 480 adopting internal sprinkler cooling method. It shows the spectrum response ranged from 3.7 to 5.0 ㎛ and covers the temperature ranged from -15℃ to 2000℃. Its frame speed ranged from 5Hz to 380Hz with the resolution of 0.02℃. The test piece was a carbon/carbon composite sized based on ASTM D 3039. Its shape is shown in figure 3.

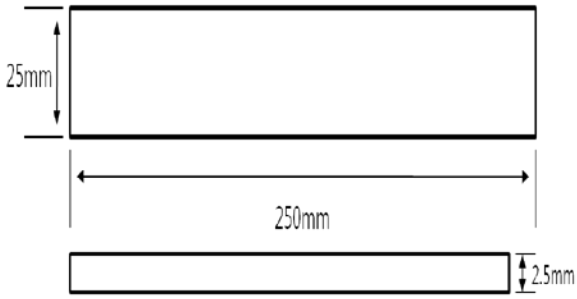


Fig. 3 Shape of specimen(unit:mm)

Black radiant paint was applied to the test piece to make its radiation ratio close to 1. The tensile speed of the test piece was set as 2mm/min. At the same time the tensile test was initiated, temperature change of the test piece was measured over time using the infrared camera.

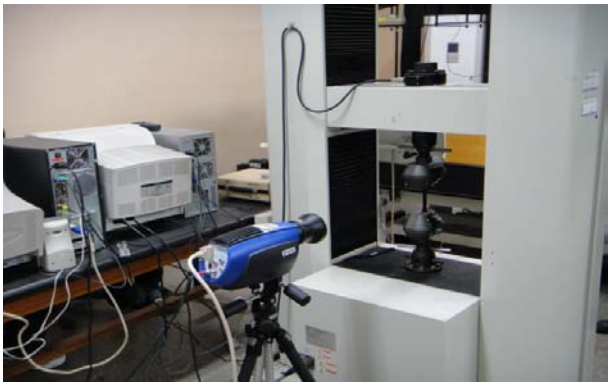
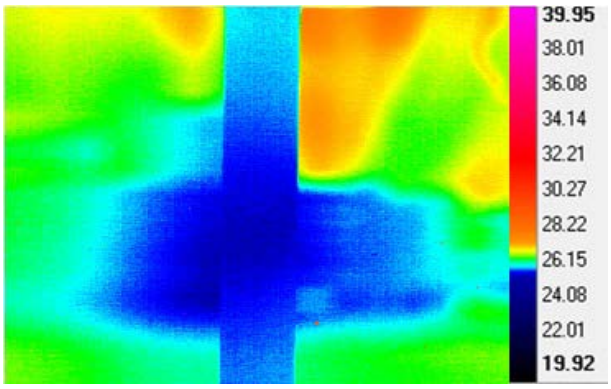
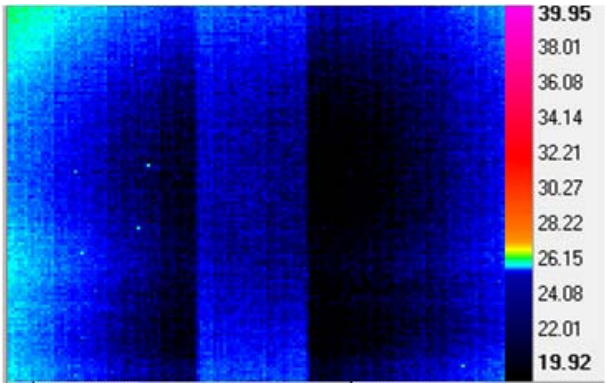


Fig. 4 Experiment system



(a) Long Distance



(b) Short Distance

Fig. 5 Image of tensile test

Figure 4 shows the overall exterior of experimental devices such as an infrared camera and UTM. A carbon/carbon composite test piece was installed in the UTM as shown in the figure 5 to observe the temperature distribution of it during the tensile test. In the tensile test, the Silver 480 was installed in front of the test piece with 1 meter distance and infrared thermographic information was gained real time through Altair program. The IR camera was set to shot 1 frame per l second (1Hz) and the surrounding temperature was set as 25℃. The place for the experiment was shaded by black cloth to meet the conditions of darkroom.

4. Results and discussion

Fracture of the composites was initiated from the internal defects. These defects include broken fibers, cracks inside the basic materials, debonded interface, etc. Once the fracture begins, the spreading process of cracks can be described by a simple model. For example, a crack tip model can be represented as in figure 6. This model shows several possible patterns of local fracture which appears during the fracture of the fiber reinforced composites. The front of the crack remained undamaged within a certain distance. In the region of high stress near the crack, however, fibers were fractured. Fibers right behind the crack were pulled out from the matrix[7].

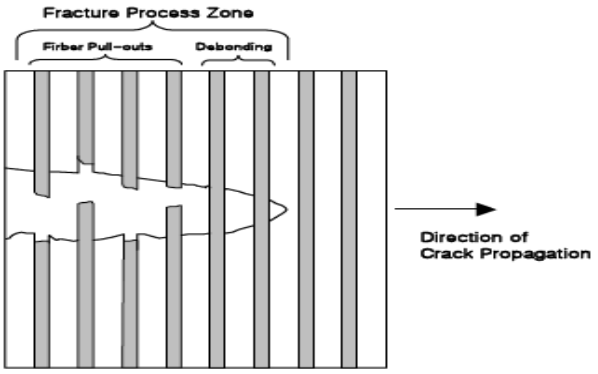
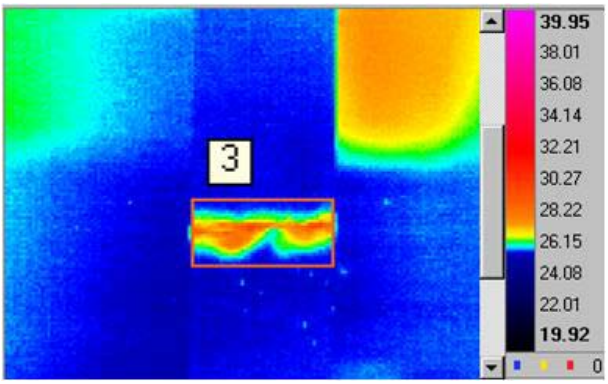


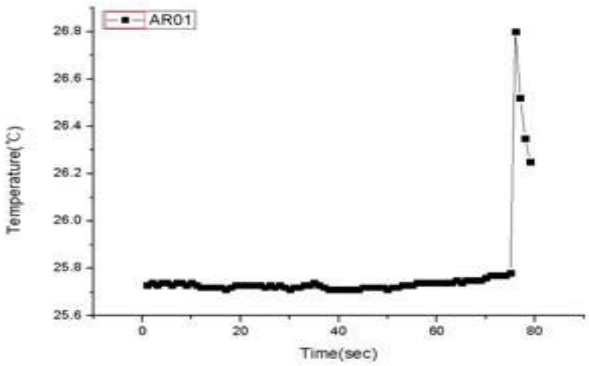
Fig. 6 Model of fracture process

After the tensile test of carbon/carbon composites was started, the area(AR01) was selected and measured to identify the overall temperature of the area surrounding the fracture. In addition, the highest temperature of the fracture was marked as spot(SP01), the temperature of the area surrounding the fracture as spot(SP02), and the external angled area of the spot which yielded the highest temperature as spot(SP03). These areas were selected and measured.

The spot showed the max stress point in the test piece was represented as a graph measuring the highest temperature, and the relations between the max stress point and temperature distribution were verified. Figure 7 illustrates temperature profile of the fracture in tensile test of carbon/carbon composites. It showed that the temperature increased steeply when the test piece was fractured.

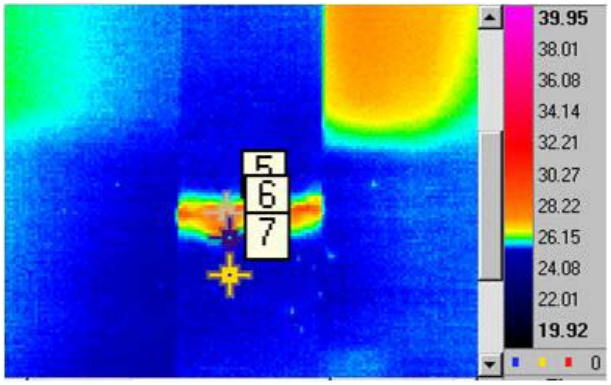


(a) Temperature distribution of area(AR01)

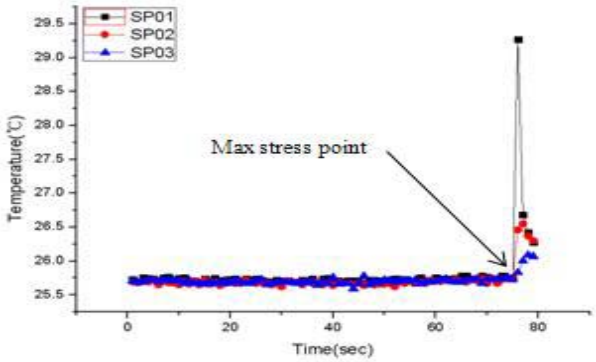


(b) Profile of tread in area(AR01)

Fig. 7 Temperature change measurement on time of area(AR01)



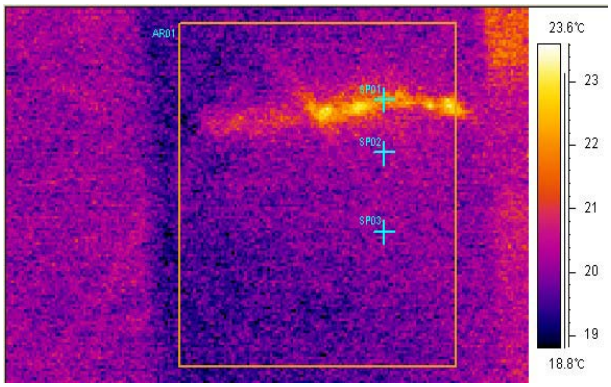
(a) Temperature distribution of 3 spots



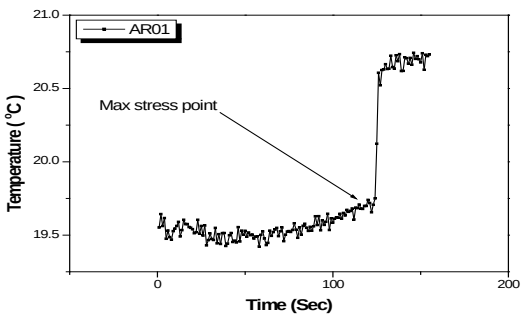
(b) Profile of tread in 3 spots

Fig. 8 Temperature change measurement on time of 3 spots

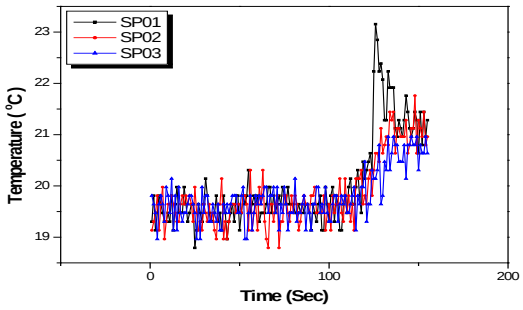
Figure 8 illustrates the spots where the temperature was the highest when the test piece was fractured. It also shows the temperature of the area surrounding the fracture and temperature distribution of the exterior angled area. As shown in the graph, the temperature steeply increased immediately after the spot with the max stress point.



(a) Temperature distribution



(b) profile of tread in area



(c) Profile of tread in 3 spots

Fig. 9 Temperature change measurement on time (J=0.3 , 10wt%) of GFRP [7]

Figure 9 is a graph representing GFRP's temperature change over time in the tensile test, which was measured by the infrared camera. When compared with that of carbon/carbon composites', it is similar in the pattern but different in the fracture time and temperature change of the test piece. These differences appear to be caused by the mechanical properties of the materials.

5. Conclusion

In this study, temperature change on the fracture of carbon/carbon composites was observed by conducting the tensile test using an infrared camera. It showed that the temperature slightly increased over time and steeply ascended when the test piece got the max stress point at the spot of local contraction.

Postscripts

"This research was supported by basic science research program through the national research foundation of korea(NRF) funded by the ministry of education, science and technology (No. 2010-0023764)"

Refernce

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