Infrared Thermal Wave Nondestructive Testing for C_f /SiC Ceramic Matrix Composite

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Abstract:

In this paper the principle and experimental process of the infrared thermal wave nondestructive testing (NDT) on carbon fiber reinforced silicon carbide (C_f /SiC) ceramic matrix composite sample are demonstrated. The experiment results compared with X-ray testing results show that the infrared thermal wave NDT is an effective method for the C_f /SiC ceramic matrix composite, and it can be used as the additional and vicarious method of the conventional NDT.

Keywords: infrared thermal wave, C_f /SiC composites, thermal image

1. Introduction

Carbon fiber reinforced silicon carbide (C_f/SiC) ceramic matrix composite is one kind of new-style high temperature structural matrix composite. The increasing widely used of this material in aerospace has heightened the need for the research of material's quality control. [1]And lots studies have been concentrated to the X-ray testing. In this paper a novel infrared thermal wave nondestructive testing technique is introduced for this material's quality testing. With this method, a visible light pulse heated on the surface of the sample and an infrared camera monitors the surface temperature field change continuously. Then the computer analyzes and processes the thermal images for detection. The 2.5D C_f /SiC ceramic matrix composite with prefabricated flaws was detected by infrared non-destructive testing. Much information was shown on the thermal images. Compared with other NDT methods, the dominances of the infrared thermal wave NDT are rapid, large-area, and real-time.

2 The principal of the thermal wave NDT

Infrared thermal wave nondestructive testing (NDT) method is based on the thermal wave theory. Unlike the conventional thermographs that only monitor the surface temperature variations passively, the thermal wave NDT uses controllable heating sources to actively excite the detected material. The material's subsurface physical properties will change the thermal wave's conduction, and then the change will be shown on the surface's temperature field. At the same time the infrared camera monitors and records the surface's temperature field continuously. By controlling the heating sources and recording the surface's temperature field variation, the material's subsurface structure and abnormality information will be acquired. [2]

Pulsed heating thermal wave NDT is a relatively mature technology at the present time. Two high energy flash lamp pulses are used to excite the detected material. Its operating principle is as shown in Figure 1.

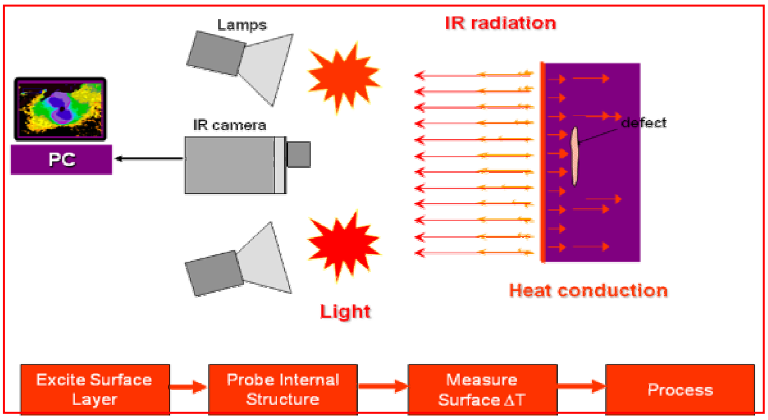

Figure 1.The operating principle of the Pulsed heating thermal wave NDT

3 Experiments

3.1 experimental equipments

The pulsed heating thermal wave NDT system was used in the experiments. The system is composed by three parts: Pulsed heating sources, infrared camera and special software. Pulsed heating sources are two linear xenon flash lamps. Each flash power supply can deliver maximum of 4.8 kilo joules energy. And depending on the discharging circuit time constant, the flash pulse width can be as short as 2ms. The ThermaCAMTM SC3000 infrared camera is used as the center part of the thermal wave NDT system, The SC3000 infrared camera has a 320x240 InSb focal plane array (FPA) detector with sensible infrared radiation spectrum range from 8μm to 9μm. After image collecting, thermal wave imaging software provides user with powerful image processing functions and tools to display and analysis the images. [3] In the following sections and chapters, all the images and curves shown were obtained by using this software.

3.2 experimental processes

The sample is a 240cm long, 135cm wide and 0.4cm thick 2.5D C_f/SiC ceramic matrix composite with prefabricated flaw of occluded carbon cloth (see Figure2). It was provided by the high temperature structural matrix composite laboratory in northwestern poly-technical university.

Figure 2.The operating principle of the Pulsed heating thermal wave NDT

The experimental condition setting: The flash energy is 4.8KJ, the collecting time of images is 10 seconds and the collecting frequency is 60Hz. In order to acquire a uniform and clear view field, non-uniformity correcting and focus adjust had been done for the infrared camera.

3.3 experimental results

By using pulsed heating infrared thermal wave nondestructive testing to detect the sample, the original image at 0.067 second is obtained, as shown in figure 2. Because of the well thermal conduction character, the prefabricated flaw and other thermal abnormity can be seen at the earlier time. It is necessary to point out that the dispersed black-pots on the thermal image are the sample's reinforced structure rather than flaws.

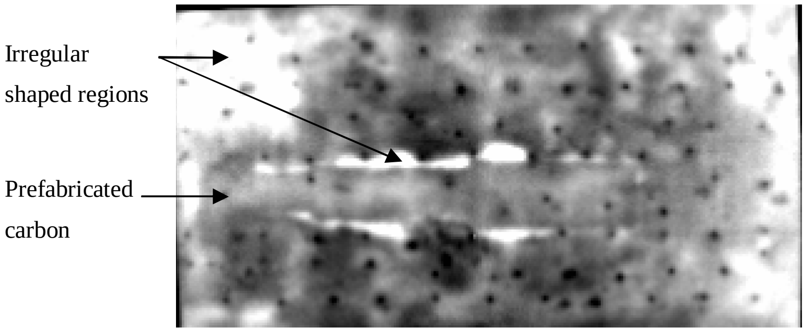

Figure 3.Original thermal image obtained by the thermal wave NDT

As can be seen in figure 3, the grey-scale difference between the area of the prefabricated flaw and the referred matrix is not obvious. It is because the thermal character of the prefabricated carbon cloth and the C_f /SiC ceramic matrix composite are closely. Moreover, the brighter and irregular shaped regions around the prefabricated flaw in the thermal image indicate that the fabrication technology of the artificial flaws may draw into unexpected flaws such as local density changing and air gap. Furthermore, the overview of the whole thermal image is non-uniform. For example the upper left corner on the thermal image is obvious brighter than the other area, which is caused by the noises or the density changing.

Through the first order differential operator, the thermal rate of change image is achieved, as shown in figure 4. The thermal signal can be accurately reflected by the thermal rate of change images. Moreover, it can effectively reduce the noise disturbance and magnified the difference between the "thermal normality" and the "thermal abnormality", which may benefit to the judgment of the internal flaws.

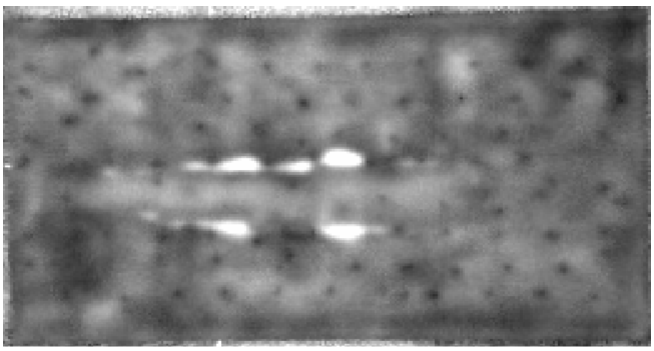

Figure 4. Thermal rate of change image after first order differential operator

The sample is dissected by the sample provided laboratory. The dissected results show that around the prefabricated carbon there are lots of air gaps, which agrees to the infrared thermal testing results.

The sample is also tested by the X-ray NDT, as shown in figure 5. The dusky area of the image is the prefabricated carbon.

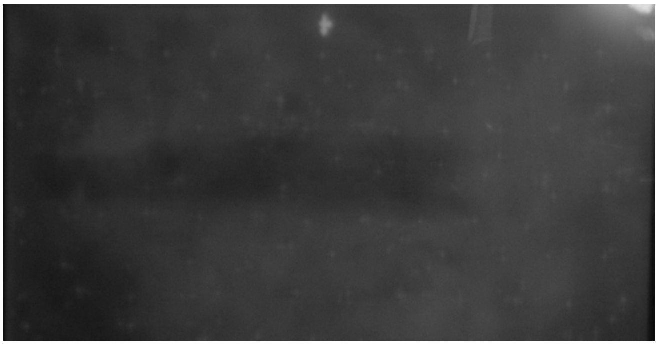

Figure 5. Testing result by the X-ray NDT

4 Conclusions

Comparing the testing results of infrared thermal wave NDT and X-ray NDT, we can draw into some conclusions.

(1)Besides the prefabricated carbon, the air gaps caused by the fabricated technology can also be detected by the infrared thermal wave NDT. However, the X-ray NDT can only detect the density changing caused by the carbon insert.

(2)The thermal images can report the internal flaws of the sample; thermal rate of changing images can effectively reduce the noise disturb and magnified the difference between the “thermal normality” and the “thermal abnormality”, which may benefit to the judgment of the internal flaws.

Furthermore, Compared with other NDT methods, the dominances of the infrared thermal wave NDT are safe, rapid, large-area, and real-time. [4]It can be used as the additional and vicarious method of the conventional NDT.

5 References

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