A STUDY ON THE INFRARED THERMOGRAPHY CAMERA NONDESTRUCTIVE EVALUATION OF CARBON/CARBON BRAKE DISKS

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Abstract

Carbon/Carbon brake disks using impregnation carbon fiber in carbon matrix have been used widely as aircraft part and automotive brake disk, because of its high strength, high heat conductivity, low density and excellent mechanical properties. Carbon/Carbon brake disks require high product cost and multi manufacturing process. Safety factor and efficiency of material will remarkably drop down, if product is defective, and nondestructive is required to grasp the quality, homogeneity and integrity of material. In general, radiograph evaluation makes safety problem of radiation, and ultrasonic flaw detecting evaluation is very hard to assess due to much influence under specimen surface state. This study is focused on the using of infrared thermography camera technique which is not get much influence under surface state to grasp the heterogeneity of material at manufacturing process and to proof its relation in order to make reliability.

Keywords: Carbon/Carbon composite, Infrared Thermography

1. Introduction

Recently, the vehicles have been made larger with high speed which makes the temperature on friction surface of brake disk and heat release rate increase during braking. Thus metallic friction materials, sintered friction materials using metal power and nonmetal power, and carbon/carbon composite materials have been developed due to the needs of high performance of brake disk materials. In particular, carbon/carbon brake disk in necessary required for the speed of aircraft and for the big vehicles. In modern time, the lightweight brake disk is intensively interested [1]. In C/C composite material manufacturing process, preform is produced, and the produced preform is repeated in the process of carbonization and high temperature annealing impregnation process. Thermal Gradient chemical Vapor Infiltration (TGCVI) process and other processes are divided for high density. The void and crack happened due to the mass loss and shrinkage of the resin in the multi-process as described above. In addition, the internal properties of materials change [2]. Thus nondestructive evaluation is importantly used in C/C composite material manufacturing process for preventing the delamination, porosity and the defect factor, and also to ensure the quality and the performance of the C/C brake disk for advanced techniques [3]. Recently, many techniques have been used for nondestructive evaluation such as radiograph evaluation and ultrasonic flaw detecting evaluation. Radiograph evaluation causes the safety problem of radiation line, and the ultrasonic flaw detecting evaluation received a lot of effect depending on surface of the specimen. For those problems, the quality of material is very hard to evaluate.

In this study, the infrared thermography camera technique which is not receiving a lot of affect was
used to evaluate heterogeneity of materials during manufacturing process and to prove its association for ensuring its reliability.

2. Heat measurement theory

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 μm 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 μm.

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](image)

![Fig. 2 Principle of Infrared Thermography in surroundings](image)

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.

\[ W = \alpha W + \rho W + \tau W \]  \hspace{1cm} (1)

That is, \[ 1 = \alpha + \rho + \tau \]  \hspace{1cm} (2)

In this formula, \( \alpha \), \( \rho \), \( \tau \) 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:

\[ W = \sigma T^4 \]  \hspace{1cm} (3)

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

In the formula (3), \( \sigma \) 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 \( \varepsilon \) is as follows.

\[ \varepsilon = \frac{W_{obj}}{W_{bb}} , \quad 0 \leq \varepsilon \leq 1 \]

From the formula (4), the radiation ratio employed for infrared thermography is the average of \( \varepsilon_\lambda \) 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.

2.2 Testing method

Artifacts were processed on the front and the right view of C/C brake disk specimen. Fig.3 shows the artifact brake disk used for the experiment. And Table1 shows each size of the artifact.
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The matte black spray paint was used to set on the surface of the black body. Fig.4 shows the experiment device used in experiment.

Infrared camera used in this experiment is a product of FLIR company type A320, and its specification is shown in Table 2. The heat source was given by halogen lamp (500W x 4) on the opposite side of artifact part of the C/C brake disk. And infrared thermography camera was installed in the same direction as halogen lamp to measure temperature distribution through artifacts.

The contact thermometer was used to calibrate the temperature of specimen, and emissivity, humidity were also measured by hygrometers.

1 second per frame is set on the surface temperature of brake disk for analyzing.

3. Results and Discussion

3.1. Measurement of artifact plane

Fig.5 shows the temperature distribution measured by infrared thermography camera while artifact specimen was heated by halogen lamp on the C/C brake disk.

Thermography measurement of C/C brake disk was performed as shown in Fig.2 and Fig.3. And the artifact was placed on the opposite direction of measurement. Two points of surrounding of the artifact and the front view artifact (P1-P6) shown in Fig.5 were set to evaluate the artifact location temperature on the front view of the C/C brake disk while the halogen lamp heated the C/C brake disk. The following Fig.6, Fig.7, Fig.8 shows the artifact and vicinity of the temperature distribution in elliptical curve.

<table>
<thead>
<tr>
<th>No.</th>
<th>Diameter [mm]</th>
<th>Depth [mm]</th>
<th>No.</th>
<th>Diameter [mm]</th>
<th>Depth [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>5</td>
<td>4</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<tr>
<td>3</td>
<td>8</td>
<td>15</td>
<td>6</td>
<td>5</td>
<td>35</td>
</tr>
</tbody>
</table>

Table 1 The hole size and depth of specimen

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>-20℃~350℃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Accuracy</td>
<td>±0.2℃</td>
</tr>
<tr>
<td>Frame Rate</td>
<td>5.0 Hz</td>
</tr>
<tr>
<td>Pixel Resolution</td>
<td>320×240</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>7.5 to 13.0 μm</td>
</tr>
</tbody>
</table>

Table 2 Specifications of A320
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The more C/C brake disk was heated by halogen lamp; the temperature of the front view artifact part (P1-1, P2-1, P3-1) is higher than the surrounding temperature approximately 0.1°C~0.3°C. And it can judged that the temperature of the thin thickness part was increasingly faster than the thick thickness part due to the artifact, in the case of the internal crake of C/C brake disk happened and the C/C brake disk has the same cross section area and receive the same amount of heat.
3.2. Measurement of side artifact

Two points of surrounding of the artifact and the right view artifact (P1-P6) shown in Fig.4 were set to evaluate the artifact location temperature on the front view of the C/C brake disk while the halogen lamp heated the C/C brake disk. The following Fig.9, Fig.10, Fig.11 shows the artifact and vicinity of the temperature distribution in elliptical curve.
It is very similar to the temperature of the front view artifact part; the temperature of the right view artifact part (P4-1, P5-1, P6-1) is higher than the surrounding temperature approximately 0.1℃~0.3℃. And it can judged that the temperature of the thin thickness part was increasingly faster than the thick thickness part due to the artifact, in the case of the internal crake of C/C brake disk happened and the C/C brake disk has the same cross section area and receive the same amount of heat.

4. Conclusion

The characteristics of temperature distribution can be estimated depending on the artifact of C/C brake disk according to the results obtained from experiment. Through the experiment, it was not easy to measure the artifact of C/C brake disk on the opposite side if compared to the normal metal. And it can be known that the temperature distribution around the artifact part was higher than the surrounding temperature. Non destructive inspection using infrared thermography camera for estimating other composite materials is not meet the standard. Thus the research on the infrared thermography camera should be conducted to secure the database and to evaluate the temperature distribution of the C/C brake disk in the real-time.

Postscripts

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References