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Infrared Thermography for Nondestructive Testing†

1. Introduction

Application of nondestructive testing by infrared camera techniques to maintenance of social infrastructure is progressing, for example, use in periodic inspections of exterior walls, etc., as a result of the 2008 revision of Article 12 "Periodic reporting system" of Japan's Building Standards Act. In 2012, the Japanese Society for Non-Destructive Inspection began "Infrared thermographic testing –Qualification and certification of personnel," further increasing the attention focused on this technology.

JFE Techno-Research is engaged in development of technologies for detection of internal defects and measurement of stress distribution of buildings and civil structures, mechanical components, welds, etc. by detecting minute temperature changes with a high performance infrared camera (Temperature resolution: 20 mK or less, Frame rate: 383 Hz, Maximum frame rate with reduced pixel numbers: 20 000 Hz) which enables high sensitivity, high speed measurements[1–3]. In recent years, with expansion of applications to detection of defects such as exfoliation, cracks, void, etc. in composite materials, stricter detection accuracy was also required, and it was no longer possible to respond with conventional technologies. Therefore, as an active thermography method utilizing a new thermal infrared camera, higher resolution was achieved by combining signal analysis technology by the lock-in technique, etc. with heating methods such as the thermal wave technique, ultrasonic vibration technique and applied voltage technique.

This report presents an introduction to infrared thermography technology at JFE Techno-Research, centering on nondestructive testing and stress measurement by the thermal wave technique using a new infrared camera developed by this company.

2. Nondestructive Testing

Active thermography is a technique in which defects are detected by actively applying a thermal load to the measurement object. Among active methods, this report introduces nondestructive testing technologies utilizing the thermal wave technique and the applied voltage technique.

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2.1 Thermal Wave Method

The thermal wave technique, as shown in **Fig. 1**, is a technique in which defects (exfoliation, voids, etc.) are detected by irradiating the measurement object with a heating lamp such as a xenon flash tube, etc. and performing measurements with an IR camera. When the heating lamp applies heat (thermal wave), a temperature difference and time difference in the transmission time (phase shift) will occur if there is a difference in thermal diffusivity between the sound part and a defect when the thermal wave passes through the object. The defective part is visualized by a 2-dimensional display of this temperature difference and phase shift. The lock-in technique, etc. is used as a signal processing technology for defect detection. The lock-in technique is a signal processing technology which increases *S*/*N* by extracting only the temperature change which has the same period as that of the load (heating lamp, load, etc.) from the time-series data of temperature changes. **Figure 2** shows an example in which exfoliations of a carbon fiber reinforced plastic (CFRP) sample were identified by heating

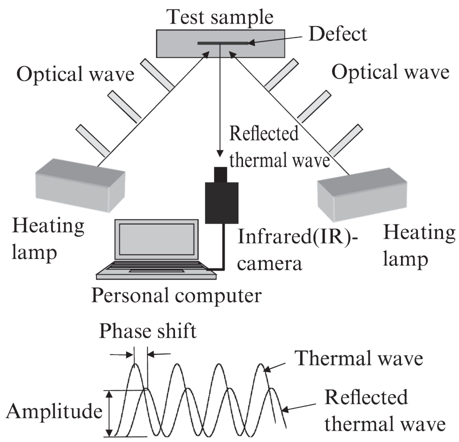


Fig. 1 Schematic illustration of thermal wave technique

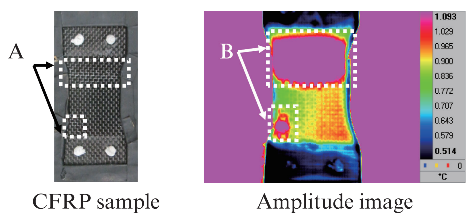
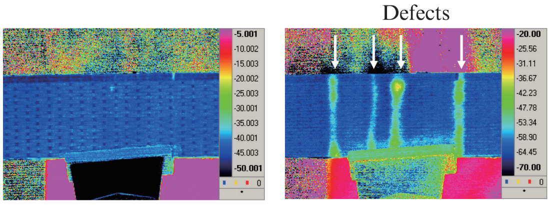
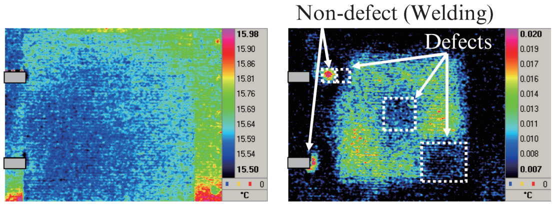


Fig. 2 Detection of exfoliations for carbon fiber reinforced plastic (CFRP) sample using thermal wave technique



(a) f = 1 Hz (μ ≒ 0.3 mm)　(b) f = 0.1 Hz (μ ≒ 1 mm)

Fig. 3 Frequency dependent of phase image by thermal wave technique



(a) Thermal image　(b) Amplitude image

Fig. 4 Detection of defects for Lithium-Ion battery applied voltage

the CFRP sample with a xenon flash tube after a fatigue test. In the results of measurements by the thermal wave technique, it can be understood that exfoliations actually occurred over a wider range (B) than the range which can be confirmed from the external appearance of the sample (A).

The heat penetration depth μ by the thermal wave technique is given by Eq. (1), using the frequency f of the heating lamp[4].

$$\mu = \sqrt{a/\pi f} \qquad (1)$$

a: thermal diffusivity

Accordingly, it is possible to obtain not only the 2-dimensional position of a defect, but also information for the depth direction from the surface, by changing the frequency of the heating lamp. **Figure 3** shows an example in which a CFRP sample with an artificial defect (reduction of material thickness) was measured while changing the frequency of the heating lamp. The artificial defect is located on the back side of the sample. In Fig. 3(a) at f = 1 Hz, the distribution of the fibers around the surface can be visualized, and in Fig. 3(b) at f = 0.1 Hz, the distribution of the defect (reduction of thickness) on the back side can be obtained.

The thermal wave technique is effective for detection of defects such as exfoliations, voids, etc. of composite materials, including CFRP and others, and makes it possible to obtain 3-dimensional information on the positions of defects.

2.2 Applied Voltage Technique

The applied voltage technique is a technique in which defects (high resistance parts in electrical wiring, etc.) in a measurement object are detected by applying a voltage periodically to the object and performing measurements with an infrared camera. **Figure 4** shows an example of detection of a defect in a lithium ion secondary battery by the applied voltage technique. If there is a part that cannot be charged due to a defect of the electrode surface, the temperature change (temperature difference) of the defective part will be smaller than that of the sound part. A battery, which had been wrapped in aluminum laminate, was charged periodically and measured with an infrared camera, and the results were analyzed by the lock-in technique. In the thermal image in Fig. 4(a), the heat propagation due to thermal conduction becomes noise, and no clear thermal difference can be observed. Thus, in this case, defects cannot be detected. In contrast, in the thermal amplitude image by the lock-in technique shown in Fig. 4(b), S/N is increased, and the minute temperature difference (<0.02°C) between the defects and the sound part can be seen.

The applied voltage technique is effective for analysis of heat generation and detection of defects in secondary cells and electronic components.

3. Stress Measurement

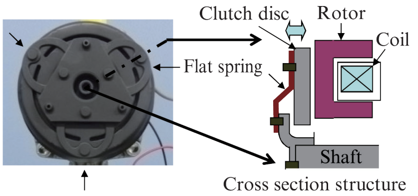
Stress is measured by utilizing the thermoelastic effect, which causes a temperature change when a substance undergoes adiabatic elastic deformation. The amplitude of change $\Delta\sigma$ of the sum of the principal stresses in a metal or other homogeneous material due to the thermoelastic effect is expressed by Eq. (2)[1].

$$\Delta\sigma = -\Delta T/(kT) \qquad (2)$$

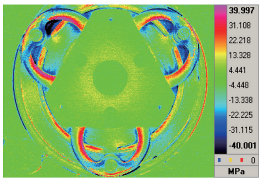
ΔT: Temperature change of object
T: Absolute temperature
k: Thermoelastic modulus

Accordingly, if the thermoelastic modulus k is known, stress can be calculated by measuring ΔT. Thermoelastic modulus, k is a characteristic value which depends on the material. For example, in the case of carbon steel, the temperature change when a stress of 1 MPa is applied to carbon steel is extremely small, being approximately 1 mK. However, it is possible to measure stress with resolution of 1 MPa by using the lock-in technique.

Figure 5 shows an example of measurement of the magnetic clutch of a compressor for use in automotive air conditioners. When the magnetic clutch is operated, it can be understood that bending stress is applied to the flat springs. Although the clutch contains three flat springs which are arranged equidistantly, the measure-



(a) Magnetic clutch of compressor for car air conditioner



(b) Image of stress distribution

Fig. 5 Stress measurement of compressor for car air conditioner

ment results in Fig. 5(b) show that the actual stress is not equal, and stress concentrations occur.

The stress distribution of complex products can be visualized by stress measurement, and the results can be applied to verification of the input data and results of computer aided engineering (CAE) during product design.

4. Conclusion

Nondestructive testing and stress measurement technologies using the high performance infrared camera were introduced, centering on the thermal wave technique.

JFE Techno-Research performs commissioned measurements using high performance infrared camera techniques, as well as development support and system development. In the future, expansion of these technologies to new fields of application is planned in order to respond to new customer needs.

References

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