Active thermographic large-area inspection using periodic scanning heating and phase image transformation

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Abstract

An active thermography testing method for large area using periodic scanning heating and phase image transformation was investigated in this study. Through experiments for a large CFRP specimen containing artificial defects, it was found that a phase gradient caused by the scanning motion of heat source appeared in the obtained phase images. The phase gradient could be theoretically estimated and removed, and the defects were clearly detected in the processed phase images. These results demonstrate that the proposed method is an effective approach for applying phase-based testing methods to large areas.

1. Introduction

Inspections of large areas using active thermography methods are challenging because the inspection area strongly depends on the heating area of the heat source. Conventionally, it is necessary to divide the inspection area and repeat the inspection multiple times, which results in longer inspection times and reduced work efficiency. To improve the work efficiency for large-area testing, this study focuses on active thermography with scanning a heat source. The heating (or testing) area can be continuously expanded by moving the heat source. Furthermore, by moving the heat source reciprocally and periodically, periodic temperature variations similar to those observed in lock-in thermography [1–3] are generated. Therefore, phase images can be obtained by applying Fourier transformation to the temperature data, which should enable high-accuracy inspections based on the phase data to large areas. In this study, experiments for a CFRP specimen using the periodic scanning heating were conducted, and the effectiveness of using phase image transformation to the temperature data obtained through the scanning heating was investigated.

2. Experimental Procedure

Figures 1(a) and 1(b) show the experimental setup and the CFRP specimen used in the experiments. The specimen had some flat-bottomed holes as artificial defects. The holes were square shaped, and the defect depth from the heated surface was 0.5–3.0 mm. A halogen line heater (LHW60/f∞/L280/100V-1kW, Fintic Tokyo Co., Ltd.) was mounted on a single-axis electric actuator (EC-B6S-2600-0, IAI Corporation) periodically moved in front of the specimen. The distance between the heater and specimen was 1000 mm, and the heater-moving distance was 2000 mm (thus, reciprocation scanning distance per cycle was 4000 mm). The periodic heating frequency was varied by changing the moving speed of the heater; experiments were performed at the heating frequencies of 0.005, 0.01, 0.02, and 0.05 Hz. The heater turned on only when moving in one direction, whereas it was turned off when moving in the opposite direction. Surface temperatures during the heating were measured using an infrared camera (A315, FLIR). The obtained temperature–time data were Fourier transformed to obtain phase data at the frequency corresponding to the heating frequency. Phase images were then constructed by arranging the phase values of each pixel.

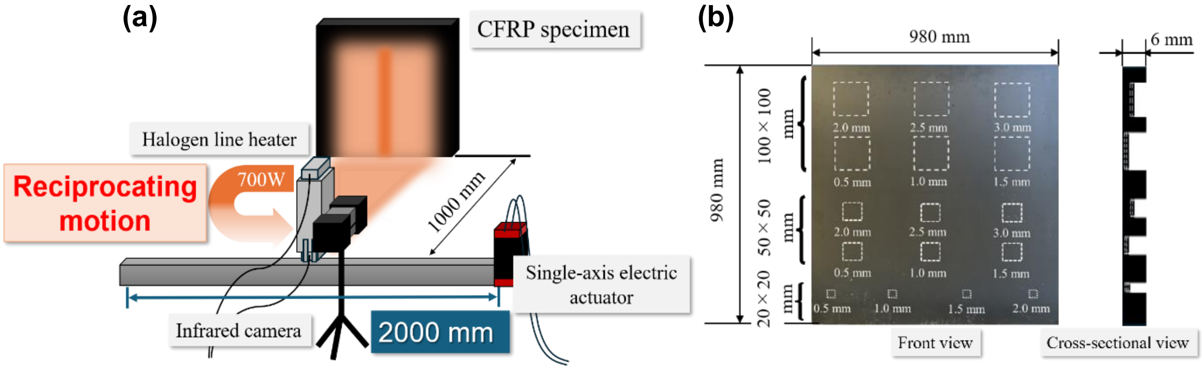

Figure 1. (a) Schematic of experimental setup, (b) CFRP specimen with artificial defects (areas enclosed by dashed lines indicate artificial defects, and numerals denote defect depth from heated surface).

3. Results and Discussions

Figure 2(a) shows the thermal image obtained at a heating frequency of 0.02 Hz, and figure 2(b) shows the phase image at the same frequency obtained from temperature data in figure 2(a). Defects can be identified as local temperature or phase differences. Figure 2(c) shows the phase profile along the dashed line in figure 2(b). It is found from figures 2(b) and 2(c) that a phase gradient along the scanning direction was observed in the phase images. This phase gradient should be caused by a delay in the heating timing resulting from the heater motion. Figure 2(c) shows the phase shift between the two sides of the specimen was approximately 90°, which should correspond to one-fourth of 360° deriving from that the specimen length (980 mm) is approximately one-fourth of the reciprocation scanning distance. Therefore, in order to remove the phase gradient, a linear phase shift corresponding to 90° from left to right was subtracted from the phase image. The result of the subtraction process is shown in figure 2(d). The phase gradient was successfully removed, and the phase difference in the defective regions are distinguished more clearly. In figure 2(d), 20 mm × 20 mm defects (located in the lower area of the specimen, which were difficult to distinguish in figures 2(a) and 2(b).) were also detected.

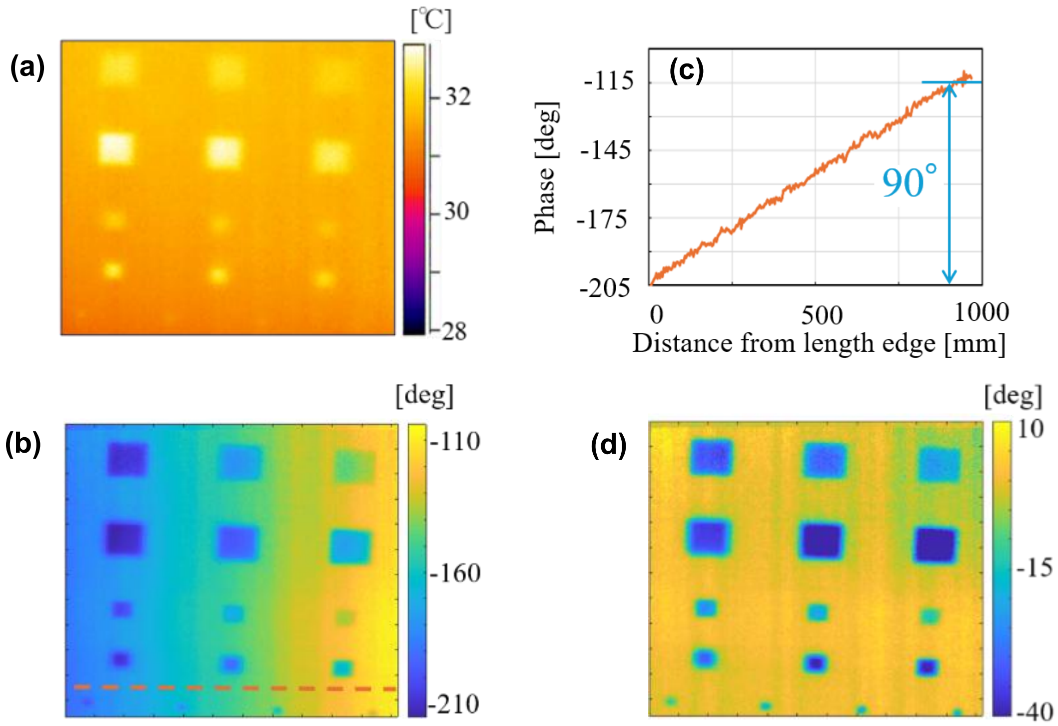

Figure 2. (a) Thermal image obtained at a heating frequency of 0.02 Hz, (b) phase image obtained by applying Fourier transformation to temperature data in (a), (c) phase profiles along dashed line in (b), and (d) phase image after phase-gradient removal.

4. Conclusion

Active thermographic non-destructive method using periodic scanning heating and phase image transformation was investigated. Although a phase gradient caused by the heater scanning was observed in the obtained phase images, that could be theoretically removed, resulting that defects were detected clearly in the processed image. These results demonstrate that the proposed method could be an effective option for applying active thermography method (or lock-in thermography using phase image transformation) to large inspection areas in large-scale structures.

References

[1] X. Maldague, «Theory and practice of infrared technology for nondestructive testing,» Wiley, 2001.

[2] D. Wu, G. Busse, «Lock-in thermography for nondestructive evaluation of materials,» Revue générale de thermique, vol. 37, n. 8, pp. 693–703, 1998.

[3] T. Sakagami, S. Kubo, «Applications of pulse heating thermography and lock-in thermography to quantitative nondestructive evaluations,» Infrared Physics & Technology, vol. 43, pp. 211–218, 2002.