Study on Measurement of Internal Defects by Infrared Thermography*1

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The authors have developed a nondestructive measurement method for internal defects using optical excited thermography. In order to find optimal measurement conditions, experiments have been carried out under different light irradiation cycles and times. Furthermore, the authors have proposed a method for quantitatively estimating the size of internal defects by differential processing of the phase difference distribution of surface temperature variation. From the experimental results, it has been found that there exists an optimal irradiation cycles and times, and that these depend on specimen. Also, it has been recognized that internal defect size can be quantitatively estimated from differential processing of the phase difference distribution of surface temperature variation, that estimation accuracy is related to the thermal conductivity of materials and materials with lower thermal conductivity show higher estimation accuracy.

***Key Words**: internal defect, nondestructive test, infrared ray, optical excited thermography*

1. Introduction

Conventionally, ultrasonic testing, the magnetic-particle testing and so on were used as nondestructive measurement methods for internal defects, however these require significant labor and time to measure a wide area. Consequently, in recent years optical excited thermography has been drawing attention as a non-contact, time-saving method of measuring wide areas. Research relating to the measurement of internal defects using optical excited thermography is essentially limited to the ability to determine internal defect depth direction using various measurement conditions and the basic study of whether or not internal defects can be detected at all. There are few reports relating to quantitatively estimating the position and size of internal defects. [1)]

In this report, the internal defects in specimens were measured under several different irradiation cycles and irradiation times using optical excited thermography. The authors have attempted to quantitatively measure internal defect size using the phase distribution of the surface temperature variation acquired from the specimen of optimal measurement conditions.

2. Experimental Method

Figure 1 shows the schematics of the measurement system. The infrared thermography used in the experiment was Cedip Silver 480M. The experiment involved periodically heating the surface of the specimen with an external light source (halogen lamp), and photographing the temperature image using infrared thermography. At this time, the control signal (square wave) for the external light source was also recorded as a reference signal. The surface temperature of the specimen fluctuates at the same cycle as the external light source. The surface temperature variation phase will change if the specimen has internal defects. To calculate the phase difference distribution of the temperature variation, the sine waves synchronized with the reference signals were made consistent to the temperature variation data taken in each position on the specimen surface to ensure minimal residual sum, and the phase difference of the reference signal and its synchronized sine wave was compared. Furthermore, the temperature variation distribution was calculated from the amplitude of the sine waves matched to the temperature variation data of each position on the specimen surface and the temperature variation phase difference distribution was compared.

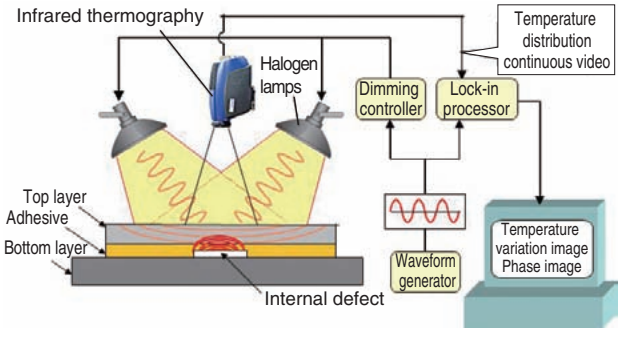

Fig. 1 Schematics of measurement system

*1 This report was prepared based on the 2010 Autumn Meet Paper (520106) published by The Japanese Society for Non-Destructive Inspection.

Internal defects were created in the specimens using three pieces of Teflon tape with varying sizes to adhere the bottom layer to the top layer. Two specimens were fabricated with top layers made from $Nd_2Fe_{14}B$ and S15C respectively. These two materials have different thermal conductivities. **Tables 1** and **2** show measurement conditions and specimen specifications for the two specimens individually. **Figure 2** provides details of the internal defects of the specimens. The experiment measured internal defects under the following conditions respectively; black bodies with emissivity of 0.94 sprayed with paint, irradiation cycles from 3 to 40 seconds at each second, irradiation times of 1, 3 and 5 seconds, an integration cycle of 10 cycles, and an infrared thermography with a frame rate of 300 Hz.

Table 1 Measurement conditions

Infrared thermography	Cedip Silver 480M
External light source	Halogen lamps 500 W × 2
Light source control method	ON/OFF control
Irradiation cycle	3 – 40 s (every 1 s)
Irradiation time	1, 3, 5 s
Integration cycle	10 cycles
Frame rate	300 Hz

Table 2 Specification of specimens

Top layer material	$Nd_2Fe_{14}B$, S15C
Top layer size	8 × 64 × 2 mm
Top layer thermal conductivity	$Nd_2Fe_{14}B$ = 7 W/(m · K), S15C = 52 W/(m · K)
Internal defect size	20, 10, 5 mm
Remarks	Black bodies with emissivity of 0.94 sprayed

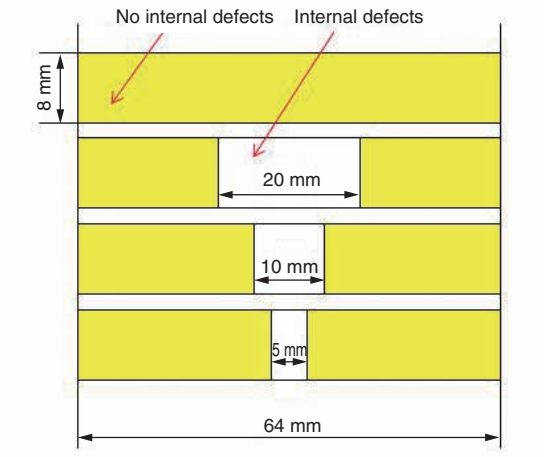

Fig. 2 Internal defects of specimens

3. Experimental Results and Observations

The distributions of temperature variation (**Figs. 3** and **4**), phase difference distributions of temperature variation (**Figs. 5** and **6**) and longitudinal phase difference distributions of temperature variation (**Figs. 7** and **8**) are given for the $Nd_2Fe_{14}B$ and S15C specimens. **Figures 3** through to **8** are the measurement conditions where phase difference variation in the internal defects is emphasized the most. Measurement conditions for the $Nd_2Fe_{14}B$ specimen were a light irradiation cycle of 15 seconds and light irradiation time of 5 seconds, while for the S15C specimen, a light irradiation cycle of 12 seconds and light irradiation time of 5 seconds were used. While internal defects cannot be detected from the temperature variation distributions of **Figs. 3** and **4**, they can be detected from the phase difference distributions of temperature variation shown in **Figs. 5** and **6**. Comparing the phase difference distribution of temperature variation for the two specimens, it can be seen that the phase variation of the internal defect of the $Nd_2Fe_{14}B$ specimen is bigger. This is considered to be caused by the thermal conductivity of the $Nd_2Fe_{14}B$ specimen being smaller than that of the S15C specimen, meaning that thermal diffusion is less as heat is isolated by the internal defect, emphasizing the phase variation of the internal defect. Although it is apparent from **Figs. 7** and **8** that there are correlations between the peak size of internal defect size and phase difference distribution, it also became apparent that thermal diffusion has caused the phase distribution size to be bigger than the actual internal defect size. The size of the internal defect was estimated from the temperature variation phase difference distribution however, due to a slope in the phase difference distribution area (presumably resulting from thermal diffusion) where the portion with internal defects and the portion without internal defects, quantitative estimation was difficult. This trend was seen under all measurement conditions, irrespective of the material the specimen was made from.

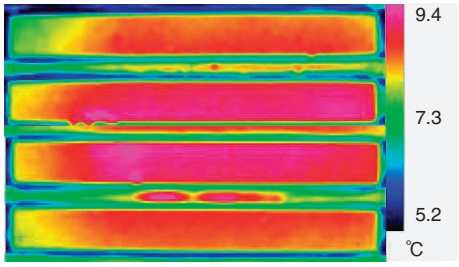

Fig. 3 Distribution of temperature variation ($Nd_2Fe_{14}B$)

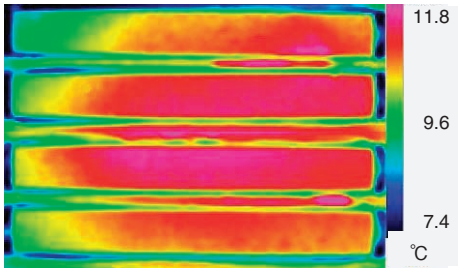

Fig. 4 Distribution of temperature variation (S15C)

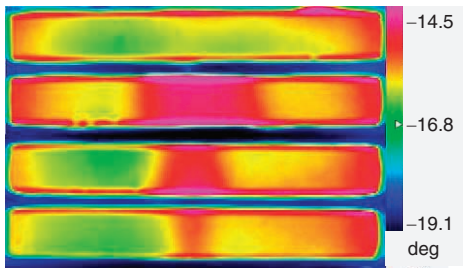

Fig. 5 Phase difference distribution of temperature variation ($Nd_2Fe_{14}B$)

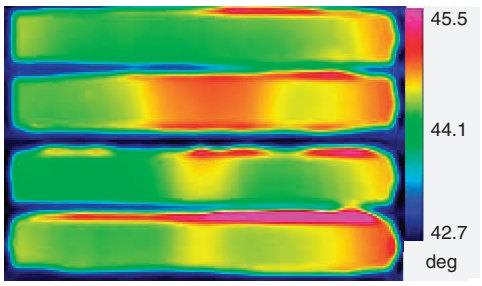

Fig. 6 Phase difference distribution of temperature variation (S15C)

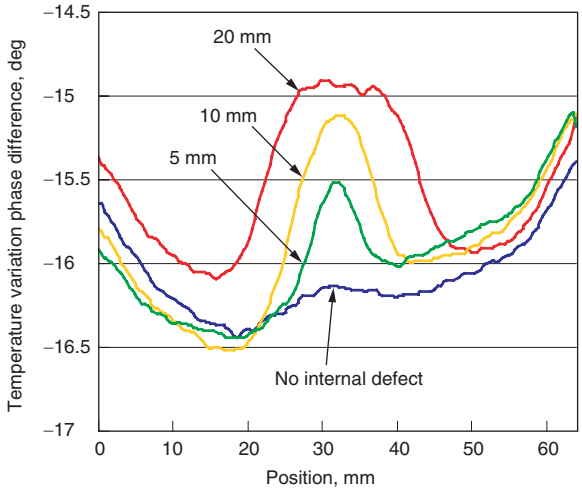

Fig. 7 Phase difference distribution of temperature variation ($Nd_2Fe_{14}B$)

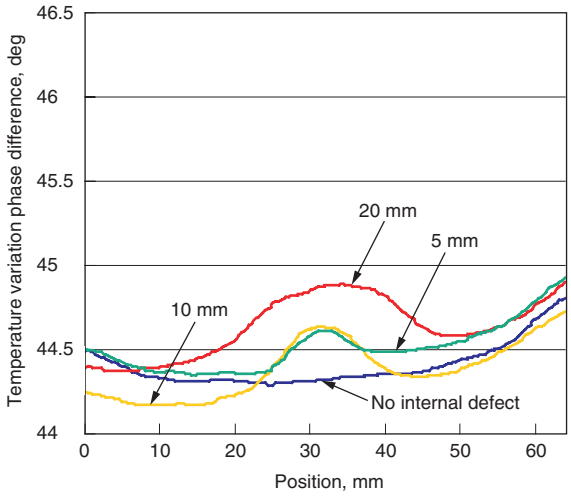

Fig. 8 Phase difference distribution of temperature variation (S15C)

4. Estimating Internal Defect using Differential Processing

In order to estimate the internal defect size from the phase difference distribution, the following data processing was carried out. First, the phase difference distribution in places free of internal defects was subtracted from the phase difference distribution of each internal defect size (**Fig. 7**). This removed any phase difference variation resulting from something other than internal defects (**Fig. 9**). Next, differential data processing was performed on the two points adjacent to the phase difference distribution and the distance at the position where the differential value was at its extreme was estimated to be the size of the internal defect (**Fig. 10**). **Figure 11** shows a comparison of the estimated internal defect size versus the actual size for both the $Nd_2Fe_{14}B$ and S15C specimens. It can be seen that, regarding both the $Nd_2Fe_{14}B$ and S15C specimens, the estimated internal defect size was close to the actual size. Furthermore, the estimate value for the $Nd_2Fe_{14}B$ specimen was closer to the actual size than the S15C specimen, and it was found that when the internal defect is small, the difference between estimated size and actual size is more notable. This is considered to be due to the $Nd_2Fe_{14}B$ specimen possessing a small thermal conductivity, and only a small thermal diffusion as it is isolated by the internal defect.

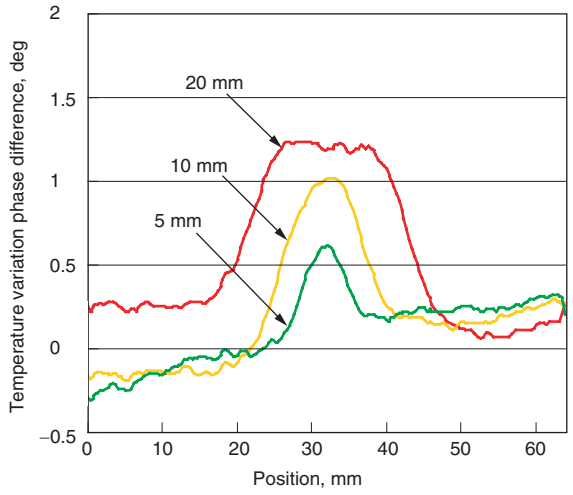

Fig. 9 Phase difference distribution after data processing ($Nd_2Fe_{14}B$)

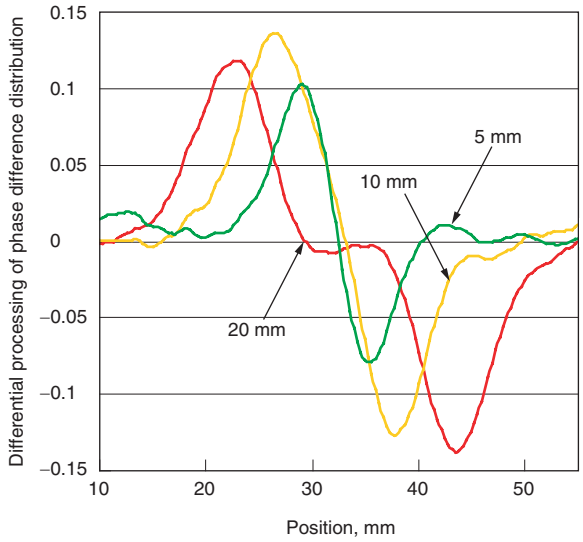

Fig. 10 Distribution of phase difference differential value ($Nd_2Fe_{14}B$)

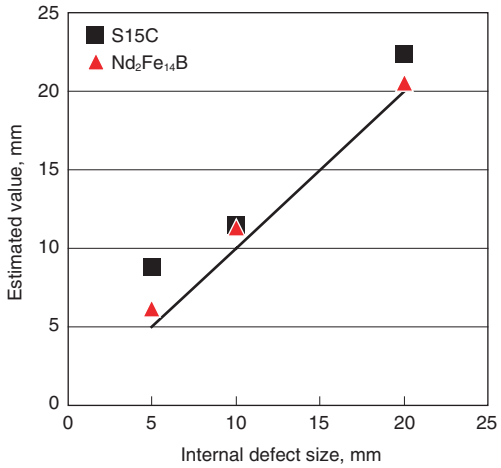

Fig. 11 Estimates of internal defect sizes

5. Conclusion

The internal defects of specimens were measured under several different irradiation cycles and irradiation times using optical excited thermography. Results of this experiment verified that, rather than the distribution of the specimen surface temperature variation, the phase difference distribution could be used to measure internal defects. Furthermore, it was discovered that there existed an optimal irradiation cycle and irradiation time where the phase difference of the specimen surface temperature variation was the biggest, and those optimal values varied depending on the material of the specimen itself.

Finally, it was found that the size of internal defects could be quantitatively estimated through performing differential processing on the phase difference distribution of the temperature variation, and that the accuracy of this quantitative estimation was higher for material with low thermal conductivity.

Reference

1) H. Terada, T. Sakagami: Handbook of Equipment Diagnosis and Nondestructive Evaluation by Infrared Thermography, The Japanese Society for Non-Destructive Inspection (2007).



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