Measurement of fatigue damage parameter by sacrificial test piece and thermography†

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KEY WORDS: (Fatigue damage parameter) (Thermography) (Sacrificial test piece) (Bridge maintenance) (Crack growth)(Thin steel plate)

1. Introduction

"The sacrificial test piece" is used as a specimen attached to the member of a main structure in order to evaluate the damage before the appearance of a crack in a member of that structure. The sacrificial test piece is designed so that it is damaged earlier than the main members under the same loads because of crack and stress magnification. The damage to the bridge members can be estimated by the observation of the sacrificial test piece. If the fatigue damage parameter can be made clear by the behavior of the sacrificial test piece, the maintenance management of the structure can be determined.

Thin steel plates, which have initial cracks at the center, are used as the sacrificial test pieces in this study. When strains are applied to the main member, these are transmitted from the main member to the thin steel plate and the crack in the thin steel plate will grow as a result. Therefore, the monitoring of fatigue damage parameters on the bridge can be carried out by the observation of the crack growth in the thin steel plate. If the thin steel plate can be used as the sacrificial test piece, it seems that fatigue damage on a bridge can be monitored widely. Because the thin steel plate is cheap, everyone can obtain it easily [1].

In this paper, a measuring method for the crack length of the sacrificial test piece from a long distance by self-reference lock-in thermography is proposed. Applicable stress ranges and frequency of measurement by the proposed method are clarified.

2. Remote Measurement of Crack Length by Self-Reference Lock-in Thermography

The sacrificial test piece was attached to four steel jig-plates by bolts. The shape and the dimensions of the jig-plates are shown in **Fig. 1**. The thickness of the sacrificial test piece is 0.5 mm, and the thickness of one side edge of the jig-plate is 12mm and other part of the jig-plate is 10mm. Using the jig-plates, the strain between the connected points is concentrated at the sacrificial test piece by the difference in stiffness between the thin plate and the jig-plate. Strain in the sacrificial test piece is concentrated more than about 3 times that of the flange by theoretical calculation. This strain concentration makes the crack growth faster, and the measurement in bridge members can be carried out in a short period. The specimen is attached on the lower flange of bridge members with high strength vices at the edge of the jig-plates.

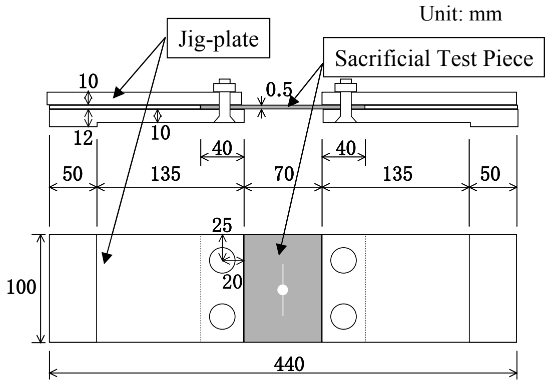

Fig. 1 Sacrificial test pieces with jig-plate

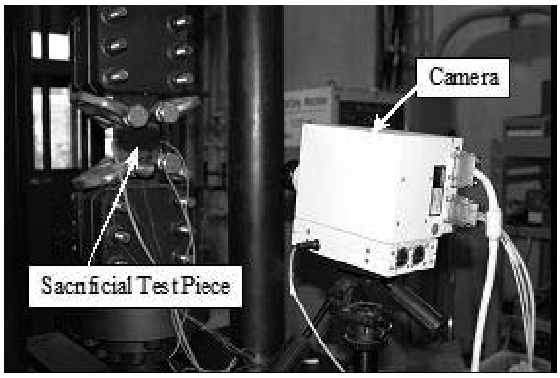

Fig. 2 Measurement of crack length in sacrificial test piece by self-reference lock-in thermography.

If the crack length of the sacrificial test piece can be measured from a long distance, the damage in a member of a bridge can be evaluated more easily and cheaply. We propose a measuring method of the crack length from a long distance by thermoelastic stress analysis.

A self-reference lock-in infrared thermography technique is newly proposed, in which a reference signal is constructed by using the same sequential data on

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Transactions of JWRI is published by Joining and Welding Research Institute, Osaka University, Ibaraki, Osaka 567-0047, Japan

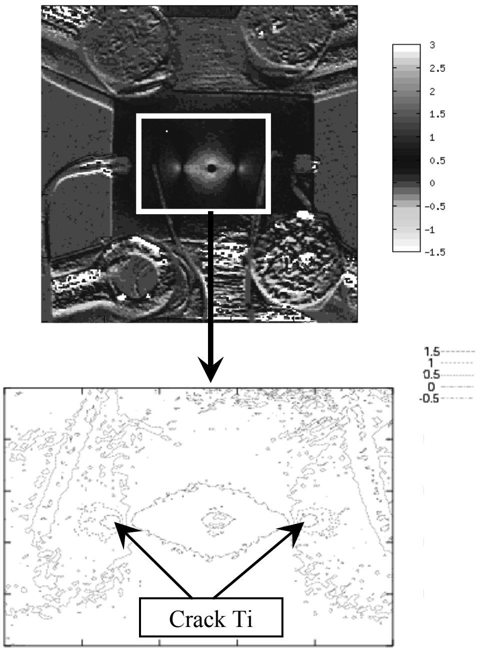

Fig. 3 Crack tip in sacrificial test piece searched by self-reference lock-in thermography ($\Delta\sigma$=120MPa, 10Hz, Crack length: 20.5mm)

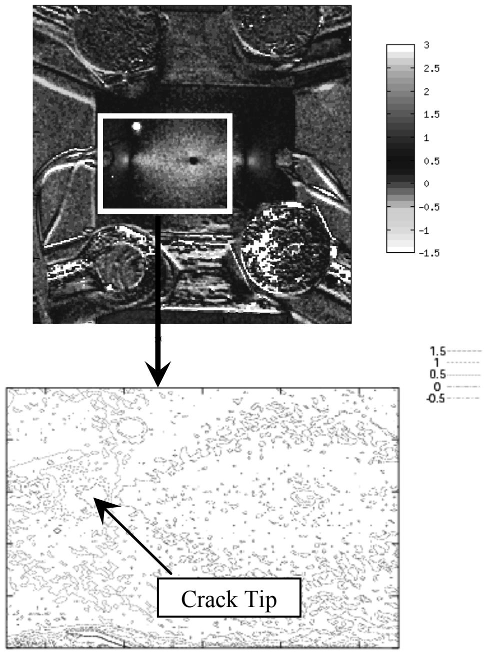

Fig. 4 Crack tip in sacrificial test piece searched by self-reference lock-in thermography ($\Delta\sigma$=120MPa, 10Hz, Crack length: 38.0mm)

thermoelastic temperature change. Temperature change in a region of interest, such as crack tip, is correlated with that in a remote area, where uniform stress is applied, for reference signal construction. The temperature changes obtained from the region of interest and remote area are in-phase and have similar waveforms but big differences are found in their amplitudes. Consequently if a reference signal could be constructed from the signal obtained from a remote area, it is possible to perform correlation processing without an external reference signal. The lock-in algorithm based on the least squares method is employed for signal processing under random loading. It enables us to measure the distribution of relative intensity of applied stress under random loading without using any external loading signal [2].

To examine the applicability of self-reference lock-in thermography to the measurement of the crack length of the sacrificial test piece from long distances, fatigue tests of the sacrificial test pieces were performed and crack length was measured by the proposed method. As shown in **Fig. 2**, 0.5 mm thick steel plate as the sacrificial test piece without jig-plates was fixed to the 9 mm thickness of a main member. Backing plates are put between the main member and the thin steel plates and then the thin steel plates and backing plates are fixed by the high strength vices. Material of the main member and backing plates are mild steel. In order to propagate the fatigue crack, cyclic load was applied to the main member using a servo-hydraulic testing machine.

Crack gauges (pitch = 0.5 mm), fixed in the back side of the thin steel plate, were used to measure the length of crack. Measurement of the crack length by self-reference lock-in thermography was performed every 0.5 mm of crack growth measured by crack gauge. Distance from the lens to thin steel plate was 2 m. Loading stress range and frequency during measurement were 120MPa-10Hz and 60MPa-3Hz.

Figure 3 and 4 show contours drawings of the relative thermoelastic temperature change distribution obtain by the self-reference lock-in thermography in the measurement of 20.5 mm and 38.0 mm. The applicable crack length of the sacrificial test piece is from 20 mm to 40 mm [1]. So Fig. 3 and 4 show the results of just about the lower and upper limits of applicable range. In spite of the crack length, the location of the crack tip can be estimated as the largest point of the thermoelastic temperature change.

Figure 5 shows the comparison between the crack lengths measured by crack gauge and those estimated by the self-reference lock-in thermography. Good agreement can be found between the crack length measured by crack

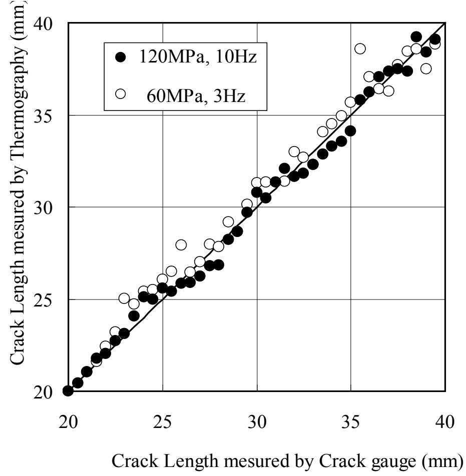

Fig. 5 Comparison between crack lengths measured by crack gauge and thermography

gauge and those estimated by the self-reference lock-in thermography in all ranges, not only in the case of 120MPa-10Hz, but also in the case of 60MPa-3Hz. So it can be said that the proposed method of self-reference lock-in thermography can measure the crack length of the sacrificial test piece accurately.

3. Conclusions

(1) Even when the frequency is as small as 3Hz, the self-reference lock-in thermography can measure the crack length of the sacrificial test piece accurately in the case that the stress range is 60MPa or more.

(2) The possibility of measurement of crack length in the sacrificial test pieces in the bridge members from long distance by the self-reference lock-in thermography is demonstrated.

Acknowledgments

The authors would like to thank Mr. Nishimura and Mr. Nakatsuji for their help during the experiments.

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