Stress Intensity Factor Measurement by Photoelasticity

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Abstract. The stress intensity factors of specimen with inclined cracks under tensile load are measured by use of isochromatics that are obtained from circular polariscope in photoelastic experiment and processed with digital image processing technique. The results of stress intensity factors obtained by photoelastic experiment are comparable to those by empirical equations and finite element method. This means that the photoelasticity can measure accurately the stress intensity factors.

Keywords: Crack, Photoelasticity, Fringe, Stress Intensity Factor

1 Introduction

If various structures under unusual circumstances are destroyed in significantly lower than the material strength, crack can be the main cause [1,2]. Especially, it could cause brittle fracture in high-strength materials. Formulation of the concept of fracture mechanics has made a vigorous study for stress intensity factor through theoretical analysis, numerical analysis, and various experimental techniques [3,4].

In this paper, the stress intensity factors are measured by the isochromatics that are obtained through the photoelastic experiment and the image processing technique. The results are compared with those by empirical equations and finite element method (FEM).

2 Photoelastic Measurement of Stress Intensity Factors

The photoelastic fringes around a crack tip are represented in Fig. 1(a). The stress intensity factors (κΤ, κΝ) from photoelastic experiment are obtained with experimental equations by use of maximum radius (rα) from fringe loop, fringe order (Nα), and angle (θα) of fringe loop in Fig. 1(a) [5,6].
The specimen with inclined crack at the center in Fig. 1(b) is used in photoelastic experiment to measure the stress intensity factors. The tensile load is applied to the specimen that is installed in loading device of the circular polariscope in order to get photoelastic fringes. Five different specimens are made for five inclined angles of crack ($\beta$) that are $0^\circ$, $30^\circ$, and $60^\circ$.

Fig. 2. Fringes of specimen with inclined crack at center obtained from light-field setup of circular polariscope.

Fig. 3. Fringes of specimen with inclined crack at center obtained from dark-field setup of circular polariscope.

The material of specimen is PSM-1, its material fringe constant ($f_\sigma$) is 7,500 N/m, and its Young's elastic modulus is 2,482 MPa. The crack tip is machined sharply as a natural crack by use of electrical discharge machining tool at $60^\circ$.

The specimen is installed in the circular polariscope and applied tensile load enough to observe the $3^{rd} - 5^{th}$ orders of fringe loop is applied to the specimen, depending on the crack angle.
The fringes in Fig. 2 are obtained by the polariscope in light field set-up and the fringes in Fig. 3 are obtained by the polariscope in dark field set-up. Image processing technique is applied to the fringes in Fig. 2 and Fig. 3 for two-time multiplication [7]. Two-time multiplied fringes are shown in Fig. 4. Using the fringe sharpening algorithm, the two-time multiplied fringes in Fig. 4 are sharpened as shown in Fig. 5.

Normalized non-dimensional stress intensity factor \( K_{n} \) of Mode I and the ratio of \( K_{II} / K_{I} \) are obtained by use of FEM [9], empirical equation [1,2], photoelastic experiment and as seen in Table 1.

Table 1. Comparison of stress intensity factors obtained from FEM, empirical equation and photoelasticity.

<table>
<thead>
<tr>
<th>Crack angle</th>
<th>( K_{I} )</th>
<th>( K_{II} / K_{I} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FEM</td>
<td>Equation</td>
</tr>
<tr>
<td>0°</td>
<td>1.074</td>
<td>1.065</td>
</tr>
<tr>
<td>30°</td>
<td>0.814</td>
<td>0.799</td>
</tr>
<tr>
<td>60°</td>
<td>0.277</td>
<td>0.267</td>
</tr>
</tbody>
</table>

\[ K_{n} = K_{I} / \sigma \sqrt{\pi a} \]

3 Conclusions

The tensile load is applied to the specimens that have inclined crack of 0°, 30°, and 60° at the center and the stress intensity factors of specimen, \( K_{I} \) and \( K_{II} \), are
investigated by photoelastic experiment. The results obtained from these experiment are as follows:

(1) The results of the photoelastic experiment are close to those of empirical equation or FEM within 5.8% for \( \kappa_i / \sigma \sqrt{a} \) and 4.6% for \( \kappa_n / \kappa_i \).

(2) From the photoelastic experiment, the ratio of maximum radius \( (r_m) \) from fringe loop and crack length \( (a) \) is \( r_m / a = 0.16 \), which is measured at a much wider range than \( r_m / a = 0.02 \) in Refs. [5, 6].

Applied load, material fringe constant, geometries, and the coordinate of a crack tip of specimen should be closely examined because they affect the stress intensity factors in the photoelastic experiment.

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