IMPROVED METHOD FOR THE PHOTOELASTIC DETERMINATION OF MIXED MODE STRESS INTENSITY FACTORS

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ABSTRACT

Most of the existing methods of photoelastic determination of stress intensity factors (SIF) employ data from an extremely small measurement zone very close to the crack tip, thus presenting measurement difficulties and uncertainties. A modified photoelastic method was suggested by the authors for the determination of mode I SIF using data from a convenient measurement zone slightly away from the crack tip. This was extended to a mixed mode case by Srinath and others. In this paper some of the limitations of the method of Srinath and others are pointed out and improvements suggested which give reliable values of mixed mode SIFs.

KEYWORDS

Photoelasticity; stress intensity factors; mixed mode fracture; isochromatics; 'not too near' zone; SEN specimen.

INTRODUCTION

Mose of the practical fracture problems exhibit mixed mode situations involving the opening and the sliding modes of fracture characterised by the stress intensity factors (SIF) K_I and K_{II} respectively. Photoelasticity gives an easy indication whether a crack in a two dimensional problem will propagate in mode I or mixed mode.

In an uncracked photoelastic model if the portion where the crack is to be made is marked by a line AA as shown in Fig. 1 oriented at an angle θ with reference to some fixed direction and the model is studied in a plane polariscope for isoclinics, in case the crack is in mode I situation the ($\theta \pm 90°$) isoclinic will cover the line AA completely. Otherwise the crack will be in a mixed mode situation.

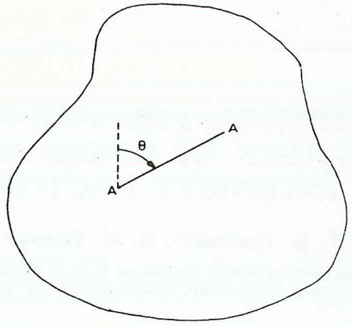


Fig. 1.

Almost all the existing photoelastic techniques to determine SIF make use of data obtained from a very limited measurement zone near the crack tip. The measurements outside this zone give highly inconsistent & erroneous values of SIF because the stress singularity equations used in these methods are nearly valid only in the near neighbourhood of the crack, barring the yield zone and away from this zone the farfield stress distribution affects the near field stress distribution. The extent of the data zone to obtain reliable results is also a matter of opinion yet and with all the measurement difficulties involved in a small zone one is at a loss in relying on a single method to obtain correct values of SIF.

The authors (1982) presented a modified method wherein photoelastic data obtained from a convenient 'not too near' zone can be used to determine consistent and accurate SIF in the case of mode I loading configuration. This paper also gave a long list of reference literature dealing with the gradual development in the area of photoelastic stress analysis applied to fracture mechanics studies. An extension of the modified method for mixed mode situation involving K_I and K_{II} was tried on a cracked cylindrical shell subjected to pure torsion by Srinath and others (1983) and was reported to give accurate results.

The equations used in the mixed mode case were:

$$\sigma_1 - \sigma_2 = K/\sqrt{r/a} + B_1 \, (r/a) \qquad (1)$$

$$\text{where } K = \frac{1}{\sqrt{2\pi a}} \left[(K_I \sin\theta + 2K_{II} \cos\theta)^2 + (K_{II} \sin\theta)^2 \right]^{1/2} \qquad (2)$$

This is the same equation developed by the authors (1982) with suitable modifications to accommodate both K_I and K_{II} in K and truncated to the first term of the polynomial $\sum_1^M B_m (r/a)^m$. It should be noted that K and B_1 are functions of θ, whereas K_I and K_{II} should be independent of θ.

The method involves determination of fringe orders at two points 'not too near' the crack tip and located along a same arbitrary θ. Using the stress optic relation:

$$\sigma_1 - \sigma_2 = NF/t \qquad (3)$$

in conjunction with Eq. (1), the values of K and B_1 can be calculated for this particular θ, say θ_A. This is repeated for another arbitrary angle θ_B.

Using Eq. (2) and the values of K calculated for the two angles θ_A and θ_B, K_I and K_{II} can be computed. To check these values, these are substituted in Eq. (2) and the value of K is calculated for a third arbitrary angle θ_C. For this angle, K is again separately calculated using fringe order data at two points in Eq. (1) as was done for θ_A and θ_B. The two values of K thus obtained are compared.

The authors observed that K is not so sensitive to the various parameters in comparison to the sensitiveness of K_I and K_{II} values. As the parameters of interest are K_I and K_{II} and not K, the above method of checking and obtaining the so called unique values of K_I and K_{II} is felt to be unsatisfactory. To elaborate this, if one checks the values of K_I and K_{II} obtained from two arbitrary angles as given above, one may find that the deviation in K is well within the accepted experimental error of 5%. Alternatively, if one takes sets of two angles at a time and calculates K_I and K_{II}, one may get three sets of values of K_I and K_{II} and these may be quite different and the deviation may be beyond the accepted experimental error of 5%.

Hence, to study the validity of the above method for a mixed mode situation in obtaining unique values of K_I and K_{II}, the present work was undertaken. In this work, single edge notched (SEN) specimen with inclined notches and subjected to uniaxial tension were studied. Srinath and others (1983) reported that the fringe loops on one side of the crack were very prominent in comparison to those on the other side and the analysis was carried out on these prominent loops. In the mixed mode SEN specimen the difference in size of the loops on the two sides of the crack is not considerable. So, another objective of this study was to check whether the above method gives comparable values of K_I and K_{II} for both the fringe loops on the two sides of the crack.

EXPERIMENTS

SEN specimens of 250 x 50 x 6.76 (mm) size with crack length "a" of approximately 15 mm ($a/W \simeq 0.3$) and subjected to uniaxial tension as shown in Fig. 2 were studied. Three angles of inclination of the crack each under two different loads of 48.3 Kg and 64.36 Kg were studied. The cracks were simulated by saw cuts using a fine blade of 0.35 mm thickness. The slot tips were left untouched (without any deliberate rounding off). Similar slots had given accurate results by the modified method for the mode I SEN (Prabhu and others, 1982). Live loads were employed to avoid the effect of Poisson's ratio difference in stress freezing technique and also the possible crack tip blunting and plastic zone errors.

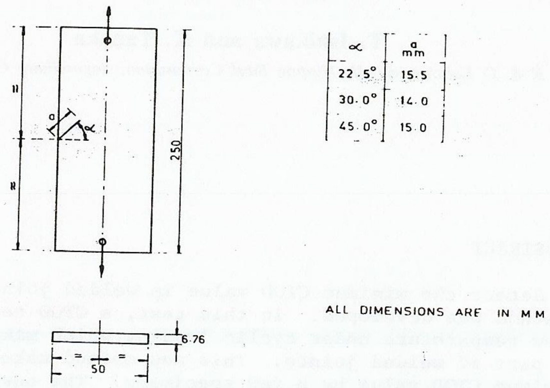


Fig. 2. SEN specimen

Both dark field and bright field fringe loops were photographed for each specimen under each load. These photographs were magnified in the range of 10 x to 15 x and the fringe order and distance measurements were carried out. As the method was found to be extremely sensitive to r, the combination of positive error in the smaller r and negative error in the larger r being the worst, the clear boundaries of the fringes were traced and the midpoints were measured accurately. The midpoints, thus measured, were found to give better results in comparison to other r values in the fringe width.

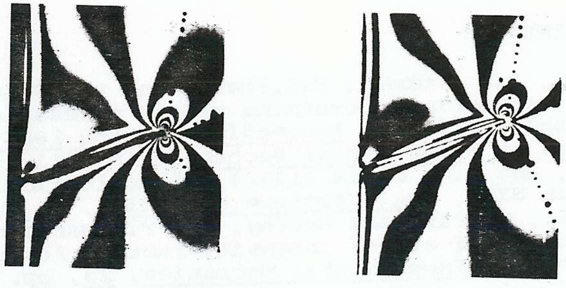
The approximate θ_m value, corresponding to the maximum r for a fringe loop were determined and measurements were made on a number of lines 10° apart on either side of θ_m. The theoretical results of Wilson reproduced by Smith & Smith (1972) were taken for comparison.

Typical crack tip isochromatic fringe loops observed in the mixed mode SEN specimen is shown in Fig. 3.

RESULTS AND DISCUSSION

Typical results obtained on one of the specimens are given in Table 1. It can be seen that the backward tilting loop (BTL)

which tilts behind the crack, gives very high K_I value and very low K_{II} value, not comparable with the theoretical values. Also, the scatter in K_{II} values is extremely high.



(a) DARK FIELD (b) BRIGHT FIELD

Fig. 3. Crack tip isochromatics

In the forward tilting loop (FTL), which tilts ahead of the crack the zone $\theta \leqslant \theta_m$ tends to give lower K_I values and higher K_{II} values in comparison to the zone $\theta \geqslant \theta_m$. The average over the entire FTL zone results into K_I and K_{II} values quite comparable with the theoretical values.

As can be seen from the above table, for the FTL, K_I value ranges from 55.42 to 63.27 and K_{II} value from 13.55 to 20.34. But if K_I and K_{II} values obtained from any two arbitrary angles is used to obtain value for any arbitrary third angle, it generally does not exceed $\pm$ 5%. For example, consider $\theta_A = 60°$, $\theta_B = 80°$ and $\theta_{C_3} = 70°$. The 60° and 80° lines give K_I and K_{II} values of 61.82 Kg/cm $^3/2$ and 16.00 Kg/cm$^{3/2}$ respectively. If these values are substituted in Eq. (2) for the 70° line, the resulting K, in non dimensional form is 1.188, which in comparison to the value of 1.186 obtained from Eq. (1) for the 70° line deviates only by about 0.2%. Now, if the 70° line is taken in combination with the 60° and 80° lines by turn and K_I and K_{II} obtained using Eq. (2), the resulting values are as in Table 2.

It can be seen that the scatter in K_I is 2.3% and in K_{II} 9.3%, whereas in K it is only 0.2%. The difference in the scatters of K_I and K_{II} values in comparison to that of K is worse when the lines are in different zones.

For the entire FTL zone, the maximum scatter as a percentage of the average value is 13.8% in K_I and 38.8% in K_{II}, though that in K is only about 9%. If the average values are determined over

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