Experimental and Finite Elements Stress Analysis of a Double Edge Notched Specimen

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Photoelasticity and finite elements analysis are used to determine the stress field developed in a birefringent double edge notched specimen loaded in tension. Experimental isochromatic fringes and isoclinics fringes are obtained on a regular polariscope by using circularly polarized light and plane polarized light. Simulated isochromatic fringes and isoclinic fringes are obtained particularly in the neighborhood of the notches. The shear stress along the weakened cross section in the neighborhood of the notches are determined numerically and experimentally with the help of the isochromatic fringe pattern. Details of the procedure are fully given in the paper. Relatively good agreements are obtained between the experimental and the simulated results.
Keywords: Isochromatic, isoclinic, stress, birefringent, notch

1 Introduction

In stress analysis experimental procedures can sometimes be time consuming and theoretical studies can also be in some cases very complex. Numerical solutions can therefore be very helpful. Various authors (see Refs. [1] to [8]) have used experimental techniques as well as finite elements analysis to solve these kinds of problems. In this study, a stress field is applied to a double edge notched specimen (see Fig. 1); the load is applied in a loading frame equipped with a dynamometer that measures the applied load. The stress field is then determined experimentally on the analyzer of a regular polariscope by using both plane polarized light and circularly polarized light. The isochromatic fringe pattern is used to determine stress values, particularly in the neighborhood of the notches. A finite element analysis is used to simulate the isochromatic fringe pattern and the isoclinic fringe pattern for comparison purposes. We consider that the material of the model behaves as a purely isotropic material. To achieve better approximation, the mesh is refined in the neighborhood of the contact zone.

2 Theory and experimental procedure

Fig.1 shows the photoelasticity method which is based on the birefringent phenomenon. In some transparent isotropic materials an incident light beam splits in two independent light beams which travel through the model thickness at different velocities $v1$ and $v2$. The corresponding refractive indexes $n1$ and $n2$ depend on the principal stresses developed in the stressed model. In the light intensity obtained with plane polarized light on the analyzer of a polariscope (see Eq. (1)), the terms $\sin^2 2\alpha$ and $\sin^2 \varphi/2$ give respectively the isoclinic fringes and the isochromatic fringes [9].

$$I = a^2 \sin^2 2\alpha \sin^2 \varphi/2 \tag{1}$$

The isochromatics (loci of points of equal maximum shear stress) are used to determine the principal stresses difference in the whole model particularly in the neighborhood of the notches (see Eq. (2)).

$$\sigma_1 - \sigma_2 = \frac{N(\lambda/C)}{e} \tag{2}$$

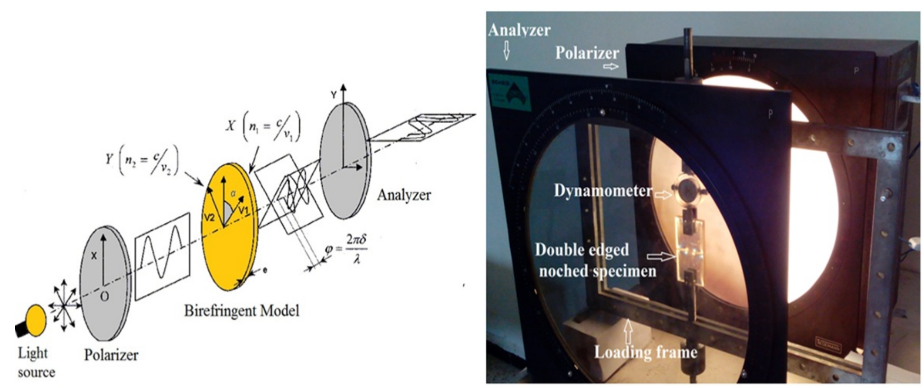

Figure 1: Light propagation through a photoelastic model and experimental setup.

3 Experimental results

The isochromatic fringe pattern (see Fig. 2) is obtained on a white field circular polariscope, two quarter wave plates are added in the light path in order to eliminate the isoclinic fringes that can hide the isochromatic fringes. The isochromatic fringe pattern is then recorded for further analysis. The fringe orders are easily determined from the isochromatic fringe pattern (see Fig. 2), the first order being $N = 0.5$ since we use a white field. In the neighborhood of the notches we observe higher fringe orders as one might expect. The fringe orders in the neighboorhood of the contact zone are determined easily and accurately by zooming in the neighboorhood of the notch (see Fig. 2 right) in order to obtain the principal stresses difference for comparison purposes with the finite element solution. The order reaches $N = 10.5$ near the tip of the notch. The following values given here after are used to implemente the experimental solution as well as the numerical one: Young's modulus ($E = 2437N/mm^2$), Poison's ratio ($\mu = 0.37$), applied load ($F = 850N$) and fringe value ($f = \lambda/C = 11N/mm/fringe$).

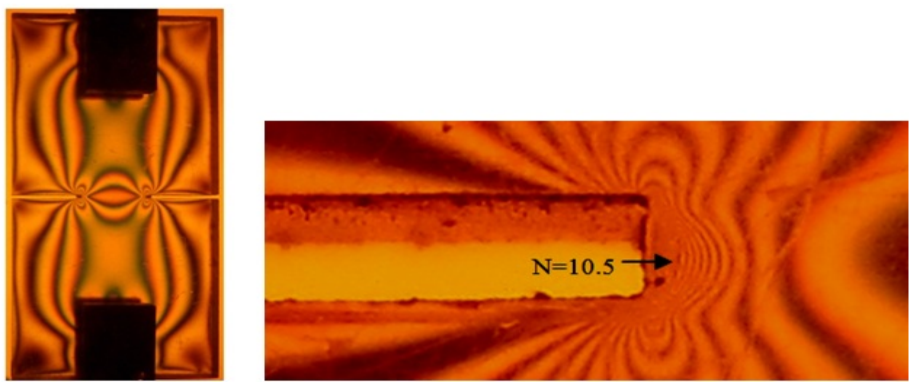

Figure 2: Experimental isochromatic fringes (left), Close-up of the notch (right).

4 Finite elements analysis

Since we are using two dimensional photoelasticity, we understand that we are dealing with plan stress problems, stresses do not vary along the thickness of the model. Therefore, in the finite element solution we simply consider that the stress is constant along the thickness. The meshing of the model is refined in the in the neighborhood of the notches to obtain more accurate results. The details of the procedure are shown here after.

4.1 Isoclinic reconstruction

The values of the isoclinic parameter are calculated with the following relation (see eq. (3)) that can be readily obtained from Mohr's circle of stresses.

$$\alpha = \arctan(2\tau_{xy}/(\sigma_x - \sigma_y)) \quad (3)$$

The isoclinic fringes $(\sin^2 2\alpha)$ can therefore be calculated for different polarizer and analyzer settings. In the finite elements solution a color scale is used to represent the different values of the isoclinic term. On the reconstructed isoclinic fringe pattern, the blue color corresponds to a dark isoclinic fringe obtained experimentally on the analyzer of a plane polariscope.

4.2 Isochromatic reconstruction

Isochromatic fringes are calculated with the term $\sin^2 \varphi/2$. Using Mohr's stress relations and (Eq.2), one can easily obtain the values of the isochromatic parameter φ, the isochromatic parameter (see Eq. (4)).

$$\varphi = \frac{2\pi e}{(\lambda/C)} \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2} \tag{4}$$

The program calculates the isochromatic fringe pattern on the whole model. In the color scale used by the software, the blue color corresponds to a dark isochromatic fringe.

5 Comparison between experimental and simulated results

5.1 Experimental and simulated isochromatic fringes

The experimental and the simulated isochromatic fringe patterns (see Fig.3) are relatively similar; the blue simulated isochromatic fringes correspond to the dark experimental isochromatic fringes. We see clearly a concentration of isochromatic fringes in the neighbourhood of the notches. In the finite element solution we see also stress concentrations in the neighbourhood of the holes but these are not taken into account in this study as the experimental loading frame hides this zone. We are therefore mainly interested in the stress fields developed in the neighbourhood of the notches.

We can see relatively good agreements between experimental values and numerical ones (see Fig. 3). Stresses are higher in the vicinity of the notches, and then decrease to a lower constant value.

5.2 Experimental and simulated isoclinic fringes

One should know that experimentally it is not possible to obtain the isoclinics alone. We have therefore, on the recorded experimental photoelastic fringes, both the isochromatics which appear in color when we use polychromatic light and the

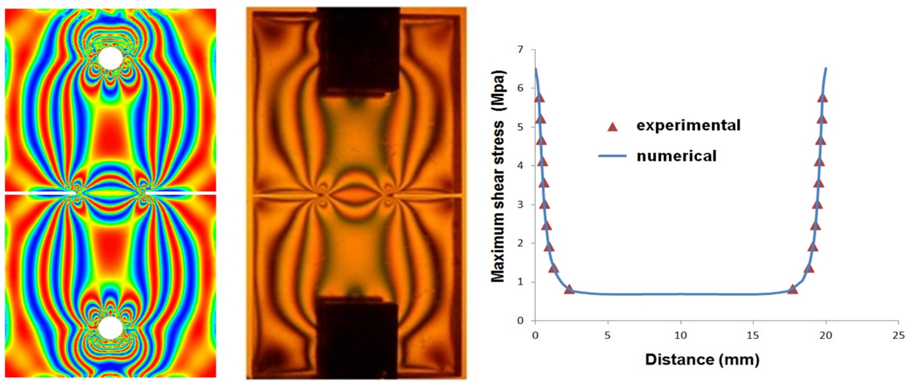

Figure 3: Simulated and experimental isochromatic fringes and shear stress in the neighbourhood of the notches.

isoclinics. We show the isoclinics for four positions of the polarizer and the analyzer axis (see Fig. 4). We can see relatively good agreements between the simulated and the experimental isoclinics, the blue color corresponds to a dark isoclinic fringe. The isoclinics can further be used to determine the stress trajectories called also isostatics.

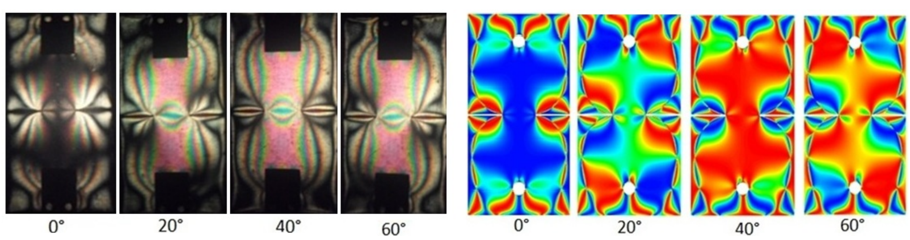

Figure 4: Experimental and simulated isoclinic fringes.

6 Conclusion

We have analysed a stress field developed in a birefringent double edge notched specimen by using photoelasticity and finite element analysis. The purpose is to analyse the stress field, particularly in the neighbourhood of the notches. We showed that photoelastic fringes and stresses can be simulated easily and accurately. Since the fringe order at the notch tip is difficult to determine experimentally, stress at the notch tip is determined more accurately with the finite element analysis and this is of great importance in the design of mechanical components.

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