ME 457 Experimental Solid Mechanics (Lab)

Photoelasticity Experiment

Introduction:

The analytical and numerical (computer simulation with finite elemental modeling) determination of stresses in the field of practical engineering design often becomes so complicated that an accurate knowledge of the stresses can only be obtained by experimental means. Photoelastic stress analysis is widely used for determining stress under such circumstances. The physical theory involved includes the double refraction of polarized light passing through translucent material which is under stress.

Light is plane polarized by altering the waves emitted from a source so that waves are produced which vibrate only in one direction normal to the direction of wave propagation. Experiments have demonstrated that if this uni-directional beam is passed through a transparent crystal, such as quartz or tourmaline, the beam will be divided into two mutually perpendicular components, a phenomenon termed double refraction. Experiments have also shown that transparent materials become doubly refractive under the action of stresses. We thus see that the initial uni-directional beam emerges as two mutually perpendicular beams, and that since their velocities were not the same within the stressed material, they are out of phase when they emerge. If these two beams are now brought back into the same plane of vibration, an interference pattern will be formed due to the difference of phase. If the image is projected upon a screen, a pattern of color bands will be produced.

The most convenient means of obtaining plane-polarized light is through the use of polarized discs. One disc is used to plane polarize the light from the source, which is doubly refracted in passing through the specimen and analyzed by means of a second polarized disc.

Figure 1
The 030 – series polariscope is a precision optical instrument for performing quantitative strain measurements by the photostress method of reflection photoelasticity. The instrument is compact and lightweight, and no more difficult to operate than a fine camera. Designed for either hand held or tripod mounting, the polariscope is equipped to accept a number of special purpose accessories which adapt it for performing wide range of strain measurement tasks with photoelastic coatings.

The 030 – series polariscope is shown in Fig. 2. The model is commonly replaced by an actual test object or structure which has been coated with photoelastic plastic bonded in place on the surface with a reflective adhesive.

**Apparatuses:**
1) Polariscope
2) Cantilever beam apparatus
3) Notched specimen in 4 point-bending apparatus
**Procedure:**

**CANTILEVER BEAM EXPERIMENT – Calibration Test**

1. Set up the polariscope so that its beam of light hits the mid-point marker on the cantilever beam apparatus. See Fig. 4.

2. Set the COMPENSATOR ring on the analyzer to zero and move KNOB B to the M (magnitude) position (Refer to Fig. 3). Make sure also that the dial counter of the angle reads 90° by adjusting KNOB H.

3. The unloaded beam viewed through the analyzer should appear black except for the edge of the beam and areas near where the beam is clamped. Load the beam sufficiently to produce at least 3 fringes, or by applying a displacement of 0.7 in. Note that in a cantilever beam, the bending stress varies linearly from zero at the point of load application to the maximum at the clamped end. The fringe colors in the coating should vary correspondingly and progress as follows: black, yellow, red, purple, blue, yellow, red, purple, blue – green, yellow green, red, green.
4. The integral fringe order is represented by the purple fringe or green/red fringe. Because of its distinctiveness and resolution, the purple tint of passage is selected to mark increment in relative retardation equal to a fringe order of unity (N = 1). Subsequent recurrence of the tint of passage with greater relative retardation signifies the presence of higher fringe orders (N = 2, N = 3, etc.). Note that if the marks are correctly located, the distance between the point of load application and the point for N = 1 is the same as the distance from N = 1 to N = 2 and from N = 2 to N = 3. This demonstrates the linear stress distribution in the beam.

![Figure 4 - Dimensions of Aluminum Alloy Beam: ¼ x 1 x 12 in](top view)

Clamped here 5 in 5 in loaded here

Start counting fringes from here

5. The fringe orders observed in photoelastic coatings are proportional to the difference between the principal strains in the coating (and the surface of the test part). This simple linear relationship is expressed as follows:

\[ \varepsilon_x - \varepsilon_y = f \times N \]

where \( \varepsilon_x - \varepsilon_y \) = principal strains in coating and part surface
\( f \) = fringe value of the coating (values dependent on the types of coatings)

in this case, \( f = 1120 \times 10^{-6} \) \( \varepsilon \) / fringe
\( N \) = fringe order

6. Engineers and designers often work with stress rather than strain. For this purpose, the following equation can be used to find the stress at the midpoint of the beam:

\[
\sigma_x = \left[ \frac{E}{(1 - \nu^2)} \right] \times (\varepsilon_x + \nu \varepsilon_y) \\
\sigma_y = \left[ \frac{E}{(1 - \nu^2)} \right] \times (\varepsilon_y + \nu \varepsilon_x) \\
\sigma_x - \sigma_y = \left[ \frac{E}{(1 + \nu)} \right] \times f \times N
\]

\( \sigma_x \) and \( \sigma_y \) = principal stresses in test part surface
\( E \) = elastic modulus of test part = 10,500 ksi
\( \nu \) = Poisson’s ratio of test part = 0.33

Therefore, for the Aluminum Alloy, \( E / (1 + \nu) = 7.90 \times 10^6 \) psi
7. Because the cantilever beam is in a uniaxial state of stress, \( \sigma_y = 0 \). With KNOB B in the M (magnitude) position, rotate the COMPENSATOR ring counterclockwise if the setup is shown as in Fig. 4. Notice that the first (lower) – order fringe moves towards the test point. Adjust the analyzer until the first – order fringe covers the test point (the cross).

8. Read the fraction, \( r \) from the COMPENSATOR scale and calculate the total fringe order from:

\[
N = n + r
\]

where \( n \) = lowest fringe order that moves to the test point
\( r \) = fraction read from the COMPENSATOR scale

9. Calculate the bending stress at the test point from:

\[
\sigma_x = \left[ \frac{E}{(1 + \nu)} \right] f N
\]

\[
\Rightarrow \sigma_x = \left[ \frac{E}{(1 + \nu)} \right] f (n + r)
\]

**NOTCH CONCENTRATION FACTOR EXPERIMENT**

1. Set up the polariscope so that its beam illuminates the top of the center notch.
2. The total weight exerted on the system by the hanger and weights will be 16.28 lbs.
3. Make certain that the angle display reads \( 0^\circ \) by adjusting KNOB H. Also make certain that knob B is set to the M (Magnitude) position. Turn off the laboratory lighting for best results.
4. Obtain the fringe order, \( N \), with the method and formula described in steps 7 to 9 of the CANTILEVER BEAM EXPERIMENT procedure.
5. With the value of \( N \), obtain the maximum stress applied on the notched tip with the formula:

\[
\sigma_x - \sigma_y = \left[ \frac{E}{(1 + \nu)} \right] f N
\]

\( \sigma_x \) and \( \sigma_y \) = principal stresses in test part surface
\( E \) = elastic modulus of test part
\( \nu \) = Poisson’s ratio of test part

6. In this case, \( \sigma_y = 0 \), \( E = 360,000 \text{ psi} \), \( \nu = 0.38 \) and \( f = 204 \times 10^{-6} \varepsilon / \text{fringe} \)
7. Obtain the stress concentration factor with:

\[
K_t = \frac{\sigma_x}{\sigma_{nom}}
\]

where \( \sigma_{nom} \) was calculated to be 93.1 psi.

8. Note that the notch has the following dimensions :

- \( r = 0.5 \text{ in} \)
- \( t = 0.375 \text{ in} \)
- \( h = 1.673 \text{ in} \)
- \( H = 2 \text{ in} \)
Analysis:
1. Compare the result from the cantilever beam experiment with the calculated value of 14900 psi. Determine the percent error with respect to this value.
2. Compare the value of $K_t$ obtained from the Polariscope with the actual stress concentration factor for the notch $K_t = 1.475$. (See Fig. 5 below) Calculate the percent error.
3. What were the causes of error in your results?
4. In your opinion, what is the best way to obtain more accurate results in this experiment?
5. Make a sketch showing the fringe position for a beam subjected to pure bending.

![Figure 5](image-url)
Appendix: Blackboard material

CANTILEVER BEAM EXPERIMENT

\[ \delta = \frac{PL^3}{3EI} \]
\[ \Rightarrow P = \frac{3EI\delta}{L^3} \]

\[ \sigma = \frac{Mc}{I} \]
\[ \Rightarrow \sigma = \frac{PL_xc}{I} \]

\[ \sigma = \left[ \frac{E}{1 + \nu} \right] f * N \]
where \( f = 1120 \times 10^{-6} \)
\( E_{\text{aluminum}} = 10,500 \text{ ksi} \)
\( \nu = 0.33 \)

NOTCH CONCENTRATION FACTOR EXPERIMENT

\( H/h = 1.19 \)
\( r/h = 0.3 \)
\[ \sigma = \left[ \frac{E}{1 + \nu} \right] f N \]

where \( f = 204 \times 10^{-6} \)
\( E = 360,000 \text{ psi} \)
\( \nu = 0.38 \)
\( \sigma_{\text{nom}} = 93.06 \text{ psi} \)
\( K_t = \frac{\sigma_{\text{max}}}{\sigma_{\text{nom}}} \)

<table>
<thead>
<tr>
<th>Initials</th>
<th>N (cantilever beam)</th>
<th>( \sigma ) (cantilever beam) [psi]</th>
<th>N (notch concentration factor)</th>
<th>( K_t )</th>
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