Purpose

The purpose of this laboratory exercise is to introduce the optical stress measurement technique of photoelasticity. This is a non-invasive and powerful experimental tool used for measuring and visualizing stress distributions in loaded members. The laboratory will occur in two parts; a single report will be due at the completion of both parts. In this second installment of the photoelasticity lab exercises, we will use a circular polariscope arrangement to visualize and measure the stress distribution of a loaded birefringent test specimen. The specific loading scenario will be that of a circular disk in diametric compression. By analyzing load/fringe data acquired during the experiment the fringe constant \( f_\sigma \) for the material will be determined. Quantitative information regarding the stress distribution within the disk will be extracted from photographs and compared with the theoretical stress distribution.

Procedure

In this experiment you will be using the Instron™ testing machine to apply a point-wise diametric loading to a thin disk of birefringent material.\(^1\) The teaching assistant will provide a brief overview

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\(^1\) The fringe constant of the material will be supplied by the teaching assistant.
of the operation of the Instron machine with details sufficient to perform the experiment.

**Instron Machine and Specimen Set Up**
- Set up the Instron machine for operation in *compression mode* and for a load range of 0-1 kN. Also set the displacement speed at the lowest setting, 1 mm/min.
- Zero the load cell so that it reads 0 N
- Measure the diameter and thickness of the circular disk
- Center the disk on the bottom plate of the sample holder and slowly lower the upper plate until it just contacts the disk and the disk is then held in place. The painted side of the disk should be at the back with the clear side facing forward (see Figure 1)
- Adjust the position of the disk in the holder as needed to make sure that it is centered horizontally and vertically.
- Record the load (ideally it should be zero, but in reality a load of ~20-30 N is fine

**Polariscope Set Up**
- The set up of the polariscope (Figure 2) should be essentially when done when you arrive for the laboratory; if you have any concerns about this check with the teaching assistant
- Verify that the outermost ring is set to “M” mode for dark-field imaging. The innermost ring (“Compensator”) should also be set to 0/90.
- A digital camera with an attached monochrometer should be attached to the tripod
- To ensure the best possible imaging of the fringes, the polariscope/camera arrangement should be leveled and its height above the floor equal to that of the disk; i.e., the line of sight should be horizontal.
- Adjust the distance of the polariscope to the specimen so as to maximize the image of the disk; also adjust the manual focus to produce the sharpest image of the disk
- The teaching assistant will demonstrate the use of the digital camera and how it will be used to photograph fringe patterns

**Photoelastic Imaging of the Loaded Disk**
- With a good image on the disk in the camera’s viewfinder (or with a video display, if available) begin loading the disk with the Instron machine. Initially the entire disk will be completely dark (or nearly so!) – this amounts to the n=0 fringe for dark-field imaging. As the loading takes hold, this “fringe” will narrow and move outward to the side boundaries (a stress-free state)
- When the first fringe (n=1) appears at the center of the disk stop the Instron machine and record the force loading; this will be defined by the merging of fringes propagating from the top and bottom loading points at the center of the disk (see Figure 3). There is a bit of inertia with the

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**Figure 2** – The reflection polariscope arrangement. The bright circle on the right is the light source with plane polarizer and quarter-wave plate. The dark circle on the left is the second quarter-wave plate and plane polarizer; behind this is the digital camera.
Instron machine so you will need to anticipate the merging somewhat. If you overshoot or undershoot, simply reverse the loading a little bit and try it again.

- Repeat this process for fringe orders 2-5, recording the loads at each point. Do not load beyond a order 5 fringe else you will risk plastic deformation or fracture of the specimen.
- Take a digital photograph of the disk with fringe pattern; it should look similar to Figure 3
- Now repeat this process in reverse as you unload the specimen. Your data points in loading and unloading should be similar but need not be exact given the uncertainty in your definition of the “fringe formation”

![Figure 3 – Photograph of dark-field fringe pattern for n=1 to n=5](image)

**Analysis and Report Guidelines**

**Calibration of the Material Fringe Constant – Method #1**

One method of establishing the fringe constant is to monitor the stress level at a specific point as a function of the loading. In this case, it is convenient to monitor the exact center of the disk because the theoretical stress distribution reduces to a simple expression at that point. The appearances of fringes at that location is of course the signal of the current stress level.

- Prepare a table of the load/fringe data that you acquired. From this table construct a plot of Fringe Order (n) vs. Load (P). Is it linear?
- From the slope of this plot, determine the fringe constant for the material using the relation derived in lecture:

  \[
  f_\sigma = \frac{4}{\pi R} \left( \frac{h_{\text{eff}}}{h} \right) \left( \frac{P}{n} \right)
  \]

- Perform a least-squares fit on the data and add this theoretical line to your plot of the experimental data
Calibration of the Material Fringe Constant – Method #2

An alternative procedure for computing the fringe constant is to make use of the fringe distribution along the symmetry plane of the loaded disk. As shown in class, the difference in principal stresses along this plane is given by

$$\sigma_1 - \sigma_2 = \frac{4P}{\pi Rh} \left[ 1 - \frac{x_*^2}{(1 + x_*^2)^2} \right]$$

$\times = \frac{x}{R}$

A plot of this curve in dimensionless variables is shown in Figure 4.

Replacing the difference in principal stresses with the fringe orders, we arrive at the relation between fringe orders and location:

$$\sigma = \pi \left[ 1 - \frac{x_*^2}{(1 + x_*^2)^2} \right]$$

To make use of this relation, we will analyze the locations of the various fringe orders from the photograph taken at the known largest load $P$.

- Make a print-out of your digital photograph and draw a horizontal line at the symmetry plane; with a ruler measure the diameter (and hence the radius) of the disk
- Mark the intersections of the fringes with this horizontal diameter and measure their locations; non-dimensionalize these positions with respect to the disk radius. Create a table of the fringe order $n$ and $x_*$ positions.
- Make a plot of Fringe Order vs. $x_*$. Does it look like the plot above?
- For each data pair, compute the fringe constant using the above relation. From this ensemble of

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2 Alternatively, all of this can be done on a computer within an appropriate image analysis software.
values determine the mean value and the standard deviation. How does this compare with the results obtained from Method #1?

Discussion

- Compare the experimental value obtained for the fringe constant using Methods #1 and #2 with the value cited by the manufacturer (this will be provided by the teaching assistant).
- Did one method perform better than the other? If so, why do you think this is so; if not, why?
- Identify the sources of error in this experiment. How might this be improved?