

Optics Laboratories I and II

Polarization, birefringence and photoelasticity

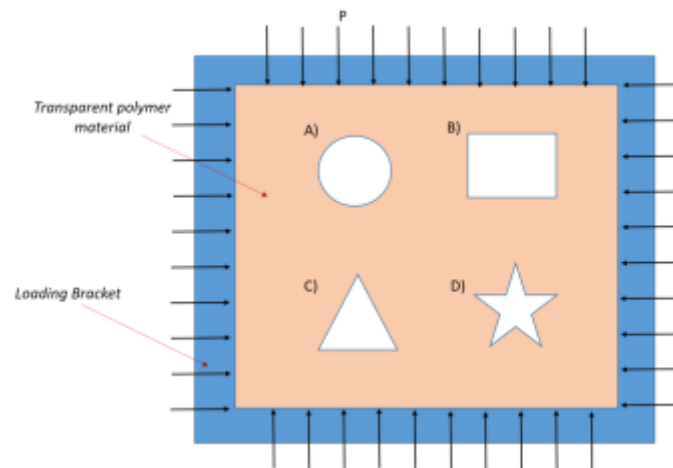
This practical work is divided into two distinct sessions. The first one is theoretical, involves reading the essential literature as well as the answering selected questions and problems. The second part is more practical and it involves the manipulation of optical components, the control of the polarization of light and the measure of the retardance of a sample in order to estimate the amplitude of its internal stresses.

Session 1:

The goal of this session is to familiarize yourself with concepts such as the polarization of light, polarizers, wave-plates, retardance, interference and birefringence. Some simple exercises and situations will be presented, to help the understanding.

1. Read carefully the supporting documents of the TP, i.e. *Supports 1, 2 and 3* (chapter 15.4). In particular, *Support 2* is in English and contains information that might be useful for the practical part of the TP. You are encouraged to search and read your own sources if you feel the need.
2. Discuss the following questions within your group:
 - a. What is the difference between a polarizer and a wave-plate?
 - b. What is the difference between a half wave-plate and a quarter wave-plate?
 - c. In a plane polariscope configuration, which experimental conditions are necessary to obtain *isochromatic*, respectively *isoclinic* points?
 - d. How can someone exploit these effects to measure the residual stresses of a transparent material?
 - e. Can you describe the working principle of a Soleil-Babinet compensator?
3. Solve the following problem: Mr. X wants to have an open sunroof for his new house. For this, he made a small model of his roof on transparent polymer to perform photoelastic studies, as in the figure below. He milled or drilled different designs, as shown in figure (A to D), and attached a loading bracket to load the sample along the boundary. He has the following optical components and light sources in his home,
 - i. White light source
 - ii. LED source
 - iii. Laser source
 - iv. Half wave-plates
 - v. Polarizers
 - vi. Quarter wave-plate
 - vii. Microscope objective and camera for imaging
 - viii. Mirrors

- ix. He can also buy other optical components, if needed (He is a rich guy !!!)



However, he does not know how to conduct a photoelastic study!

To help him, your job is to propose an optical setup for this photoelasticity measurement (using the components he has and eventually adding one he does not have) and to explain how this setup works. Which optical design should he choose, and why? Can you estimate and plot the stress distribution of the best design and the worst design?

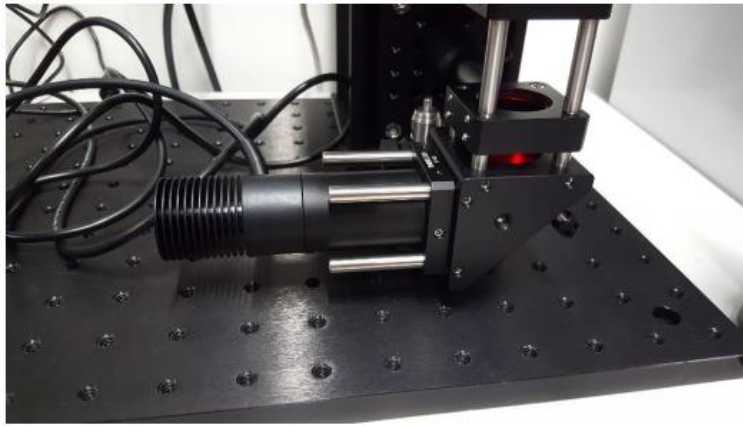
Session 2:

The goal of this session is to put into practice what has been learned last time and to perform an estimation of residual stress using retardance measurements.

It is strongly recommended to have a look at the manual of the Soleil Babinet compensator *before* the practical work to familiarize yourself with the working principle of this equipment.

PART 1

1. Familiarize yourself with the setup: locate the light source(s), the optical components, the imaging system and the sample holder.
2. Connect the camera, open the ThorCam software and start capturing images. For a better visualization, you can use tools such as the histogram and the line profile.



3. Start the red LED light source at low intensity to avoid saturation of the camera. Check the alignment of the setup with a paper sheet.



4. Insert the polarizer in the slot right after the light source as shown above.

5. Rotate the two polarizers (the analyzer is already attached to the bottom of the camera) and observe the changes in intensity using the ThorCam software. Discuss the results.

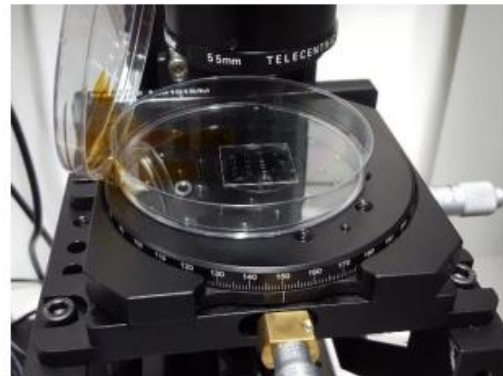
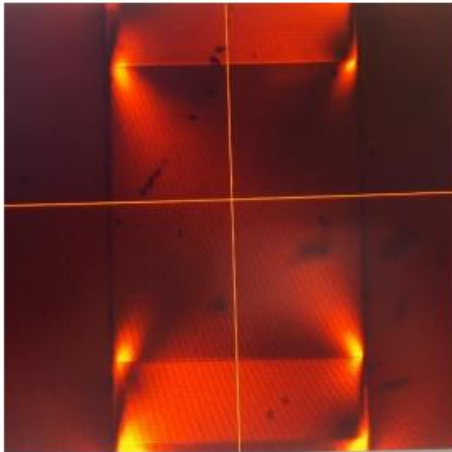


6. Remove the bottom polarizer and insert the half wave-plate as shown above.
7. Rotate the half wave-plate and observe the changes. Next, rotate the half wave-plate together with the top polarizer. Interpret the results. What is the difference between a half wave-plate and a polarizer? How are they affecting the two different light sources?

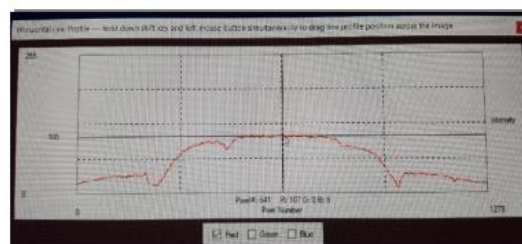
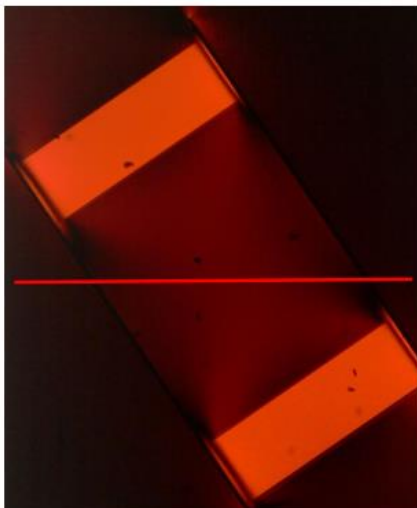


8. Remove the red LED and insert the laser source as shown below ("enable" switch facing up, in this configuration, the polarization of the laser is vertical). Switch on the laser, press "enable" and ensure that the shutters are open. BE CAREFUL while installing the laser into the mount to avoid misaligning the setup.

9. Repeat points 4 to 7 with the new light source (avoid image saturation by tuning camera settings). What changes do you observe with respect to the previous light source? Interpret the results.
10. Remove the laser source and place back the red LED source.
11. Load the sample and find a laser-inscribed feature, which is basically a stress loaded “wave-plate” as shown in the first picture below, and orient it vertically.



12. Achieve cross-polarization between the two polarizers. Observe the changes when you rotate the stage and find the angle that corresponds to the maximum intensity of light in the middle of the “wave-plate” (as shown here using the horizontal line profile). Why is maximal brightness achieved at this angle, and why is the amount of light passing through the sample orientation- dependent? Discuss the results. A similar example is shown below.



13. Insert the two quarter wave-plates, one after the bottom polarizer and the second just in front of the top polarizer as shown below. Find the arrangement of the wave-plates that is able to eliminate the rotational dependence of the intensity/brightness. Why are you able to

eliminate the intensity dependence on the sample's angular orientation after inserting the quarter wave-plates?

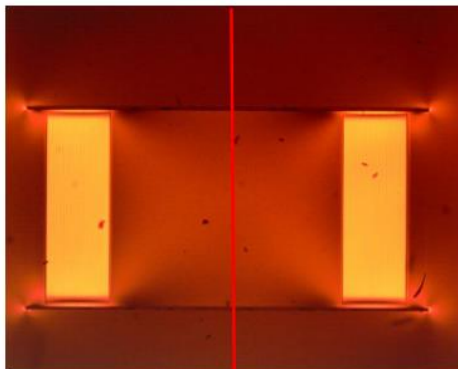


PART 2

14. Remove the sample and achieve cross-polarization of the polarizers, then carefully insert the Soleil Babinet as shown below.



15. Calibrate the Soleil Babinet by following the manual instructions (section 2.4).
16. Insert the sample and position it horizontally as shown below. Place the vertical line profile in the center of the "wave-plate" to look at the stress state.



17. Next, for calculating the retardance, follow the manual instructions in Chapter 4.
18. Calculate the principal stress by substituting the measured value of retardance in the following equation.

$$\sigma_1 = \frac{R}{t \cdot C} \qquad R = N \cdot \lambda$$

R is the retardance [μm]

t is the thickness of the sample = 500 μm

C is the stress-optic coefficient of fused silica = $3.55 \cdot 10^{-12} \text{ Pa}^{-1}$

λ is the wavelength of the light source [μm]

N is the retardance expressed in cycles (measured by the Soleil babinet)

Bonus questions

1. What are the “rings” that you see with the laser source? Why are they absent when the LED is used?
2. Can you speculate what are those sets of lines that you see at the two borders of the laser-inscribed feature?
3. What changes do you expect in the stress measurements in Part 2 if the LED is replaced with a HeNe laser?

R. Ricca (ruben.ricca@epfl.ch)

Prof. Y. Bellouard (yves.bellouard@epfl.ch)

Original work of E. Casamenti, S. Nazir, A. Radhakrishnan, T. Scharf

<http://galatea.epfl.ch>