Photoelasticity: Investigating the distribution of strains in mechanically stressed bodies

Object of the experiment

- To investigate the distribution of strains in mechanically stressed bodies using linearly polarized and circularly polarized light.

Principles

In photoelasticity, the magnitude and direction of mechanical strains is determined in plastic models, in order to gain knowledge regarding the stability of complex components under load. Transparent plastics which become birefringent under strain are used for modeling. For reasons of symmetry, the optical axis of birefringence is always in the direction of the respective elongation and compression; thus, the strains in the model can be made visible using the tools of polarization optics.

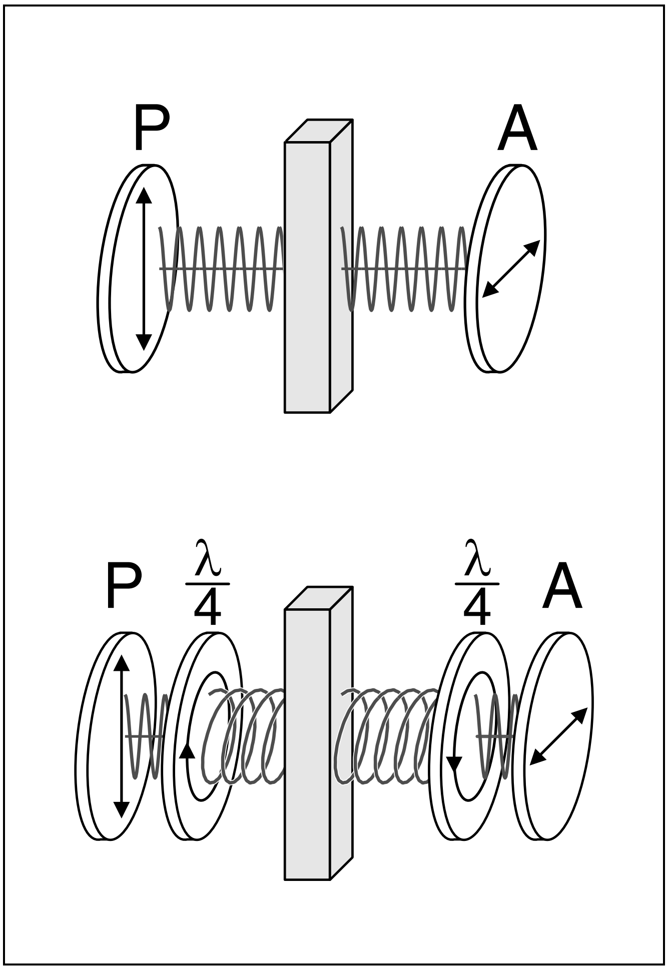


Fig. 1: Schematic representation of the investigation of a model using the principles of polarization optics, with linearly polarized light (top) and circularly polarized light (bottom)

The birefringence, or more accurately, the difference between the refractive indices for the ordinary and extraordinary rays, is

$$n_2 - n_1 = C \cdot (\sigma_2 - \sigma_1). \qquad \text{(I)}$$

Here, C is the photoelastic constant of the plastic and $_1$ and $_2$ are the principle strains caused by the load. The strain birefringence is not very great; depending on the material, it can reach values of $n_2 - n_1 = 0.002$.

Illumination with linearly polarized light:

The plastic model is illuminated e.g. in an arrangement consisting of a polarizer and analyzer aligned at right angles to each other. As long as there is no stress on the model, the field of view behind the polarizer remains dark, as the strain-free plastic does not change the polarization of the light. This situation changes when the plastic is subjected to stress. Due to birefringence, the light is generally elliptically polarized as it passes through the plastic, i.e. it receives a component in the direction of analyzer. The load points of the plastic model can thus be perceived as bright areas on the screen.

Dark lines (isoclines) may be seen between the bright spots at the points where the locally occurring optical axis of the plastic model happens be aligned parallel or perpendicular to the polarizer. The isoclines move when the polarizer and the analyzer are rotated in concert while retaining their perpendicular alignment. The isocline positions are recorded for various polarizer positions, and the directions of the principle strains are constructed from these observations.

The bright areas show a colored structure (isochromates), as the light does not contain a component in the analyzer direction for all wavelengths. The components with the wavelength

$$\lambda = \frac{d \cdot (n_1 - n_2)}{m} \qquad \text{where } m = 1, 2, 3 \ldots \qquad \text{(II)}$$

remain polarized parallel to the polarizer, and are extinguished in the analyzer. If the influence of the isochromates is to be

Apparatus

1 Set of photoelastic models	571 95
1 Pair of polarization filters	472 40
1 Pair of quarter-wave plates	472 60
2 Lenses in holder, f = +150 mm	460 08
1 Prism table	460 25
1 Iris diaphragm in holder	460 26
1 Optical bench, 1 m, standard cross-section	460 32
9 Optics riders, H = 60 mm, W = 36 mm	460 353
1 Translucent screen	441 53
1 Saddle base	300 11
1 Halogen lamp with housing 12 V/50 W/100 W	450 64
1 Halogen lamp 12 V/100 W for 450 64	450 63
1 Picture slider for 450 64	450 66
1 Transformer 2 ... 12 V	521 25

Connecting leads

Setup

Fig. 2 shows the experiment setup; the position of the left edge of each optics rider on the optical bench is given in cm.

– Set up the halogen lamp with the 100 W bulb and reflector. Attach the picture slider with heat-protection filter.
– Mount the iris diaphragm **(a)** at the position indicated in the diagram and reduce the diameter of the opening to approx. 4 mm.
– Using the adjusting and focusing rod of the halogen lamp (see the Instruction Sheet supplied with the lamp), adjust the lamp filament along the optical bench and perpendicular to the beam so that its image appears on the iris diaphragm.
– Place the lenses in the beam path. Shift lens **(d)** as necessary until the light is parallel and lens **(f)** is illuminated as precisely as possible.
– Mount the prism table **(b)** with the photoelastic model in the setup. Move lens **(f)** until the model is imaged on the translucent screen at the desired distance.

avoided, a model with the lowest possible photoelastic constant is used, and the model is illuminated with monochromatic light.

Illumination with circularly polarized light:

In a further arrangement, the plastic model is illuminated with circularly polarized light produced using a polarizer combined with a quarter-wavelength plate. A second quarter-wavelength plate is placed behind the model and oriented perpendicular to the first plate, with an analyzer behind that. Here too, the screen is dark as long as the model is not under stress (see Fig. 1, bottom), and strain points are indicated by bright spots on the screen.

In this arrangement, isoclines are avoided, as there is no direction of linear polarization. The isochromatic lines are now caused by the fact that the light components with the wavelength λ which fulfill equation (I) retain their circular polarization and are extinguished by the quarter-wavelength plate/analyzer combination. When we compare this with (I), we can identify the isochromates as points of equal principle-strain difference:

$$\sigma_2 - \sigma_1 = m \cdot \frac{\lambda}{C \cdot d} \quad \text{where } m = 0, 1, 2, \ldots \qquad \text{(III)}$$

As the principle-strain difference increases, the isochromates occur closer and closer together. We can determine the level of strain by counting the isochromates starting from the strain-free state (m = 0). The accuracy can be improved by using materials with a high photoelastic constant.

This experiment uses models made of unsaturated polyester resins, which have a high photoelastic sensitivity. Internal mechanical strains have been largely eliminated by heat-treating, and retain this condition for long periods.

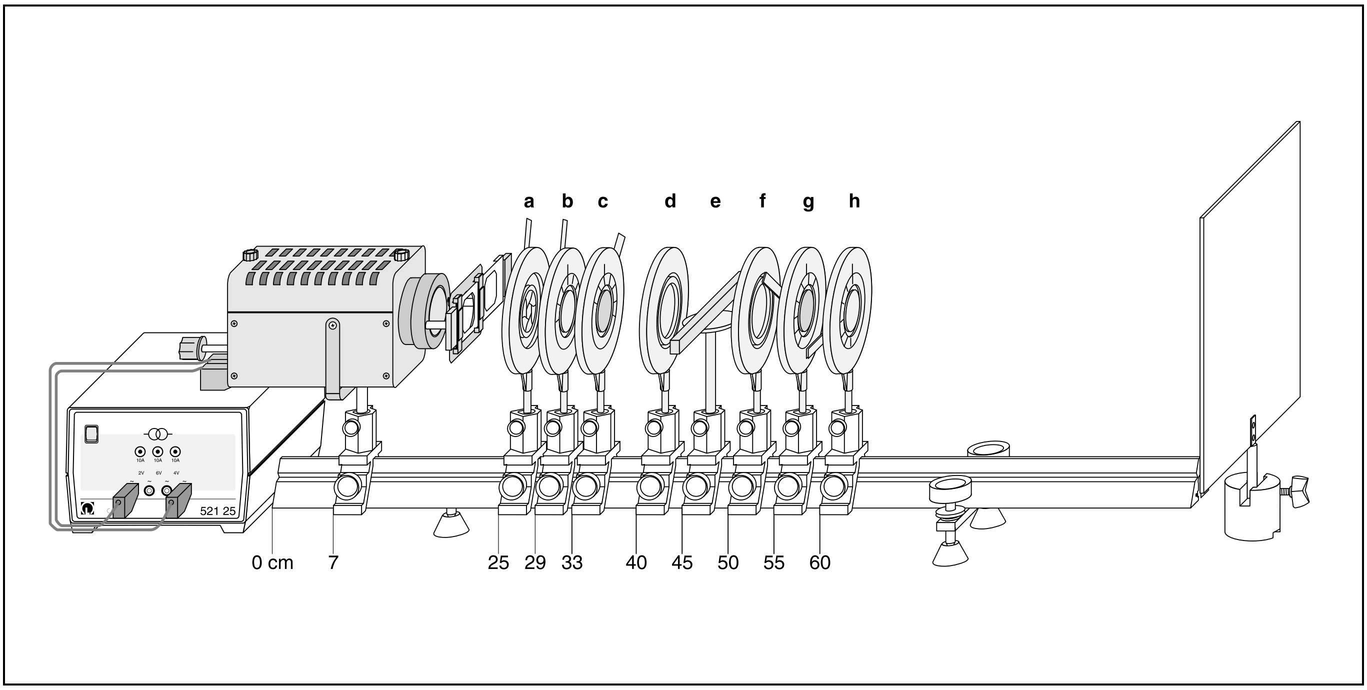
Carrying out the experiment

a) Illuminating with linearly polarized light:

– Place the polarizer **(b)** with the direction of polarization Ψ_P = 45° in the beam path at the specified position, and place analyzer **(h)** with the direction of polarization Ψ_A = –45° approximately 10 cm away from lens **(f)**.
– Place each of the photoelastic models on the prism table one after another, deform each one by hand and observe the screen (Fig. 3 shows some suggested arrangements for the models).
– Vary the polarization directions of the polarizer and the analyzer by the same angle $\Delta\Psi$ = 15°, 30° or 45° and observe the changes on the screen.

b) Illuminating with circularly polarized light:

– Change the direction of polarization of the polarizer to Ψ_P = 0° and the analyzer to Ψ_A = –90°.
– Set up quarter-wavelength plate **(c)** at the position specified in the diagram and quarter-wavelength plate **(g)** approx. 5 cm from lens **(f)** in the beam path.
– Align the first quarter-wavelength plate to Ψ_1 = 45° and turn the second quarter-wavelength plate to Ψ_2 = –45°.
– Place each of the photoelastic models on the prism table one after another, deform each one by hand and observe the screen.
– Vary all alignments by equal angles $\Delta\Psi$ = 15°, 30° or 45° and observe the changes on the screen.



Result

As the stress on the model increases, the points of equal strain are indicated on the screen by lines of the same color. We cannot distinguish between elongation and compression; the neutral line remains dark.

The isochromates are clearly visible, as the photoelastic sensitivity of the plastic models is extremely high.

When illuminated with linearly polarized light, isoclines are superimposed on the isochromates. Thus, by rotating the direction of polarization, we change the entire distribution of colors. This is not the case when illuminating with circularly polarized light.

Fig. 2: Experiment setup on the optical bench with positions for the left edge of each optics rider specified in cm
(a) Iris diaphragm
(b) Polarization filter as polarizer
(c) Quarter-wavelength plate
(d) Lens, f = + 150 mm
(e) Prism table with photoelastic model
(f) Lens, f = + 50 mm
(g) Quarter-wavelength plate
(h) Polarization filter as analyzer

Fig. 3: Suggestions for mechanically stressing the plastic models