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Raw optical glass — Determination of birefringence

Verre d'optique brut — Détermination de la biréfringence

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 11455 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 3, *Optical materials and components*.

Annex A of this International Standard is for information only.

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Introduction

Raw optical glass in bulk and preshaped forms may have permanent stress caused by the manufacturing procedure or temporary stress caused by thermal or mechanical load. These stresses cause anisotropy of the refractive index which causes path differences of the light path in the given object (in centimetres) which are measurable by interference optics. The birefringence, in nanometres per centimetre, is valid for the glass piece when isothermal and not mechanically altered and is the integrated value for the resultant wavefront deformation caused by an anisotropy of the refractive index.

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Raw optical glass — Determination of birefringence

1 Scope

This International Standard describes the stress optical method for determining the birefringence in glass, especially in raw optical glass in bulk and preshaped forms. This method is also used in photoelasticity.

NOTES

1 The calculation of the elastomechanical stress from the birefringence is not the subject of this International Standard.

2 The indication on the drawings of birefringence is specified in ISO 10110-2 (see reference [2] in annex A).

This test method is applicable for simple geometrical shapes of glass (see clause 5).

2 Definition

For the purposes of this International Standard, the following definition applies.

2.1 birefringence (of glass): An anisotropy of refractive index in optically homogeneous and isotropic glasses, usually induced by mechanical and/or thermal stress. The refractive index depends on the orientation of the plane of polarization and the propagation vector of the electromagnetic wave with respect to the axis of the principal stresses.

[Definition taken from ISO 9802.]

3 Principle

Measurement of the optical path differences by compensation using an optical interference method with polarized light.

In the compensation procedure described by de Sénarmont and Friedel a phase retardation of one wavelength is produced by a rotation of 180° in a linear function, using light of wavelength near maximum of sensitivity of human eye (i.e. 546 nm to 589 nm).

If an optically isotropic glass body under stress is irradiated with polarized light in the direction of one principal stress (such as σ_3, see figure 1), the oscillating components in the direction of principal stress, σ_1 and σ_2, show a different speed of propagation related to the value in a stress-free glass body.

The refractive indices n_1 and n_2 are related to the principal stresses σ_1, σ_2 and σ_3 by:

$$n_1 - n_0 = p\sigma_1 + q(\sigma_2 + \sigma_3) \qquad \ldots (1)$$

$$n_2 - n_0 = p\sigma_2 + q(\sigma_1 + \sigma_3) \qquad \ldots (2)$$

where

n_0 is the refractive index of the unstressed glass;

p and q are related to the type of glass.

From equations (1) and (2), equation (3) for the difference in refractive index may be obtained:

$$n_1 - n_2 = (p - q)(\sigma_1 - \sigma_2) \qquad \ldots (3)$$

The difference in refractive index $(n_1 - n_2)$ is the birefringence Δn, which is related to the stress optical coefficient $K = p - q$ at the wavelength used as follows:

$$\Delta n = K(\sigma_1 - \sigma_2) \qquad \ldots (4)$$

For the correlation between birefringence, Δn, and the optical path difference, Δs, between the wave components in the principal stress direction, σ_1 and σ_2, after passing through the sample thickness a (which

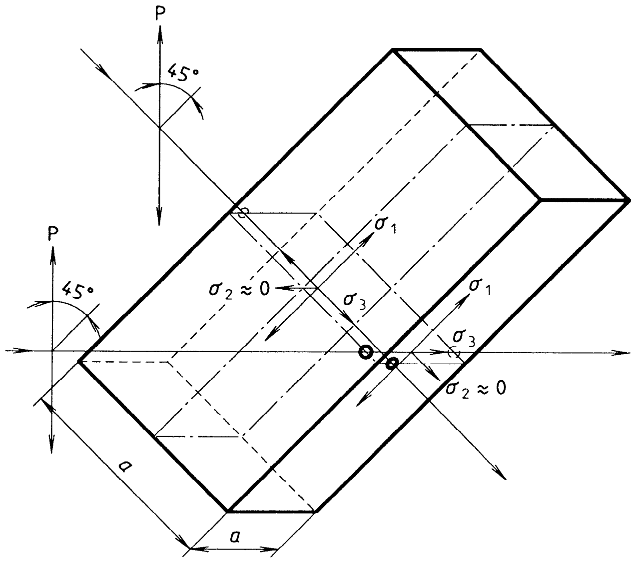

Figure 1 — Principal stresses shown in a rectangular plate

is usually equal to light path a), the following equation may be applied:

$$\Delta n = \frac{\Delta s}{a} \quad \ldots (5)$$

The birefringence Δn is given in nanometres per centimetre.

4 Apparatus

4.1 Instrument for measuring the thickness of the specimen at the measuring points to 1 % e.g. callipers.

4.2 Polarimeter with a compensator as described by de Sénarmont and Friedel.

4.2.1 Polarimeter components

The polarimeter shall consist of the following components (see also figure 2).

a) Source of collimated light, e.g. white light source with monochromatic filter for a wavelength λ of 546 nm or 589 nm.

b) Diffuser, e.g. an opal glass or a uniformly ground glass screen.

c) Polarizer, containing a cross-section line at 45° to the polarizing direction. The polarizer is mounted between glass and housed in a rotatable mount capable of being locked in a fixed position.

d) Specimen holder.

e) Quarter-wave plate, having a retardation equivalent to one quarter of the wavelength of the light being used. It shall be housed in a rotatable mount capable of being locked in a fixed position.

f) Analyser, identical to the polarizer. It shall be housed in a rotatable mount capable of being locked in a fixed position. This mount shall then be housed within a graduated mount capable of being rotated ± 180°.

In addition, the following components may be used:

g) Full-wave plate, having a retardation of 565 nm which produces, with white light, a violet-red colour. It shall be housed in a rotatable mount capable of being locked in a fixed position.

h) Telescope, i.e. a short-focus telescope having a suitable magnifying power over the usable focusing range in case of parallax-free light passing close to the edge of the glass body.

i) Immersion cell, non-birefringent, for testing samples and optical elements having non-parallel or unpolished surfaces. The immersion cell shall contain a non-birefringent fluid which closely matches the index of refraction of the specimen glass.

It is possible to build up a reversed set de Sénarmont compensator with the light source at the position of

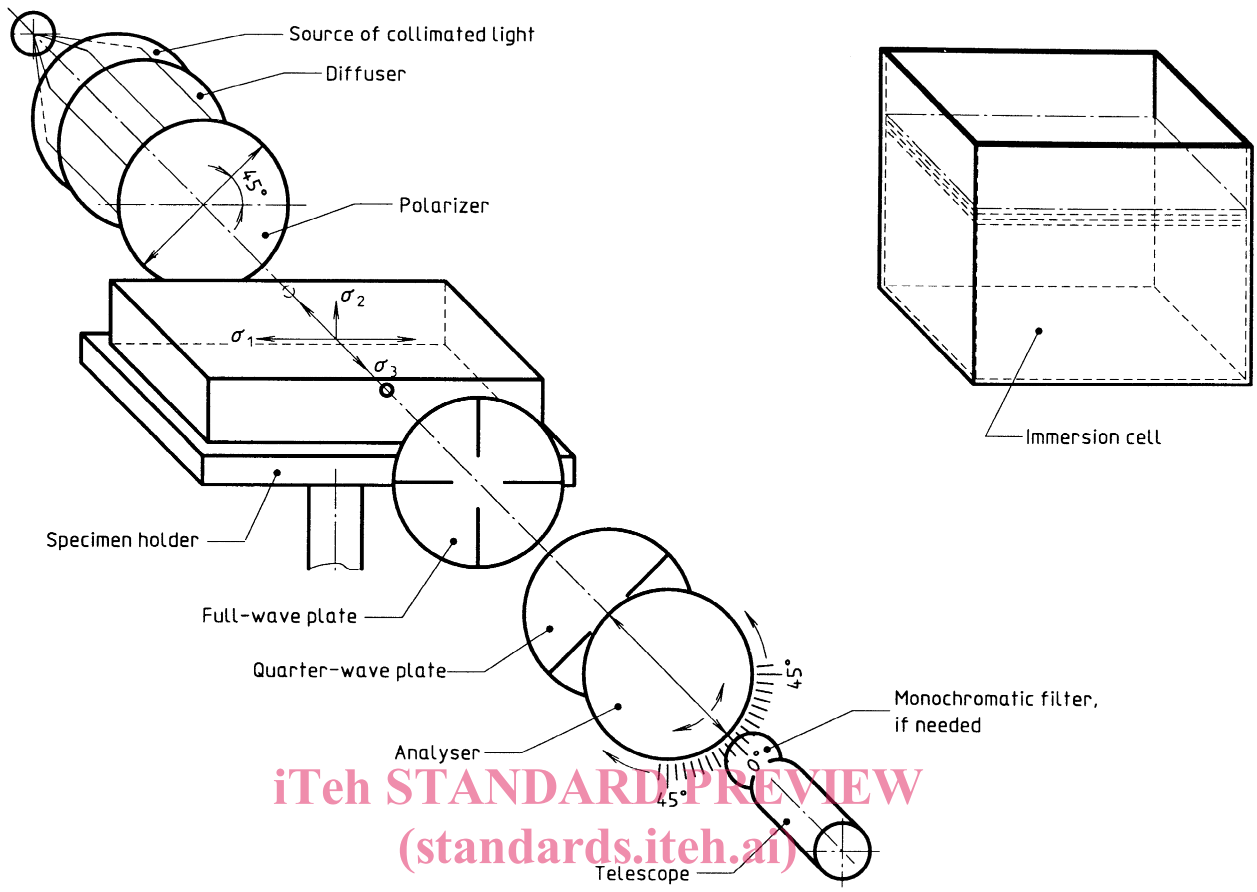

Figure 2 — Test arrangement as described by de Sénarmont and Friedel, including the specimen

the viewer (see figure 2) and the viewer looking at the polarizer.

4.2.2 Adjustment of the polarimeter

The polarimeter shall be adjusted so that the 45° line on the polarizer is parallel to the edge of the sample.

The analyser shall be rotated without the full-wave plate and the quarter-wave plate to zero-position to produce homogeneous darkness.

Finally, the quarter-wave plate shall be adjusted to maximum darkness through rotation and fixed in position.

In case of using a full-wave plate to help in determination of tensile or compressive stress at the edge, the full-wave plate shall be adjusted to maximum darkness in the case of monochromatic light.

Switch to a white light source with the full-wave plate [interference-colour red-violet ("first order red")].

The sensitivity in compensating of very little brightening, caused by small birefringence, or small path length, in the glass body depends on the surface polishing and on the quality of polarizer, analyser and quarter-wave plate. Best results are obtained only with parallax-free long distance optics using the short-focus telescope.

5 Test samples

The test samples should be of simple geometrical shapes, e.g. rotationally symmetrical, rectangularly cut plates and blocks, and equilateral, rectangular triangles.

The test samples should have two opposite planeparallel polished surfaces. For these test samples, apply the normal test procedure. In case of test samples with non-planeparallel and/or unpolished surfaces, use the immersion cell [see 4.2.1 i)].

Examples of test samples with polished surfaces and measuring points are given in figure 3.

The test samples shall be held in isothermal conditions at room temperature to reach an equilibrium temperature before and during measurement.

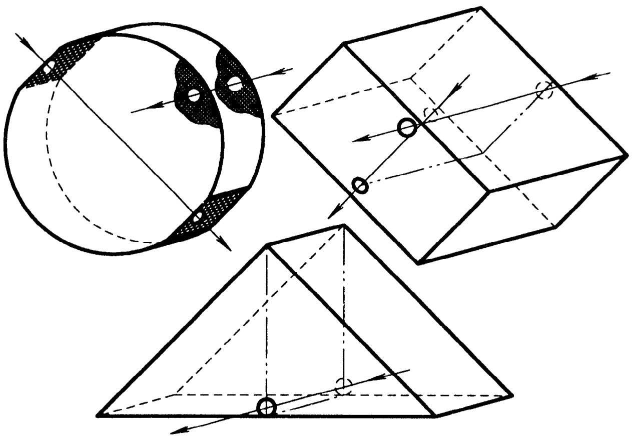

Figure 3 — Examples of test samples, including possible measuring points

6 Procedure

6.1 Place the test sample so that the principal stress direction lies at 45° to the oscillating plane of the light. In this way, the oscillating components in the direction of the principal stresses σ_1 and σ_2 have the same amplitude but a different optical path length, Δs, when leaving the test sample (elliptical polarized light).

The point of birefringence measurement shall be close to the edge of the test sample, at a distance of approximately 5 % of the diameter of the width from the edge.

6.2 The tangent plane at the measuring point for round test samples shall lie at 45° to the polarizer. For rectangular cross-sections and right-angled triangular cross-sections, the point of measurement shall be as shown in figure 3.

6.3 Determine the light path by measuring the thickness of the test sample at the measuring point to 1 %.

6.4 Rotate the analyser until the path difference is compensated, this means until the maximum darkness has occurred at the selected point of measurement.

During passage through the quarter-wave plates, linearly polarized light is produced, whose plane of oscillation is rotated relative to the original plane of the polarizer by an angle proportional to the optical path difference.

Note the angle ϕ at this position. The sign of the angle ($\pm$) depends on the sense (compression or tension) of the principal stress difference (see 6.5).

Repeat the measurement for further measuring points (figure 3).

6.5 For information on the sign of the stress close to the edge of the test sample, switch to the white light source by taking out the monochromatic filter and putting in the full-wave plate. Colourless brightening caused by minor path differences (smaller than half wavelength) appear in the well-known sequence of white light interference colours from red-violet to blue or yellow in the other direction. The determination of tension or compression can be made by comparison to single-axis prestressed rods or test discs. Using the full-wave plate, the analyser shall be in zero-position.

NOTES

3 The change of colour depends on the orientation of the principal stress cross in the test sample to the polarizing direction.

4 For glasses with negative stress optical coefficients (for instance glasses with a mass fraction of PbO of more than 75 %), interference colours will be reversed from the stress correlate determined with prestressed rods or test discs of glass with positive (normal) stress optical coefficients.

Another way to determine the sign of the stress is to introduce a point-like force on the test specimen leading to regions of known stress orientations.

6.6 The compensation range given by the procedure described by de Sénarmont and Friedel is limited to a maximum retardation of one wavelength (180°).

If the path-difference exceeds one wavelength, the interference lines shall be counted starting with the neutral black line as zero which has to be determined previously with the white light source (without the monochromatic filter).

The visible region beyond the highest coloured line (after switching to monochromatic light, it is a black line) shall be compensated in accordance with 6.4 and shall be added to the already counted wavelengths.

7 Expression of results

For each measuring point, calculate the birefringence according to the following equation:

$$\Delta n = \frac{\Delta s}{a} = \frac{\phi}{180} \times \frac{\lambda}{a} \qquad \ldots (6)$$

where

Δn is the birefringence, in nanometres per centimetre;

Δs is the optical path difference, in nanometres;

a is the light path (sample thickness), in centimetres;

ϕ is the rotation of the analyser required to produce darkness at the measuring point, in degrees;

λ is the wavelength of the light used, in nanometres.

8 Test report

The test report shall include the following information:

a) reference to this International Standard;

b) identification of the test sample;

c) shape of the test sample;

d) kind of light source used (wavelength λ);

e) kind of polarizer used;

f) position of the measuring points;

g) direction of the light path through the test sample;

h) birefringence, in nanometres per centimetre, rounded to the nearest 1 nm/cm.