Designation: ~~C1901 – 21~~ C1901 – 21$^{\varepsilon 1}$

Standard Test Method for Measuring Optical Retardation in Flat Architectural Glass[1]

This standard is issued under the fixed designation C1901; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Font of examples in Appendix X4 was changed, a duplicate subsection in Appendix X4 was removed, and editorial changes to grammar were made throughout in February 2021.

1. Scope

1.1 This test method addresses the measurement of optical anisotropy in architectural glass.

1.2 This test method is a test method for measuring optical retardation. It is not an architectural glazing specification.

1.3 The optical retardation values may be used to calculate/predict the amount of visible pattern, commonly known as anisotropy or iridescence, present in heat-treated glass.

1.4 This test method applies to monolithic heat-treated (heat-strengthened and fully tempered) clear, tinted and coated glass.

1.5 This test method does not apply to:

1.5.1 Glass that diffuse light (that is, patterned glass, sand blasted glass, acid etched, etc.), or

1.5.2 Glass that is not optically transparent (that is, mirrors, enameled or fritted glass).

1.6 The optical measurement is integrated through the glass thickness, and therefore cannot be used to assess the level of tempering. It does not give information on the surface stress or center tension.

1.7 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 Reference to these documents shall be the latest revision unless otherwise specified by the authority applying this test method.

[1] This test method is under the jurisdiction of ASTM Committee C14 on Glass and Glass Products and is the direct responsibility of Subcommittee C14.08 on Flat Glass.
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2.2 *ASTM Standards for Glass:*[2]
C162 Terminology of Glass and Glass Products
C1036 Specification for Flat Glass
C1048 Specification for Heat-Strengthened and Fully Tempered Flat Glass

2.3 *ASTM Standards for Optical Stress and Retardation Measurements:*[2]
C1279 Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened, and Fully Tempered Flat Glass
D4093 Test Method for Photoelastic Measurements of Birefringence and Residual Strains in Transparent or Translucent Plastic Materials

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Specifications C1036, C1048, and Terminology C162, as appropriate.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *analyzer, n*—a polarizing element, typically rotatable and positioned between the specimen being evaluated and the ~~viewer.~~observer.

3.2.2 *anisotropy, n*—property of being directionally dependent whereby measurements taken along different axes produce differences in a material's physical or mechanical properties (absorbance, refractive index, conductivity, etc.).

3.2.3 *Babinet-Soleil compensator, n*—an optical compensator that can be used to measure phase shifts locally in a polariscope or polarimeter using shifting quartz wedges.

3.2.4 *birefringence, n*—the optical property of a material having a refractive index that depends on the polarization and propagation direction of light.

3.2.5 *compensation methods, n—(1)* Sénarmont compensator uses linearly polarized light incident to the specimen; it couples a quarter wavelength plate with a 180° rotating analyzer to provide retardation measurements; *(2)* Tardy compensator uses circularly polarized light incident to the specimen, thus independent of the specimen orientation; it also couples a quarter wavelength plate with a 180° rotating analyzer to provide retardation measurements.

3.2.6 *index of refraction, n*—the ratio of speed of light (*c*) in vacuum and the phase velocity of light in the medium (*v*).

3.2.7 *iridescence, n*—also known ~~in the industry~~ as quench pattern/marks, strain pattern or anisotropy, visible pattern in heat-treated glass that may be visible under certain polarized lighting conditions.

3.2.8 *isochromatic, adj*—having the same color or wavelength.

3.2.9 *photoelasticity, n*—the property exhibited by transparent isotropic solids of becoming doublerefracting when subjected to either tensile or compressive stress.

3.2.10 *polarizer, circular, n*—an optical assembly that creates circularly polarized light for a given wavelength.

3.2.11 *polarizer, linear, n*—an optical assembly that transmits light vibrating in a single planar direction.

3.2.12 *retardation, n*—the optical path difference between two perpendicular polarized light waves created in a birefringent material.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.13 *retardation standard, n*—see *waveplates*.

3.2.14 *specular light, n*—radiation emerging from the specimen is parallel to the beam entering.

3.2.15 *wave retarder, n*—see waveplates.

3.2.16 *waveplates, n*—birefringent materials that retard the polarization state or phase of light traveling through them.

4. Summary of Test Method

4.1 This test method provides an accurate non-destructive method of quantifying optical retardation in transparent glass using principles of photoelasticity and high-speed image processing. The result is a high-resolution retardation map in nanometres (nm). Optionally, the apparatus can compute an additional map of retardation axis orientation (azimuth) in degrees. This test method provides a process for monitoring these variations.

5. Significance and Use

5.1 Stress may be applied intentionally through a heat treatment or tempering process to increase mechanical strength and improve safety characteristics of glass sheets. The process itself makes it practically impossible to achieve a homogenous residual stress profile over a full glass panel. These variations are due to variations in type of glass (clear, tinted, coated, etc.), the fabrication, sheet geometry, heating, quenching, and cooling. Even though the level of inhomogeneity may not interfere with the global mechanical property of the glass sample, it can produce optical patterns called anisotropy (often commonly referred to as leopard spots). Today to evaluate this stress homogeneity people may use the subjective, non-standardized method of viewing through a polarized filter or employing a polariscope. The present test method provides guidelines for measuring a physical parameter, the optical retardation, directly linked to the local residual stress, at many locations on each heat-treated glass sheet.

5.2 Through this test method one can obtain in a non-destructive manner, on-line to the tempering furnace equipment, a map of the retardation value of all glasses. That information can then be used:

5.2.1 By the tempering operator to adjust the settings of the heat treatment process to optimize/tune both the levels optical retardations and its homogeneity on heat treated glass sheets.

5.2.2 To provide a standardized way to measure optical retardation values for each glass panel that can be archived and communicated when desired.

5.2.3 By customers and other stakeholders to develop/write specifications for the optical retardation values (not the visibility of the pattern) that are independently verifiable.

5.3 This test method can also be used off-line to evaluate the optical retardation level and homogeneity of any heat-treated glass, for quality assurance or other purposes.

6. Limitations

6.1 A series of factors will affect the results. These factors should be either avoided or documented to explain how they affect results.

6.1.1 The *light transmission* of the specimen at the wavelength(s) being used to measure optical retardation should be in accordance with apparatus manufacturer specification.

6.1.2 The deviation from *flatness* of the glass after the heat treatment process might affect the measurement, as the light may travel out of the equipment range. The glass flatness, overall bow, edge kink, roller wave must be in accordance with apparatus manufacturer specifications.

6.1.3 The *thermal state* of the specimen when measured will affect the results as non-uniform temperature across the thickness and from one region to another on the same pane will induce stresses. Variance can occur with glass temperature.

6.1.4 When measuring optical retardation using photo-elastic devices, attention should be paid to external *mechanical stresses* applied to glass.

6.1.5 Area around *geometric features* (holes, notches, openings) and edges will have high retardation values that may exceed equipment range (see example of edge stress in Test Method C1279). Including retardation values in these regions may bias calculations such as uniformity and averages. Exclusion zones can be setup to eliminate some regions, for example: perimeter bands or partially enameled areas. These zones should be properly identified in the report.

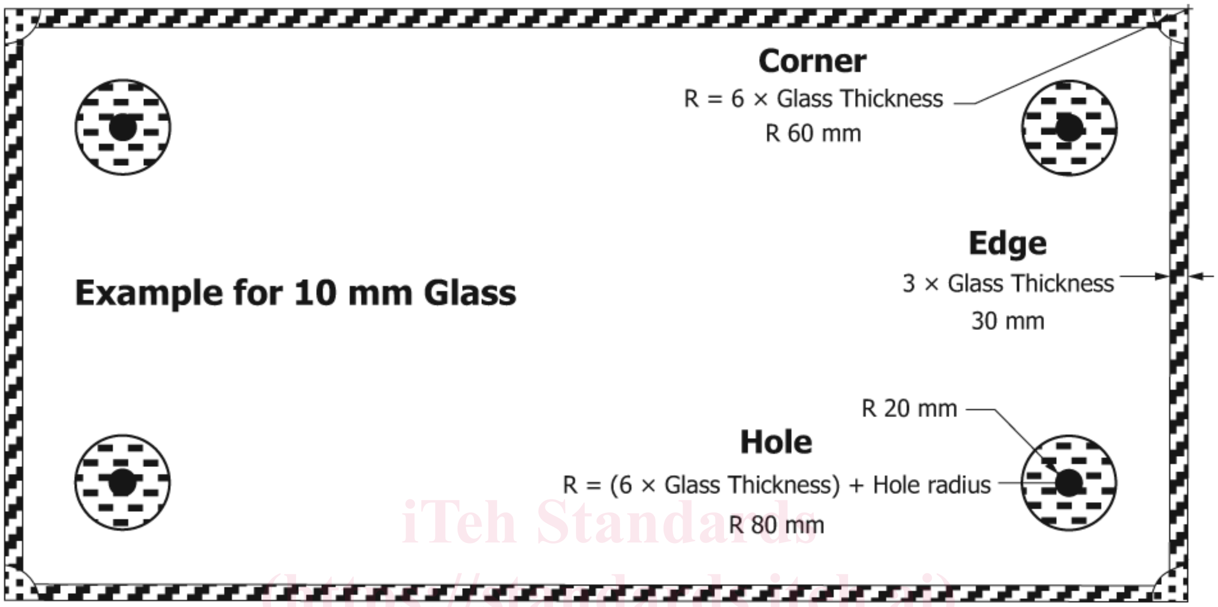


FIG. 1 Exclusion Zones Example

6.1.6 See Fig. 1 for example of exclusion zones.

6.1.7 See Appendix X1 for further discussion about more complex circumstances (that is, laminates, insulated glass units) that must be approached carefully when applying the test method.

7. Apparatus and Compatibility

7.1 *General:*

7.1.1 The apparatus measures the spatially resolved optical retardation of an area according to the principles of digital photoelasticity. The apparatus must be designed in such a way that reproducible, direction-independent retardation values are generated. The optical components must match the wavelength range of the light source. The image acquisition may be done with any suitable digital sensor (camera, linear sensor, etc.).

7.1.2 See Fig. 2(a) and Fig. 2(b) for images of apparatus.

7.1.3 Please consult Appendix X2 for more nonmandatory information on apparatus, their suggested range, precision, and bias.

7.2 *Procedure A—Calibrated Polarimeter:*

7.2.1 A polarimeter directly measures the optical retardation and its axis orientation (azimuth) by means of a polarization-sensitive matrix or line scan detector ("polarization camera") using quasimonochromatic circularly polarized light. Instead of using a mechanical or electro-optical rotating analyzer, as known from the Sénarmont or Tardy polarimeter setup, it is sufficient to analyze a few discrete polarization planes, typically 0, 45, 90, and 135°.

7.2.2 Commercially available or proprietary polarization cameras can contain multiple sensors (one for each polarization orientation) or a subdivided sensor (one quadrant for each polarization orientation) in combination with suitable beam-splitting optics. Alternatively, each pixel of the camera can be equipped with individual micro-scale polarizers (like the color filters of a single-sensor RGB camera).

7.2.3 Since the measuring range is physically limited to a certain fraction of the illumination wavelength (the value of which is depending on the used optical setup and the quality of the used optical components), the measuring range can be extended by analyzing multiple wavelengths and correlating the results mathematically or by using phase-unwrapping image algorithms, or both, as known from interferometric evaluation.

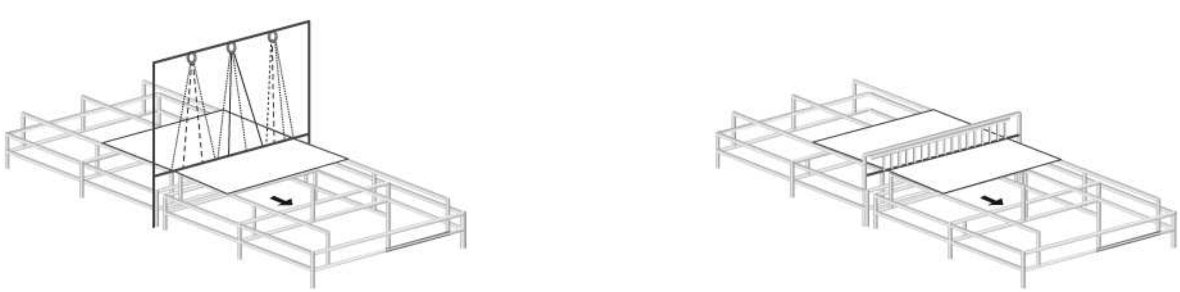
7.2.4 The linearity and absolute correctness of the measurement can be ensured by comparison to reliable retardation-generating devices such as Babinet-Soleil compensators. If necessary, a characteristic line curve can be generated to calibrate the measurement.

7.3 *Procedure B—Calibrated Polariscope:*

7.3.1 By calibration, circular polariscopes can be used practically to quantify retardation based on isochromatic images. Due to the optical configuration, the maximum optical retardation is measured independently of the direction. There are several approaches to correlate intensity values (RGB colors or gray values) with retardation values. One method is a calibration using a Babinet-Soleil compensator. A correlation of the acquired ~~calibration (in nm)~~calibration, in nm, with the isochromatic image (intensity values) using an evaluation algorithm creates a new image with retardation (nm) per pixel.

8. Hazards

8.1 Glass is a brittle material and may result in glass fracture. Glass handling safety gear should always be worn during specimen



(a) Camera System

(b) Line Scan Bar System With Light

FIG. 2 Camera and Line Scan Bar With Light Sytems handling, testing, evaluation, and disposal. Apparatus discussed in this test method may utilize high intensity light sources such as a laser. Proper care and manufacturer's instructions must be followed by the operator.

9. Calibration and Standardization

9.1 Apparatus manufacturers use proprietary methods to convert their sensor output into workable retardation values. Through self-calibration or recalibration, it ensured that this conversion method generates valid and constant values during the life of their instrument in given environmental conditions: temperature, humidity, vibration, and dust.

9.2 Operator should verify that the calibration and verification be done in accordance with apparatus manufacturer suggested practices and ~~authority~~authorities having jurisdiction (see Table 1).

9.3 A minimum of three retarders should be run though the scanner. After recording the zero (blank area), sample A, B, C values, the plate should be rotated a fraction of a complete rotation and run again. This procedure is repeated four times. Obtaining the retardation at 0, 1/16 (22.5 ± 5°), 1/8 (45 ± 5°), 1/4 (90 ± 5°) allowing to confirm the angle independence, precision, and the bias (repeatability) of measurements. Additional measurements continuing at 22.5° increments may be done.

9.4 This procedure can be repeated in different area in the width of the scanner to verify that all light emitting, and sensing elements yield the correct values.

10. Procedure

10.1 Operator should use the apparatus in accordance with manufacturer suggested practices and ~~authority~~authorities having jurisdiction.

10.2 See Appendix X3 for guidelines on operational procedures.

11. Report

11.1 *Required Information:*

11.1.1 Glass geometry (thickness and ~~size).~~size, in mm).

11.1.2 Definition of the area analyzed (base × ~~height)~~height, in ~~milimetres.~~mm).

11.1.3 Analyzed area in m^2.

11.1.4 Data aggregation methods definitions. Examples include:

11.1.4.1 Mean value ~~on~~of the analyzed area.

TABLE 1 Retarder Specification

Minimum Number of Retarders	3 (to cover the useful range)
Minimum Dimension	Workable area of 25 × 25 mm
Range[A]	Sample A: 20–40 nm Sample B: 60–80 nm Sample C: 100–120 nm
Precision	±2 nm (averaged over any 25 × 25 mm area)
Wavelength	570 nm as in accordance with Test Method D4093
Environmental Conditions	Should maintain above precision within specified conditions by the retarder manufacturer.

[A] Retarders offer certified fixed values within each value.

11.1.4.2 Maximum value onof the analyzed area.

11.1.4.3 95 % on 95th percentile distribution level of the analyzed area.

11.1.5 Measured value(s) of retardation, in (nm)nm, based on data aggregation method.

11.1.6 Retardation image.

11.1.6.1 Resolution of the image (px/mm).

11.1.6.2 Scale of the image (color/nm).image.

11.2 *Optional Information:*

11.2.1 Please see Appendix X3X4 for description of "Glass Quality Open Interchange Format" (GQOIF).

11.2.2 Version of datafile.

11.2.3 *Date/Time:*

11.2.3.1 Measurement.

11.2.3.2 File creation.

11.2.4 *Scanning Device Information:*

11.2.4.1 Manufacturer.

11.2.4.2 Model.

11.2.4.3 Software version.

11.2.5 *Glass Part Information:*

11.2.5.1 Glass type.
(1) Color.
(2) Coatings.

11.2.5.2 Product designation (FT, HS).

11.2.5.3 Serial number.

11.2.6 *Customer/Glass Use Information:*

11.2.6.1 Customer name.

11.2.6.2 Project.

11.2.6.3 Order.

11.2.6.4 Line number.

11.2.7 *Exclusion Zones*.

11.2.8 *Retardation Mean Value*.