Designation: D4093 – 23

Standard Test Method for Photoelastic Measurements of Birefringence and Residual Strains in Transparent or Translucent Plastic Materials[1]

This standard is issued under the fixed designation D4093; 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.

INTRODUCTION

Light propagates in transparent materials at a speed, *v,* that is lower than its speed in vacuum, *c*. In isotropic unstrained materials the index of refraction, $n = c/v$, is independent of the orientation of the plane of vibration of light. Transparent materials, when strained, become optically anisotropic and the index of refraction becomes directional. The change in index of refraction is related to strains. If n_o is the refractive index of unstrained material, the three principal indices of refraction, n_i, become linear functions of strain:

$$n_i - n_o = \sum A_{ij} \ \varepsilon_j$$

Using photoelastic techniques (initially developed to measure stresses in transparent models) strains in plastics can be assessed. In isotropic materials, two material constants, *A* and *B,* are sufficient to describe their optomechanical behavior:

$$A_{ij} = A \text{ when } i = j\text{, and}$$
$$A_{ij} = B \text{ when } i \neq j.$$

When light propagates through a region (where principal strains ε_1 and ε_2 are contained in the plane perpendicular to the direction of light propagation (see Fig. 1), the incoming vibration splits into two waves vibrating in planes of ε_1 and ε_2. The difference between the indexes of refraction $n_1 = c/v_1$ and $n_2 = c/v_2$ (or birefringence) is:

$$n_1 - n_2 = (A - B)(\varepsilon_1 - \varepsilon_2) = k(\varepsilon_1 - \varepsilon_2)$$

where *k* is a material property called the strain-optical constant. As a result of their velocity difference, the waves vibrating along the two principal planes will emerge out of phase, their relative distance, or retardation, δ, given by:

$$\delta = (n_1 - n_2)t = kt(\varepsilon_1 - \varepsilon_2)$$

where *t* is the thickness of material crossed by the light. A similar equation, relating δ to the difference of principal stresses, σ_1 and σ_2, can be written:

$$\delta = (n_1 - n_2)t = Ct(\sigma_1 - \sigma_2)$$

The objective of photoelastic investigation is to measure: *(a)* the azimuth, or direction of principal strains, ε_1 and ε_2 (or stresses σ_1 and σ_2), and *(b)* the retardation, δ, used to determine the magnitude of strains. A complete theory of photoelastic effect can be found in the abundant literature on the subject (an extensive bibliography is provided in Appendix X2).

1. Scope*

1.1 This quantitative test method covers measurements of direction of principal strains, ε_1 and ε_2, and the photoelastic retardation, δ, using a compensator, for the purpose of analyzing strains in transparent or translucent plastic materials. This test method can be used to measure birefringence and to determine the difference of principal strains or normal strains when the principal directions do not change substantially within the light path.

1.2 In addition to the method using a compensator described in this test method, other methods are in use, such as the goniometric method (using rotation of the analyzer) mostly applied for measuring small retardation, and expressing it as a fraction of a wavelength. Nonvisual methods employing spectrophotometric measurements and eliminating the human judgment factor are also possible.

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

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***A Summary of Changes section appears at the end of this standard**

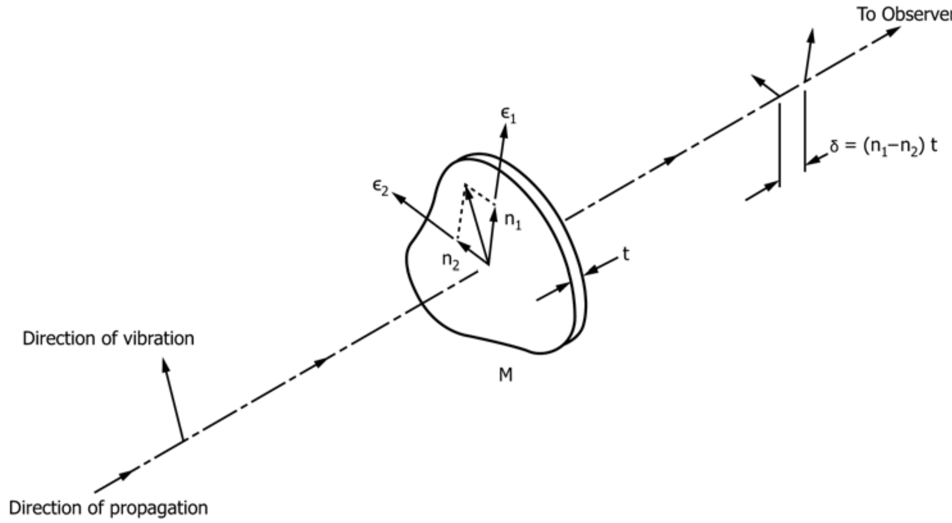

FIG. 1 Propagation of Light in a Strained Transparent Material

1.3 Test data obtained by this test method is relevant and appropriate for use in engineering design.

1.4 The values stated in either SI units or inch-pound units are to be regarded as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *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.*

NOTE 1—There is no known ISO equivalent to this test method.

1.6 *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 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing
D638 Test Method for Tensile Properties of Plastics
D882 Test Method for Tensile Properties of Thin Plastic Sheeting
D883 Terminology Relating to Plastics
D4000 Classification System for Specifying Plastic Materials
E456 Terminology Relating to Quality and Statistics
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E2935 Practice for Evaluating Equivalence of Two Testing Processes

3. Terminology

3.1 Terms used in this standard are defined in accordance with Terminology D883, unless otherwise specified. For terms relating to precision and bias and associated issues, the terms used in this standard are defined in accordance with Terminology E456.

3.2 *Definitions:*

3.2.1 *compensator, n*—an optical device used to measure retardation in transparent birefringent materials.

3.2.2 *polarizer, n*—polarizing element transmitting light vibrating in one plane only.

3.2.3 *quarter-wave plate, n*—a transparent filter providing a relative retardation of ¼ wavelength throughout the transmitting area.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *birefringence, n*—retardation per unit thickness, δ/t.

3.3.2 *retardation (δ), n*—distance (nm) between two wave fronts resulting from passage of light through a birefringent material. (Also called "relative retardations.")

3.3.3 *strain, ε-strain (or deformation per unit length), n*—permanent, plastic strain introduced in manufacturing process, or elastic strain related to the existing state of stress.

3.3.3.1 *Discussion*—Both types of strains will produce strain-birefringence in most polymers. Birefringence can also result from optical anisotropy due to crystalline orientation.

3.3.4 *strain-optical constant (k), n*—material property, relating the strains to changes of index of refraction (dimensionless).

$$k = (n_1 - n_2)/(\varepsilon_1 - \varepsilon_2)$$

3.3.5 *stress-optical constant (C), n*—material property relating the stresses to change in index of refraction. *C* is expressed in m^2/N or Brewsters (10^{-12} m^2/N). *C* is usually temperature-dependent.

[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.