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Standard Test Method for Photoelastic Measurements of Birefringence and Residual Strains in Transparent or Translucent Plastic Materials¹

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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:

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

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:

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

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:

$$n_1 - n_2 = (A - B)(\epsilon_1 - \epsilon_2) = k(\epsilon_1 - \epsilon_2)$$

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:

$$\delta = (n_1 - n_2)t = kt(\epsilon_1 - \epsilon_2)$$

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