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# 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 D 4093; 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.

$\epsilon^1$ NOTE—Symbol in X3.1 was changed editorially. Also, certain equations were re-formatted throughout the standard in December 2001.

## 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:

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

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:

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

When light propagates through a region (where principal strains $\epsilon_1$ and $\epsilon_2$ 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 $\epsilon_1$ and $\epsilon_2$. The difference between the indexes of refraction $n_1 = c/v_1$ and $n_2 = c/v_2$ (or birefringence) is:

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

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, $\sigma_1$ and $\sigma_2$, 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, $\epsilon_1$ and $\epsilon_2$ (or stresses $\sigma_1$ and $\sigma_2$), 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 test method covers measurements of direction of principal strains, $\epsilon_1$ and $\epsilon_2$, and the photoelastic retardation, δ, using a compensator, for the purpose of analyzing strains in transparent or translucent plastic materials. The test method can be used 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

[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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