MEASUREMENT OF SOME MATERIAL CHARACTERISTICS OF OPTICAL GLASSES BY MEANS OF DOUBLE-EXPOSURE HOLOGRAPHIC INTERFEROMETRY

Nina G. Sultanova
University "Assen Zlatarov"- Burgas, Physics Department, 1 Prof. Yakimov Str., Burgas-8010, BULGARIA

Abstract. Double-exposure holographic interferometry is used to determine Young's and shear elasticity moduli and the Poisson coefficient of isotropic optical glass specimens. Three types of optical glasses are applied, namely BK7, F4, and SK16. The specimens are made from homogeneous glass samples in a shape of a cylindrical beam together with the base parallelogram prism. The cylindrical beam is fastened rigidly at the base prism. The double-exposure holographic technique for measurement of object displacements is used. The first exposure is carried out when an out-of-axis force is applied which causes simultaneous bending and torsion of the beam. The second exposure is accomplished after alteration of the force application point. The shape of the fringes in the interferogram is then relatively simple for interpretation and gives the possibility to estimate the moduli of elasticity and the Poisson's ratio.

1. Introduction Holographic interferometry has a great number of engineering applications. It is commonly used for precise measurements of small object displacements and strain analysis, surface deformations, nondestructive testing, etc. [1]. In paper [2] we have reported a holographic double-exposure interferometric method of investigating the Poisson coefficient and elasticity moduli of solid state isotropic material on the example of a steel beam. It is of doubtless interest to apply this method for measurement of these important material characteristics in the case of optical glass. Nowadays, optical elements are widely used in techniques and communications in a range of various service conditions and precise determination of elastic limits is required. The reported data on elasticity moduli in literature often differ in values because of the specific glass composition and method of estimation [3].

2. Experiment Specimens in the shape of a cylindrical beam with equal dimensions had been made at the optical laboratory. Three types of optical glass were applied, namely, BK7, F4 and SK16 in accordance to the polish standard of optical glass composition. The specimens were made from homogeneous glass samples together with the base parallelogram prism. A side view of the tested specimen is presented in Fig.1a. The cylindrical beam is fastened rigidly at the base prism. The double-exposure holographic technique for measurement of beam displacements is used. The first exposure is carried out when an out-of-axis force $P$ is applied to the object. The force is perpendicular to the plane $xy$ of the chart and its arm $r$ is inclined by an angle $\alpha$ towards the beam axis. The second exposure is made after alteration of the force application point with $\Delta s$ between the two exposures. There are
two reasons for this choice of the applied force and its alteration. Firstly, the holographic method is quite precise and it records any object displacement. In practice, it is very difficult to realize cases of pure bending or torsion. So, applying the out-of-axis force $P$, we assume simultaneous bending and torsion of the object in advance. The second reason is that alteration only of the force application point between the two exposures results in an interferogram, which is relatively easy for interpretation. It consists of parallel fringes that are tilted to the axis of the beam by a constant angle (see Fig.1b, c).

![Figure 1](image1.png)

**Fig.1.a)** Side view of the tested object and loading conditions. 
**b,c)** Interferograms obtained in case of alteration of force application point between the exposures.

Figure 2 illustrates the optical configuration for recording the double-exposure holographic interferograms. The beam of an Ar-laser with wavelength of $\lambda=0.514\mu m$ is divided by the splitter 3 and by means of mirrors 1, 5 and 6 the object and the reference waves are directed towards the plane of the hologram 9. The object 8 is illuminated with a divergent beam by the fiber bundle 7, which utilization permits greater flexibility in arranging of the optical recording system. The object beam is almost perpendicular to the tested specimen. The shutter 2 controls time of exposure and element 4 is a convergent lens. Holograms are recorded with a photothermoplastic camera produced by Rottencolber. The application of photothermoplastic recording of holograms allows fast real time measurements and determination of absolute fringe number. Reconstruction is performed by illuminating the holograms with the reference beam. A video camera was used to store the images of the interference fringes.

3. Estimation of surface displacements

The applied out-of-axis force $P$ causes two deformations $w(x,y)$ and $u(x)$ denoting the displacement of point caused by the bending and torsion moment.

$$w(x,y) = \frac{P(x,y)}{I(x,y)}$$

where $u(x)$ is the displacement caused by the bending and $w(x,y)$ is the displacement due to the torsion moment of the cantilever beam in accordance with [4]

$$w(x,y) = \frac{P(x,y)}{I(x,y)}$$

where $I$ and $r$ are the arm lengths of the bending moment of inertia with respect to the y-axis and with respect to the center of the cross-section, respectively. If the application point of the force coincides with the reference point of the reference system, the refractive index $n$ of the object and the condition of bright fringes in two displacements:

$$w(x,y) = \frac{P(x,y)}{I(x,y)}$$

Determination of slope $\gamma$ of the fringe order applying Eqs.(3,4) gives:
3. Estimation of surface displacements, Poisson coefficient and elasticity moduli

The applied out-of-axis force $P$ causes simultaneous torsion and bending of the specimen. Let $w(x,y)$ denote the displacement of points on the beam surface perpendicular to the plane $x,y$ caused by the bending and torsion moment of the force $P$:

$$w(x,y) = u(x) + v(x,y)$$

where $u(x)$ is the displacement caused by the bending moment, while $v(x,y)$ is the displacement due to the torsion moment. In the case of a linear, elastic, isotropic cylindrical, cantilever beam in accordance with [4], the total displacement is:

$$w(x,y) = Pr\left[\frac{l}{6EI_y} \left(3 - \frac{x}{l}\right) + \frac{ry}{Gl_y}\right]$$

where $l$ and $r$ are the arm lengths of bending and torsion moments, $I_y$ is the cross-sectional moment of inertia with respect to the $y$-axis, $I_y$ is the cross-sectional moment of inertia with respect to the center of the cross-section, and $E$ and $G$ are Young's and shear modulus, respectively. If the application point of force $P$ is changed with $\Delta l$ between the two exposures, the arms of bending and torsion moment are altered by $\Delta l = \Delta \cos \alpha$ and $\Delta r = \Delta \sin \alpha$, and the calculated from Eq.2 difference of the displacements $w_1$ and $w_2$ in both cases results in:

$$w(x,y) = w_1(x,y) - w_2(x,y) = \frac{Pr\Delta l}{2EI_y} \cdot \frac{Pr\Delta r}{Gl_y}$$

The phase alteration of the diffusely reflected wave by the specimen is $\delta = \frac{2\pi}{\lambda} [2w(x,y)]$ and the condition of bright fringes $\delta = 2\pi n$ results in estimation of the out-of-plane displacements:

$$w(x,y) = n\lambda/2, \quad n = 1, 2, 3, \ldots$$

Determination of slope $\gamma$ of the fringes (see Fig.1c) at the center plane of the beam ($y=0$) applying Eqs.(3,4) gives:
\[ \frac{dy}{dx} = \frac{2G}{E \tan \alpha} = \frac{1}{\tan \gamma}. \]  

(5)

Using the well-known dependence \[ \nu = \frac{E}{2G} - 1 \] and Eq.5 we find the Poisson coefficient:

\[ \nu = \frac{\tan \gamma}{\tan \alpha} - 1. \]

(6)

Young's modulus of the optical glass sample is determined through Eq. (3) and (4):

\[ E = \frac{P \Delta \xi^2}{n \lambda I} = \frac{64P \Delta \xi \cos \alpha x^2}{\pi D^3 n \lambda}, \]

(7)

where \( x_n \) is the position of the \( n \)th bright fringe on the axis of the beam (\( y=0 \)) and \( D \) is the diameter of the tested sample. The shear modulus of the optical glass \( G = E/2(\nu+1) \) and sample rigidity \( R = EI \) are then calculated.

4. Results The interferograms of three beams made of different type of optical glass were analysed. The interferograms were enlarged and scanned by a Hewlett Packard scanner. The mean value of fringe slope \( \gamma \) and the position of the first ten bright fringes on the axis of the beam \( (y=0) \) were estimated from the scanned computer-enhanced images. The beams were of equal diameter \( D=15\pm0.05 \text{ mm} \) and the applied force \( P=2.453 \text{ N} \) was caused by a weight of mass \( m=250\pm1 \text{ g} \). The alteration of force application point between the exposures in all cases was \( \Delta \xi=30\pm0.1 \text{ mm} \) and the angle of the loading construction is \( \alpha=37.83\pm0.025 \text{ deg} \). The obtained quantitative values of Poisson coefficient \( \nu \), Young's modulus \( E \), shear modulus \( G \) and the rigidity \( R \) for the examined optical glasses are listed in Table 1. The relative accuracy of the obtained values derived through the logarithmic differential method is about 3%. The results are in good agreement with published data [3], which confirms the applicability of the method. The last, besides that, has the advantage of the interferometric precision, and the possibility of local estimation of the sample characteristics.

Table 1. Values of the obtained material characteristics.

<table>
<thead>
<tr>
<th>Optical glass</th>
<th>( \gamma ) deg</th>
<th>( \nu )</th>
<th>( E \times 10^9 \text{ Pa} )</th>
<th>( G \times 10^9 \text{ Pa} )</th>
<th>( R \times 10^6 \text{ N.m}^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>F4</td>
<td>42.96</td>
<td>0.199</td>
<td>5.592</td>
<td>2.332</td>
<td>138.96</td>
</tr>
<tr>
<td>BK7</td>
<td>43.62</td>
<td>0.227</td>
<td>8.074</td>
<td>3.290</td>
<td>200.63</td>
</tr>
<tr>
<td>SK16</td>
<td>44.51</td>
<td>0.266</td>
<td>8.025</td>
<td>3.169</td>
<td>199.42</td>
</tr>
</tbody>
</table>

The index of refraction of refractive indices of plastic materials was determined using the standard test methods: methacrylate (PMMA), polystyrene (PS), copolymer (NAS), styrene-acrylonitrile. The properties of plastics are rather good for important spectral areas of plastic optics and regions at wavelengths 400-1100 nm. Some of their optical transmission, refraction, and dispersion characteristics are given first. The principles and procedures for determining the properties of plastics are suitable for well-known Abbe refractometer is utilized and operating at just the sodium D line. The design projects. The OPs indices of refraction were measured with a Zeiss Pindfich-Refeke refractometric prism and a new VOF3 refractometric prism requires OPs samples having a solution of zinc chloride \( (\nu_2 = 1.51) \) for calculation. PS and PC are recommended [3].

In this paper we present the refractive indices of plastic materials for effective method and device for OPs and the OPs materials are analysed and used for...