DETERMINATION OF STRESS PROFILES IN OPTICAL-FIBRE PREFORMS

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A computational technique is presented for the nondestructive determination of the radial, axial and tangential stress profiles in optical-fibre preforms. Optical retardation which arises as a consequence of the photoelastic effect is the basis for the technique. The stress profiles are obtained by first evaluating and then numerically differentiating indefinite integrals defined on the optical retardation profiles.

Introduction: A knowledge of the stress profiles in optical-fibre preforms is important because of the effect of the stresses on the refractive-index profile[1] and also on the fibre birefringence.[2] The stress profiles can be determined by exploiting the photoelastic effect, and previously this effect has been used to obtain the thermal expansion coefficient profiles.[3] Recently, methods to obtain the stress profiles have also been presented,[4–6] but the technique in Reference 6 depends on differentiation of experimental data and this technique tends to amplify the errors inherent in the data.[7] This problem can be alleviated by numerically differentiating indefinite integrals defined on the optical retardation data. Here, results are presented based on this alternative technique.

Stress profiling technique: The experimental set-up used to obtain the retardation data is shown in Fig. 1*a*. A polarised laser beam with its principal axes orientated at 45° to the axial

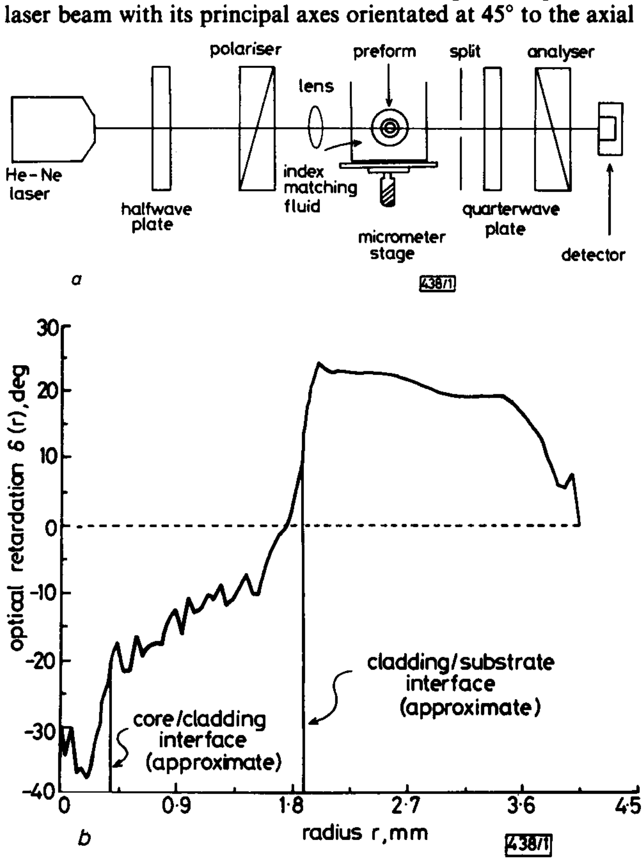

Fig. 1

a Schematic diagram of experimental set-up
b Experimental optical retardation profile of a single-mode preform

direction of the preform passes through the preform, experiences retardation due to the photoelastic effect and is incident on a PIN photodiode. The retardation $\delta(x)$ is obtained as twice the angle necessary to rotate the analyser for a minimum intensity.[3,8] A retardation profile of a single-mode preform obtained in this way is shown in Fig. 1*b*.

For a circularly symmetric structure, it can be shown[4] that the radial stress can be obtained as an indefinite integral defined on the $\delta(x)$ data. Thus

$$\sigma_r(r) = \frac{\lambda}{2\pi^2 C r^2} \int_r^R \frac{x\delta(x)\,dx}{(x^2 - r^2)^{1/2}} \tag{1}$$

Note that this equation does not involve the direct differentiation of the experimental data. The axial stress then follows by numerically differentiating the radial stress[5] using Reference 9:

$$\sigma_z(r) = \frac{1}{r}\frac{d}{dr}\left[r^2 \sigma_r(r)\right] \tag{2}$$

Also, for completeness, the tangential stress is

$$\sigma_\theta(r) = \sigma_z(r) - \sigma_r(r) \tag{3}$$

In this way, the radial-stress profile is obtained automatically without a differentiation. Furthermore, the experimental data is smoothed before the differentiation of eqn. 2 is applied to obtain the axial stress.

Results: The radial and axial stress profiles obtained from eqns. 1 and 2 and the data of Fig. 1*b* are shown in Figs. 2*a* and *b*, respectively. In order to provide a crosscheck of the

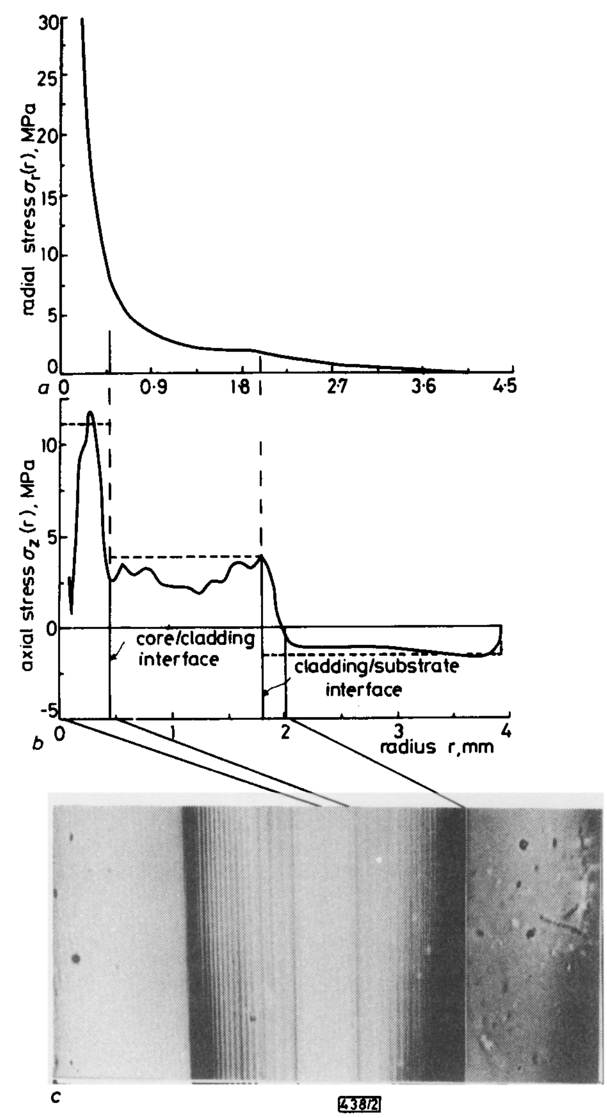

Fig. 2

a Radial stress profile
b Axial stress profile: solid line—reconstructed; dashed lines—calculated from simple three layer analysis
c Photograph of optical retardation pattern obtained using a mercury vapour light source and with the analyser and polariser crossed to give extinction for a zero-stress condition. Thus brightness gives a measure of stress

axial stress profile three methods were used. First, a refractive-index profile was obtained[10] for direct comparison,[6] and this is shown as Fig. 3 (inset to Fig. 2b). It can be seen that good correlation is obtained.

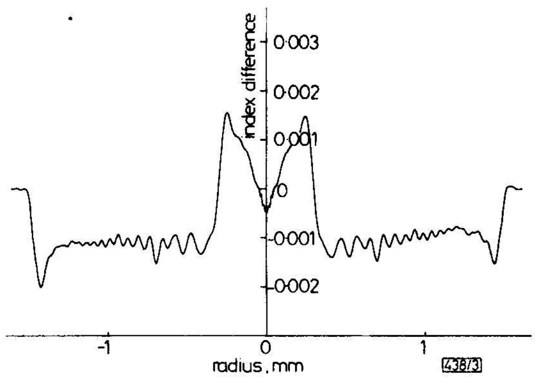

Fig. 3

Secondly, using a simple three-layer analysis,[3] the thermal expansion coefficient was calculated at the core centre, core/-cladding and cladding/substrate interfaces. From the measured values of the retardation at these points of $-32°$, $-18{\cdot}4°$ and $22{\cdot}8°$ the thermal expansion coefficients are calculated to be $\alpha_{core} - \alpha_{clad} = 1{\cdot}4 \times 10^{-7}$/deg and $\alpha_{clad} - \alpha_{sub} = 0{\cdot}6 \times 10^{-7}$/deg. The axial stress within these regions can thus be calculated as 11 MPa, 4 MPa and $-1{\cdot}4$ MPa, respectively. It can be seen that these values (marked as dashed lines) agree favourably with those in Fig. 2b.

Finally, the axial-stress profile was verified qualitatively. The He-Ne laser was replaced by a mercury vapour lamp and the analyser was crossed with the polariser to give extinction for a zero-stress condition. This result is shown in Fig. 2c, and here the brightness provides a measure of the axial stress. The reduced stress in the core centre, visible as the central grey stripe, is due to dopant outdiffusion. Furthermore, it can be seen that a dark band indicating zero or low stress exists at the cladding/substrate interface due to the transition from tensile to comprehensive stress. Finally, the successive dark and light bands correspond to the cladding layers. All these features are mirrored in the reconstructed axial stress profile of Fig. 2b. Consequently, this final method provides a quick, visual inspection of the axial stresses present in a preform.

Conclusions: A computational technique has been presented which enables the stress profiles to be evaluated directly from optical retardation data. The technique is based on first evaluating and then numerically differentiating indefinite integrals defined on the retardation data. The method provides a useful alternative for reconstructing stress profiles from optical retardation data.

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