Simultaneous Elastic and Photoelastic Calibration of Birefringent Orthotropic Model Materials

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ABSTRACT

Transmission photoelastic analysis of composite models has been shown in recent years to be a viable stress analysis method for composite structures. However, difficulties in the fabrication of the model materials require the development of efficient mechanical and optical calibration procedures. In this paper, the methods for measuring elastic and photoelastic constants of composites are briefly reviewed. Then a new method, utilizing a relatively small calibration specimen, is described. In this method, electrical resistance strain gauges are mounted at selected points of a half-plane model and photoelastic measurements and strain readings are simultaneously taken. The data are processed by a least-squares procedure to yield the elastic and photoelastic constants. Comparison of results obtained by the proposed method with the results from conventional tests shows good agreement.

INTRODUCTION

Photo-orthotropic-elasticity or the application of transmission photoelastic techniques by birefringent orthotropic model materials, is now a feasible method for the stress analysis of composite structures. The developments in this area have been reviewed by the author.\(^1\) Difficulties in the fabrication of transparent composites require the model materials to be conserved through the mechanical and optical calibration processes. The model materials have to be calibrated mechanically and optically to
establish the four independent in-plane elastic constants and the three fundamental photoelastic constants. A straightforward procedure for both elastic and photoelastic calibration makes use of tensile coupons. But these tensile coupons, especially since they include off-axis specimens, can deplete a relatively small sheet of the model material. Compared to isotropic model materials, there is a greater need to calibrate each sheet of a composite birefringent model material as variations in fibre volume fraction, thickness, etc., can influence the properties very significantly.

The present investigation resolves the calibration difficulties by making use of a relatively small calibration specimen to simulate an orthotropic half-plane subjected to a concentrated edge load. The theoretical stress distribution is known in closed-form. Electrical resistance strain gauges, mounted at selected points on the model, provide the data for obtaining the elastic constants. Photoelastic measurements taken from one-half of the model provide the data for obtaining the photoelastic constants. The details of the proposed method are described in the following sections, after a brief review of existing methods of elastic and photoelastic calibration.

**MEASUREMENT OF ORTHOTROPIC ELASTIC CONSTANTS**

The measurement of $E_L$, $E_T$, $\nu_{LT}$ and $\nu_{TL}$ is straightforward, using two tensile specimens with the specimen axes oriented along the major and minor symmetry axes, L, and T, and two strain gauges on each specimen. The determination of the in-plane shear modulus is difficult. A number of test specimens have been proposed by researchers, without any agreement regarding the best. Torsion of a thin-walled circular cylinder yields an accurate shear modulus but the test specimens are difficult and expensive to fabricate. The picture-frame specimen requires the attachment of reinforcing boundary members which result in stress concentrations. Byron\(^2\) did not observe a state of pure shear in a photoelastic study of the picture-frame specimen. The rail shear test was originally proposed for isotropic materials and later adapted for composites; analysis\(^3\) has shown that the actual stresses obtained in the specimen may be different from those assumed by dividing the applied load by the area. The cross-beam shear test, in which a cruciform shaped specimen is subjected to reversed flexural loading, has been shown\(^4\) to result in a stress state which deviates considerably from predictions based upon an elementary bending analysis. The slotted-tension coupon is a tensile specimen which is subjected to a transverse stress and the stress-diffusion effects in the transverse direction