

Calibration of PhotoStress® Coatings

Introduction

In order to translate measured fringe orders in a PhotoStress® coating into strains or stresses in the coated test object, it is always necessary to introduce the strain-optic sensitivity of the coating. In *reflection* photoelasticity, the basic relationship between strain and fringe order is:

$$\epsilon_1 - \epsilon_2 = \frac{N\lambda}{2tK} = N \times f \quad (1)$$

where: ϵ_1, ϵ_2 = principal strains, in/in (*m/m*)

N = fringe order, or number of wavelengths of relative retardation

λ = wavelength of tint of passage in white light, taken as 22.7×10^{-6} in (*575 nm*)

t = coating thickness, in (*m*)

K = strain-optic coefficient of the photoelastic plastic (dimensionless)

f = fringe value of the plastic coating, in/in (*m/m*) per fringe

It is important to note the distinction between the coefficients K and f . The strain-optic coefficient K defines a fundamental property of the PhotoStress material itself, and is independent of the plastic thickness or the length of the light path. The fringe value f specifies the strain-optic sensitivity of a particular PhotoStress coating (i.e., the difference in principal strains which will produce one fringe in that coating). As shown by Eq. (1), the fringe value accounts for the thickness of the coating, the fact that the light ray traverses the coating twice in reflection photoelasticity, and, finally, the nature of the light source. For typical PhotoStress plastics used in the stress analysis of structural materials, K varies from 0.08 to about 0.15, with the larger coefficients corresponding to the more optically sensitive materials. The fringe value f can be adjusted (by selection of the coating thickness) to suit the stress analysis problem; but, for most practical cases, will fall in the range of 500 to 3000 $\mu\text{in/in}$ ($\mu\text{m/m}$) per fringe, with the low fringe values representing the more sensitive coatings.

The nominal values of K for all PhotoStress coating materials are given in Document 11222. From these, the

fringe value for any specific coating can be calculated once the thickness is known ($f = \lambda/2tK$). For greater accuracy, however, a specimen from each sheet of PhotoStress plastic, whether precast or contourable, should be calibrated for strain-optic sensitivity.

Calibration Procedure

The simplest method of calibrating a PhotoStress coating is to use the Model 010-B cantilever calibration fixture. This procedure is now incorporated into our PSCalc software; there is no requirement for manual calculations. The calibrator, shown in Figure 1, consists basically of a rigid cast frame for mounting and deflecting a cantilever beam. The beam is loaded at its free end by a precision micrometer, permitting accurate measurement of the deflection. When a beam, to which a specimen of PhotoStress coating has been bonded, is mounted in the calibrator and then deflected by a predetermined amount, a known state of strain is imposed upon the coating. Measurement of the resultant birefringence in the coating provides the necessary information for relating fringe order to principal strain difference. Following are the step-by-step procedures for performing the calibration and reducing the data.



Figure 1. Model 010-B Calibrator

Installation of Calibration Specimen on Beam

1. The standard beam for use with the calibrator is a 2024-T4 or 7075-T6 (or equivalent) aluminum-alloy bar with the following dimensions (Figure 2): $0.250 \pm 0.001 \times 1.0 \times 12.5$ in ($6.35 \pm 0.025 \times 25 \times 318$ mm).

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Verify that the thickness of the bar is within the specified tolerance, then clean and degrease the bar thoroughly as described in Application Note IB-223.

2. Cut a calibration specimen 1.0 x 3.0 in (25 x 76 mm) from the sheet of PhotoStress coating. In the case of contoured coatings, this is done with scissors, immediately after removing the sheet from the casting plate, while the plastic is still soft and controllable. The calibration specimen is then placed back on the casting plate and allowed to polymerize completely in the form of a flat strip. When working with precast rigid sheets, the calibration specimen is removed from the sheet with a jigsaw.

Before bonding the specimen to the calibration beam, measure and record the coating thickness, then clean and degrease the specimen thoroughly.

3. Mix a small batch of adhesive (the same used to bond the parent plastic to the test part), and apply a thin layer of the adhesive to the calibration beam where the coating is to be bonded. The calibration specimen should be located on the beam as specified in Figure 2.
4. Apply the calibration strip to the beam surface by first placing one end in contact with the adhesive (holding the other end up at a small angle), and then pressing down progressively along the length of the strip, squeezing out the excess adhesive in the process.
5. Finish the installation by building a fillet of adhesive at each end of the strip as shown in Figure 2. Allow the adhesive to cure at room temperature for the time specified in the instructions for that adhesive (see Application Note IB-223).

Calibration Measurements

1. Back the calibrator micrometer out sufficiently to clear the calibration beam when it is mounted in the fixture.
2. Insert the beam all of the way into the mounting clamp, center the free end of the beam between the siderails of the calibrator, and *clamp firmly* in place.
3. Using a fine-pointed grease pencil, marking pen, or scribe, mark the coating with a small cross + on the centerline of the beam and directly in line with the index lines on the siderails of the calibrator as shown in

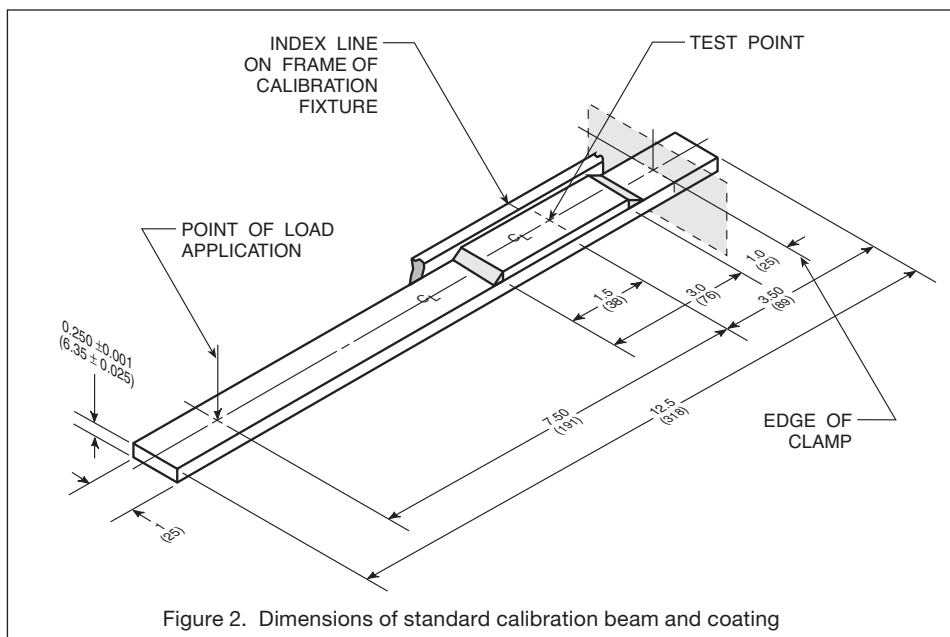


Figure 2. Dimensions of standard calibration beam and coating



Figure 3. LF/Z-2 Polariscope and Model 010-B Calibrator set up for normal-incidence fringe-order measurements

Figure 2. This will be the calibration point.

4. Set up the calibrator and LF/Z-2 Polariscope for normal-incidence measurements (Figure 3). Observe the coating at the calibration point while slowly rotating the micrometer head. When the spindle of the micrometer contacts the beam, slight birefringence will start to appear in the coating. Continue rotating until the micrometer reading reaches a convenient round number (say, 0.025 or 0.050 in).

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Note: For simplicity of presentation, U.S. customary units are generally used in the remainder of the procedure and in the numerical example. The same procedure applies, of course, when dimensions and deflections are expressed in metric (SI) units. For instance, if the calibrator is equipped with a metric micrometer having 0.5 mm travel per revolution of the spindle, the initial deflection points might be taken at a micrometer reading of 0.5 or 1.0 mm.

Align the long axis of the Model 832 Compensator with the long centerline of the calibration beam.

5. Accurately measure the fringe order at the premarked calibration point for the initial micrometer setting, and record the result.

Rotate the micrometer head four full turns (0.100-in deflection increment), and make a new fringe-order measurement. Repeat the operation, making a measurement after every 0.100-in increment of deflection, and continuing for four increments to obtain a total of five readings, including the preload measurement at the initial micrometer setting.

Tabulate the deflection versus the fringe order as illustrated in the Numerical Example (page 5).

Note: When calibrating a very thin coating, a total deflection greater than 1/2 in (13 mm) may be required to obtain readily measured fringe orders. However, caution should be exercised in the use of larger deflections to avoid exceeding the yield strength of the

beam. For this reason, the maximum deflection should be limited to 3/4 in (19 mm).

Data Reduction

1. Plot the data on graph paper to display fringe order as a function of beam deflection (see Figure 4 and the Numerical Example). Draw the best-fit straight line through the data. The plotted points should fall on or very close to the line; and, if not, the measurements should be repeated with greater care, making certain that the beam is tightly clamped and centered in the calibrator.
2. Graphically or analytically (least-squares method) determine the slope of the line $\Delta N/\Delta D$ in fringes per inch of deflection.
3. Refer to the calibration graph, Figure 5, and enter the graph with the slope $\Delta N/\Delta D$ from Step 2, and project horizontally to an intersection with the vertical projection from the coating thickness (as measured before installing the specimen on the beam). Read the strain-optic coefficient K and/or the fringe value f directly from the graph, interpolating in each case as necessary.

Note 1: The calibration graph, Figure 5, is based upon the beam and calibration strip dimensions specified in Figure 2, and includes all corrections for deflection-controlled bending.

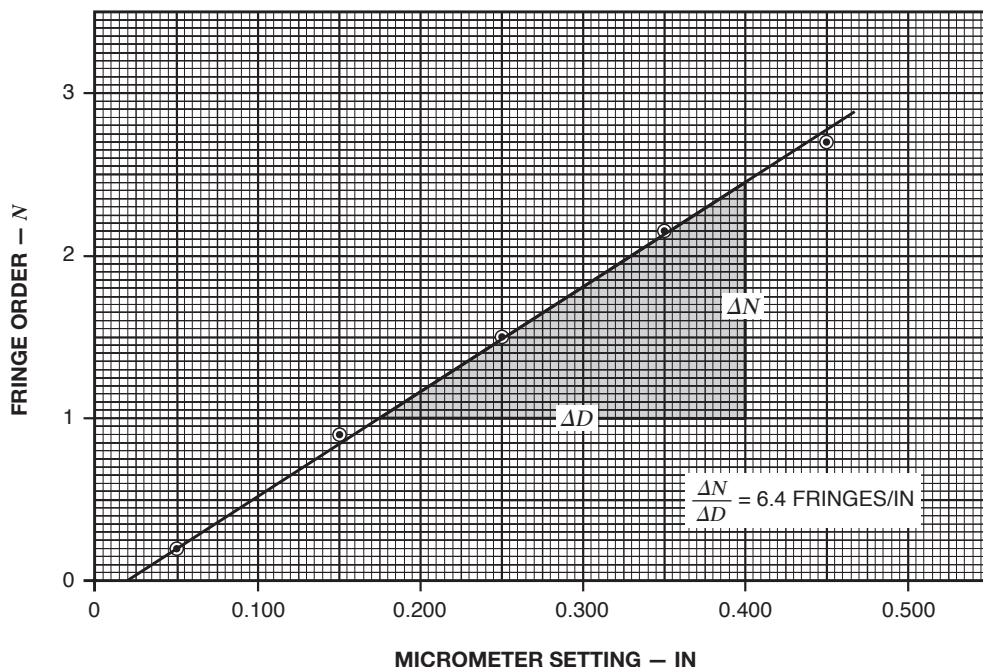


Figure 4. Graph of fringe order versus micrometer setting for determining $\Delta N/\Delta D$

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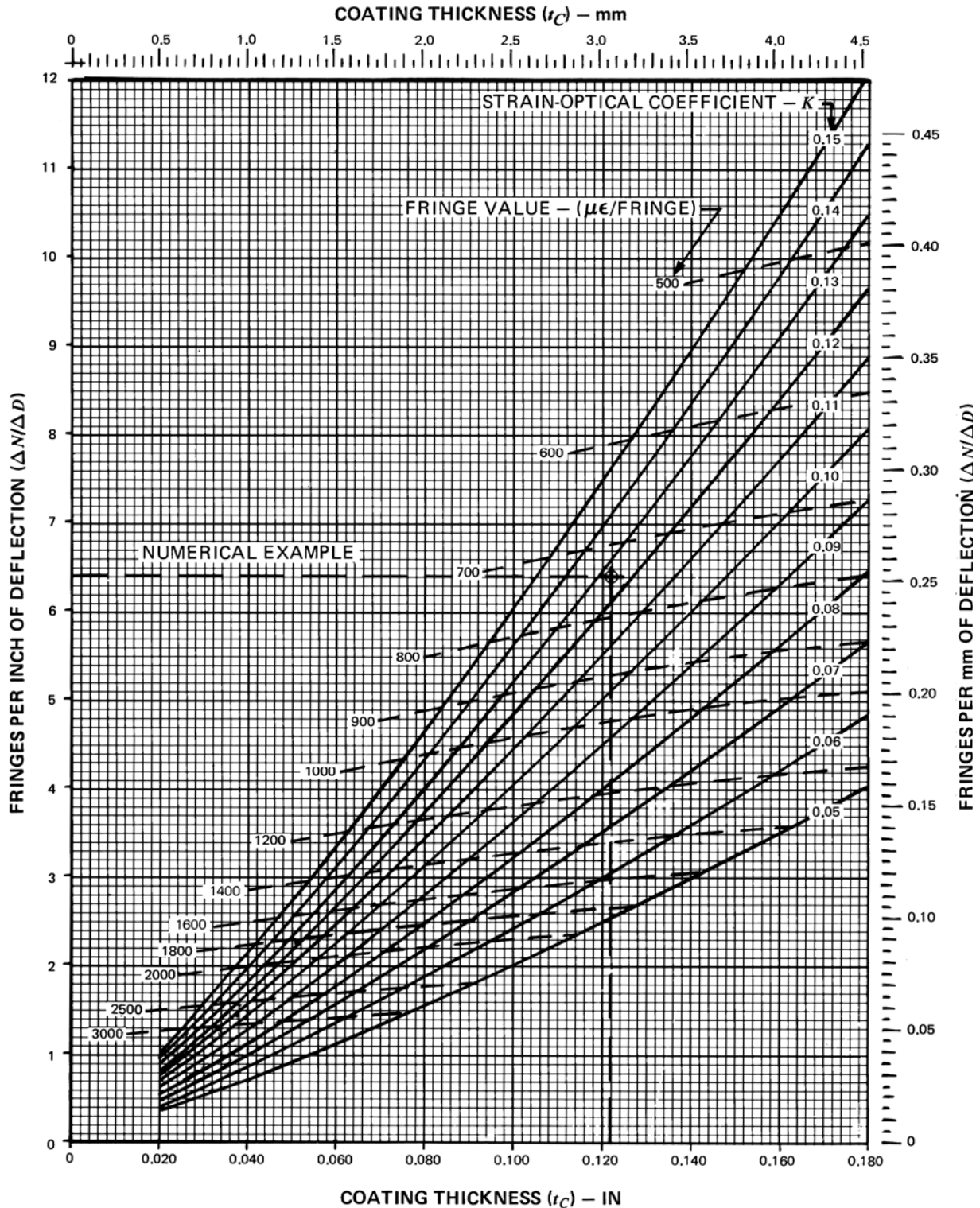


Figure 5. Calibration chart for PhotoStress coatings

TECH NOTE

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Note 2: Assumed in the development of Figure 5 was a representative adhesive thickness of 0.003 in (0.075 mm). If the adhesive is noticeably thicker or thinner than this, and if the effort is warranted by the accuracy requirements, the coefficient K can be corrected with the following relationship:

$$K = K' \left[1 + \frac{2(t'_A - t_A)}{t_B + t_C} \right] \quad (2)$$

where: K' = strain-optic coefficient read from Figure 5 for measured data

K = actual (corrected) strain-optic coefficient

t'_A = standard adhesive thickness upon which Figure 5 is based [0.003 in (0.075 mm)]

t_A = actual adhesive thickness

t_B = beam thickness [0.250 in (6.35 mm)]

t_C = coating thickness

To determine the actual adhesive thickness, measure the overall thickness of the coated beam with a micrometer and subtract away the premeasured thicknesses of the bare aluminum beam and the calibration strip.

Numerical Example

A calibration strip 0.122 in thick is bonded to the aluminum calibration beam as specified in Figure 2, and the following measurements are made:

| Micrometer Reading (in inches) | Fringe Order |
|--------------------------------|--------------|
| 0.050 (initial preload) | 0.20 |
| 0.150 | 0.87 |
| 0.250 | 1.49 |
| 0.350 | 2.14 |
| 0.450 | 2.68 |

These data are plotted in Figure 4, where a best-fit straight line has been constructed. The graphically measured slope of the line $\Delta N/\Delta \Delta$ is 6.4 fringes per inch of deflection.

Note: When needed for greater accuracy, a slightly better estimate of the slope can usually be obtained with the least-squares method. In this case, for instance, the slope calculated by this means is 6.35 fringes per inch of deflection.

Entering Figure 5 at 6.4 fringes per inch and 0.122-in coating thickness, and interpolating,

$$K = 0.126$$

and

$$f = 740 \mu\text{in/in}$$

The measured overall thickness of the coated beam is 0.378 in, from which the adhesive thickness is:

$$t_A = 0.378 - 0.122 - 0.250 = 0.006 \text{ in}$$

Substituting in Eq. (2) to correct the strain-optic coefficient for nonstandard adhesive thickness,

$$K = 0.126 \left[1 + \frac{2(0.003 - 0.006)}{0.250 + 0.122} \right]$$

$$K = 0.124$$

Removal of Coating from Calibration Beam

Heat the coated beam to about +210°F (+100°C). This will soften the plastic enough so that it can be separated from the beam with a knife blade applied to the bond line. The adhesive remaining on the beam can be removed with an epoxy stripping solution, or by sanding with coarse abrasive paper.

Clean the beam thoroughly for the next calibration operation, and measure the thickness to ensure that it is within the specified limits [0.250 ± 0.001 in (6.35 ± 0.025 mm)].

References

Refer to the publications listed below for detailed information on PhotoStress coating materials, and instructions for their proper use.

“PhotoStress Coating Materials and Adhesives,” located on our website at www.vishaypg.com/doc?11222

Application Note IB-221, “Instructions for Casting and Contouring Photoelastic Sheets,” located on our website at www.vishaypg.com/doc?11221

Application Note IB-223, “Instructions for Bonding Flat and Contoured Photoelastic Sheets,” located on our website at www.vishaypg.com/doc?11223

Post, D., and F. Zandman, “The Accuracy of Birefringent Coating Method for Coatings of Arbitrary Thickness.” *Experimental Mechanics* 1: 21-32 (January 1961).

Zandman, F., S. Redner, and E. Riegner, “Reinforcing Effect of Birefringent Coatings.” *Experimental Mechanics* 2: 55-64 (February 1962).

Zandman, F., S. Redner, and J. W. Dally, “Photoelastic Coatings,” Ames, Iowa: Iowa State University Press, 1977.