Abstract. In this paper, image processing techniques are discussed for stress analysis of the photoelastic fringes. The image processing techniques include fringe sharpening, fringe multiplication, and phase measuring technique. Gradient descent process is used for fringe sharpening. In fringe multiplication, fringes are multiplied twice for limited fringe order. Phase measuring technique is used to separate isoclinics and isochromatics. The results of image processing techniques show that they are quite useful for stress analysis in photoelasticity.

Keywords: Photoelasticity, Isoclinic Fringe, Isochromatic Fringe, Image Processing, Experimental Stress Analysis

1 Introduction

Photoelasticity is a reliable optical technology for stress analysis in mechanics [1]. Advance in a personal computer has facilitated use of photoelastic techniques. Image sharpening technique is applied to locating easily maximum or minimum values of the photoelastic fringes in this paper [2]. Fringe multiplication technique is used to identify the 1/4 order fringes [3]. In addition, 8-step phase measuring technique is presented to separate isochromatics and isoclinics from the photoelastic fringes [4]. All of algorithms in the techniques are implemented with Visual C++ of Microsoft that is convenient to use. Through optical experiment, the techniques are applied to the photoelastic specimen for stress analysis and assessed.

2 Photoelastic Fringe Sharpening and Multiplication

The sharpening algorithm based on gradient descent has been used in digital image processing [2]. The sharpening process is applied to isochromatic fringes. A comparison is made in Fig. 1(a). The upper half pattern in Fig. 1(a) is the original fringe while the lower half pattern is the sharpened fringe. It is clear that the half- and full-order fringes are processed properly to sharpened lines.
Fringes in photoelasticity can be multiplied for better analysis of stress [3]. The same specimen as for the fringe sharpening as shown in Fig. 1(a) is used in the fringe multiplication. The upper half pattern in Fig. 1(b) is the original fringe while the lower half pattern is the doubled fringe after multiplication. The effect of fringe multiplication is clearly visible along the intersection line between upper and lower fringe pattern.

![Fig. 1.](image)

**Fig. 1.** (a) Comparison of before- and after-sharpening. The upper half pattern is the original fringe while the lower half pattern is the sharpened fringe. (b) Comparison of before- and after-multiplication. The upper half pattern is the original fringe while the lower half pattern is the doubled fringe after multiplication.

### 3 Phase Measuring Technique for Separation of Isochromatics and Isoclinics

In photoelasticity, the principal stress directions and the principal stress differences are provided by isoclinics and isochromatics, respectively [3]. In this paper, phase measuring technique [4] is used to separate isochromatics and isoclinics from photoelastic fringes through a circular polariscope and photoelastic experiments are performed to verify this technique.

#### 3.1 Phase Measuring Technique

In the phase measuring technique, the output intensities of eight images, $I_1$ thru $I_8$, are used [4]. In these arrangements, the polarizer and the first quarter wave plate are fixed with angles 90 and 45 degrees, respectively, from the x-axis. These arrangements are, in comparison with prior published method [5], simple to use and take short time in actual data-acquisition.

The equations using $I_1$ thru $I_8$ are employed for the calculations of isoclinic $\alpha$ and fractional fringe order $\delta$ as
\[ \alpha = \frac{1}{2} \tan \left( \frac{I_3 - I_2}{I_1 - I_2} \right), \quad \delta = \tan^{-1} \left\{ \frac{(I_1 - I_2) \cos 2\alpha + (I_3 - I_2) \sin 2\alpha}{\frac{1}{2}[(I_4 - I_1) + (I_3 - I_2)]} \right\}. \] (1)

3.2 Assessment of Phase Measuring Technique

To assess the practical use of the developed method in this work, a stress-frozen disk under diametric compression, which is 45.2 mm in diameter and 4.0 mm thick made of epoxy, is used as the photoelastic specimen in the circular polariscope. Material fringe value and applied load at the stress freezing point are \( \sigma_f = 0.352 \) kN/m and \( P = 36.15 \) N, respectively.

Isoclinal phase map of \( \alpha \) using Eq. (1) is shown in Fig. 2(a). This isoclinic phase map of Fig. 2(a) is directly used for the calculation of isochromatic phase of \( \delta \) as shown in Fig. 2(b). In order to check the distributions of isochromatics quantitatively, unwrapped phase in Fig. 3(b) is obtained from the wrapped phase of isochromatics along a line A-A across the middle point of the upper half disk as shown in Fig. 2(b). Note that the wrapped phases of isochromatics in Fig. 3(a) are directly obtained from the wrapped isoclinic phases shown in Fig. 2(a).

![Fig. 2. Wrapped phases of (a) isoclinics and (b) isochromatics.](image)

The experimental results obtained from unwrapped isochromatics are exactly agreed to the manual measurements at the fringe centers as shown in Fig. 3(a). Figure 3(b) shows the wrapped isoclinic distributions along a line A-A in Fig. 2(a). The unwrapped isoclinic phases of Fig. 3(b) can be obtained by using unwrapped isochromatics of Fig. 2(b).

Results of the isoclinics along the line A-A in Fig. 2(a) are compared with those determined by the manual measurements as shown in Fig. 3(a). It is observed that the unwrapped isoclinics obtained by phase measuring technique are close to manual measurements.
Fig. 3. (a) Unwrapped andwrapped isochromatic phase distributions along line A-A indicated in Fig. 2. (b) Comparisons of isoclinic distributions by 8-step phase measuring technique and manual measurements along line A-A indicated in Fig. 2(a)

5 Conclusion

In this paper, image processing techniques are applied to stress analysis of fringes in photoelastic specimen. Gradient descent process is successfully used for the sharpening technique on the fringes. The fringes are multiplied twice for limited fringe order by use of dark- and light-field fringes. In addition, the phase measuring technique is shown to separate isoclinics and isochromatics. The validity of the phase measuring technique for separation of isoclinics and isochromatics is proved by use of photoelastic experiment.

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References