Measurement of Strain by Digital Shearography with a New Algorithm of Phase Calculation

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ABSTRACT: In this paper, digital shearography method has been used to measure the in-plane strain. One intensity is being recorded before loading and four intensities have been gotten after loading with the phase shifting method. With the subtraction of first intensity from the four intensities of after loading, four new intensities being calculated which from them the needed phase calculated and with use of this phase in the strain formula, the strain can be calculate. For this work, the modified Michelson system as a shearing tool is used. Testing specimen was an aluminum plate with the dimension of 35×35×1mm which is clamped in the boundary and has been loaded in the center. For the loading, a fixture has been made which has the ability of 3-micron displacement creation. For illumination on the specimen from two mutual and same directions, two diode lasers with the wavelength of 630 nm are used as the optical source. Taking into account that in the experimental measurement the conditions are real but are ideal in the numerical analysis, behavior of two graph of experimental measurement and numerical analysis is approximately the same. In the part of error analysis, the amount of relative error is approximately 18% determined.

1- Introduction

The newly developed shearography method, also known as 'Speckle Pattern Shearing Interferometry' (SPSI) is a coherent optical method of measurement and testing which is similar to holographic interferometry.

A method of obtaining pure in-plane strain in applying shearography uses two linearly independent directions of illumination (usually having identical reverse angles). The shearogram for both directions of illumination can be obtained by using the phase-shift technique [1].

The result of decreasing the phase map of both Shearograms yields a fringe pattern, depicting the pure in-plane strain component [2, 3]. Therefore, the pure in-plane strain component can be obtained directly from displacement data without numerical differentiation.

2- Methodology

As seen in Fig. 1, this procedure was performed for two lasers with identical and reverse angles:

However, the method used in this article is as follows: First, a pre-loading intensity is recorded. I

$$I_1 = 2I_0[1 + \gamma \cos \phi] \qquad (1)$$

And once the loading is done, four images will be recorded, using phase-shift technic.

$$
\begin{aligned}
I_{11} &= 2I_0[1 + \gamma \cos \phi] \\
I_{22} &= 2I_0[1 + \gamma \cos(\phi + \pi/2)] \\
I_{33} &= 2I_0[1 + \gamma \cos(\phi + \pi)] \\
I_{44} &= 2I_0[1 + \gamma \cos(\phi + 3\pi/2)]
\end{aligned}
\qquad (2)
$$

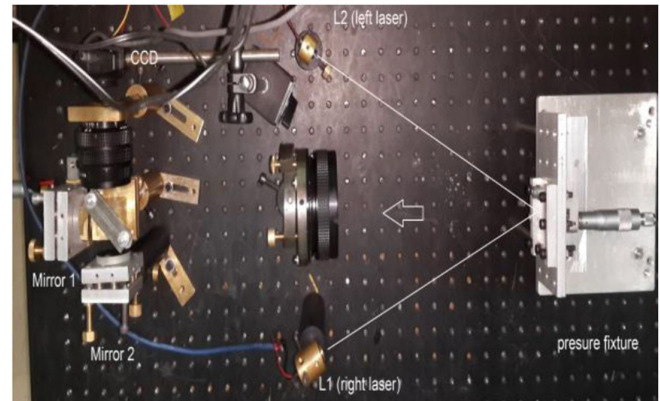Corresponding author, E–mail: r_moharami@znu.ac.ir

Figure 1. Illumination from two equal angles.

And then, each one of the intensities obtained after the loading is deducted from the intensity obtained before the loading, and thereby four new intensities are obtained.

$$
\begin{aligned}
I'_{11} &= |I_{11} - I_1| \\
I'_{22} &= |I_{22} - I_1| \\
I'_{33} &= |I_{33} - I_1| \\
I'_{44} &= |I_{44} - I_1|
\end{aligned}
\qquad (3)
$$

By using these four new intensities, a new phase is obtained.

$$\varphi = \frac{|I'_{22} - I'_{44}|}{|I'_{11} - I'_{33}|} \qquad (4)$$

The phase obtained from Eq. (4) is inserted in Eq. (5), in

which the shearing is in *x* direction [3].

$$\varphi_{+\theta} = \frac{2\pi\delta x}{\lambda}\left[\sin(+\theta)\frac{\partial u}{\partial x} + (1+\cos(+\theta))\frac{\partial w}{\partial x}\right] \qquad (5)$$

The same procedures are carried out for the laser with (-*θ*) angle.

$$\varphi_{-\theta} = \frac{2\pi\delta x}{\lambda}\left[\sin(-\theta)\frac{\partial u}{\partial x} + (1+\cos(-\theta))\frac{\partial w}{\partial x}\right] \qquad (6)$$

Where *v*, *u* and *w*, are respectively the components of the displacement vector in the direction of *x*, *y*, and *z*.

3- Results and Discussion

From the five images recorded before and after loading and using Eqs. (5) and (6), the step-by-step phase tensor for the recorded intensity data, using laser No 1 is obtained, according to Fig. 2.
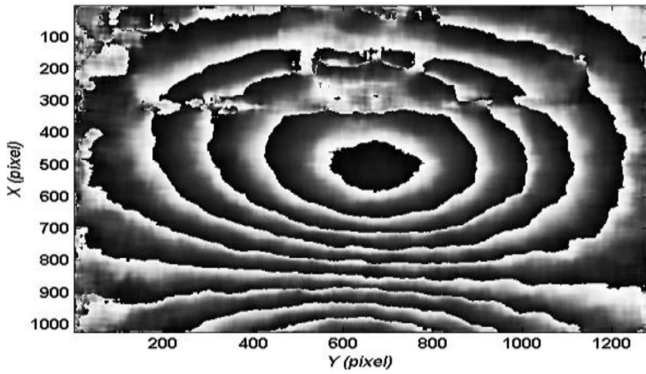
Figure 2. Final phase tensor obtained from the images taken with laser 1 (right), discontinuous phase.

The same procedures are repeated for the left-side laser (in identical loading).
By subtracting formula (5) from (6) relation (7) appears by which the pure in-plane strain is obtained.

$$\varphi_I = \varphi_{+\theta} - \varphi_{-\theta}\frac{4\pi\delta x (\sin\theta)}{\lambda}\frac{\partial u}{\partial x} \qquad (7)$$

By placing the shearing amount of *δx*=6 mm the laser wavelength (*λ* = 630 nm), the illumination angle (*θ*≈16 °) and the amount of phase obtained from Eq. (7), the pure in-plane strain is obtained, according to Fig. 3.
Assuming number 70 GPa for the elastic module and Poisson number 0.3 for the aluminum specimen and square elements for meshing outer regions of the specimen and triangular elements around the defect, the strain is calculated.
By comparing the results obtained from numerical and experimental analyses, it can be seen that the finite element analysis results also nearly confirm the experimental test results with a marginal error. Fig. 4 has made a comparison between these two analyses.
As can be seen the power in both measurements is and the maximum strain in both is close to number 11.5.
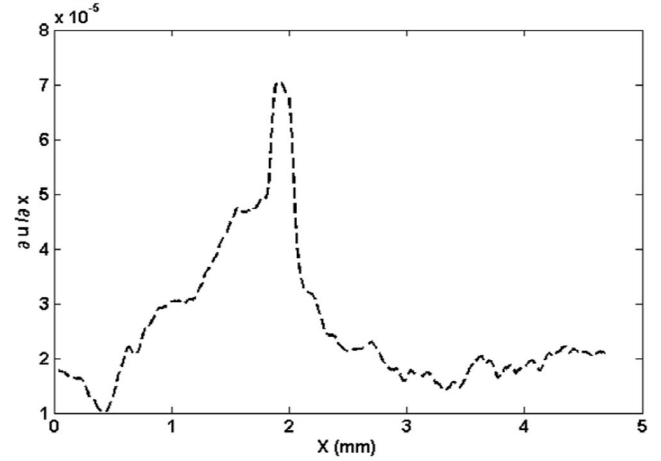
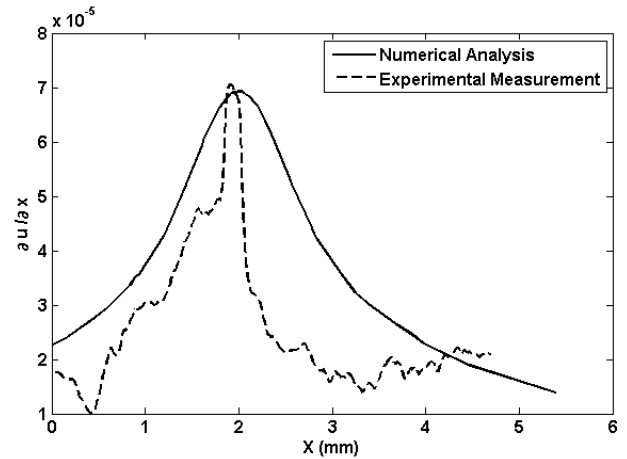**Figure 3. Graph of the pure in-plane strain component ($\partial u/\partial x$).**

Figure 4. Comparison of results obtained from numerical and experimental analyses.

4- Conclusions

In this study, non-contact optical shearography method along with the phase-shift method was used to measure in-plane strain component. Numerical analysis was carried out as a procedure for validation. To perform the tests, an aluminum specimen with dimensions of mm was used which had a defect at the center. And to apply the tensional displacement, a tensional fixture with a 3-micron accuracy was made. To apply the phase-shift method, an innovative phase calculating algorithm was used. Finally, the strain was measured, using digital shearography method whose results in shearing direction are shown in the graph.

References

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