Stress Comparison between Photoelasticity by a Polariscope Using a Light Source from an LCD Monitor and Strain Gauges

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Abstract

Photoelasticity is the method to analyze the stress, which causes the damage to structure or component. Therefore, the stress analysis is necessary in the design to prevent damage that may occur. Photoelasticity based on the refraction of light through the transparent material under applied load. A polariscope is a device to observe the stress distribution in the material. This study was aimed to construct a simple plane polariscope using an LCD monitor as a light source and verify the accuracy of constructed polariscope quantitatively. The specimen used in this experiment was a polycarbonate plate, which was machined into rectangular shape with circular hole at the center. The specimen was tested with five magnitudes of tension force. The principal stress differences obtained by photoelasticity were compared with those obtained by strain gauges. From the results, the average difference of the principal stress difference between the photoelasticity and strain gauges was 12.7 %. The results suggested the potential of using a simple plane polariscope with a light source from an LCD monitor for plane stress analysis.

***Keywords**: Photoelasticity, Plane Polariscope, Stress, Strain gauges*.

1. Introduction

In the design of mechanical parts or structure, many factors must be considered. Stress concentration is one of many problems that needs attention. Photoelasticity is one of the methods that can be used to analyze the stress in the specimen by using a polariscope to visualize the stress distribution. A plane type polariscope is one type of polariscopes that can observe the fringe pattern [1]. The plane type polariscope consisted of a light source, a polarizer and an analyzer. The light source emits the light passing through the polarizer to create the polarized light. The test specimen is placed between the polarizer and analyzer. The analyzer is used to observe the fringe pattern (Fig. 1). The liquid crystal display (LCD) monitor that is one component of computer set or laptop can emit the polarized light [2]. Therefore, the LCD monitor can be used for the polariscope to replace the light source and polarize filter (Fig. 2).

Sato *et al.* [3] created a tabletop system called PhotoelasticTouch, which could recognize tangible objects made from a transparent rubber by using an LCD table as a light source and an overhead camera. The system employed vision-

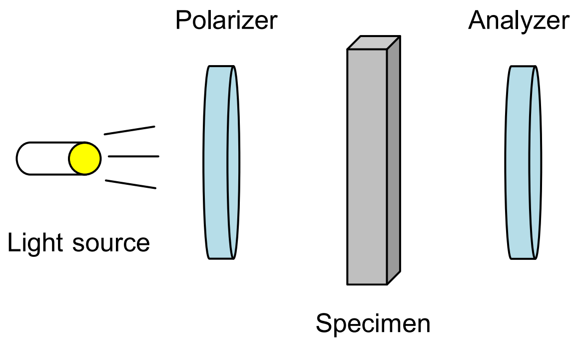

Fig. 1 Arrangement of a plane polariscope

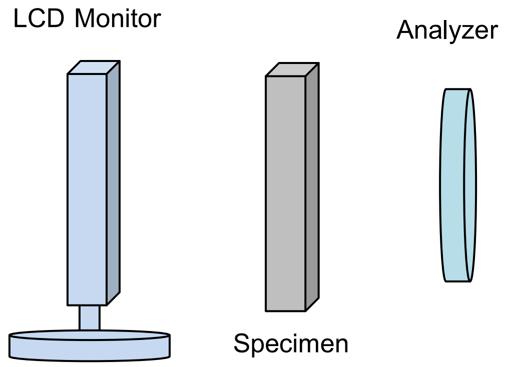

Fig. 2 A plane polariscope with an LCD monitor

based recognition techniques and the photoelastic properties of the transparent rubber to recognize deformed regions of the rubber. Pinit *et al.* [4] developed a compact table-top polariscope using a light emitting diode (LED) and an LCD monitor as light sources. However, only qualitative comparison between the images of stress field given from the developed polariscope and those from the standard polariscope was carried out. A strain gauge method is the method to measure the strains in the specimen and convert to stresses. It is used generally for stress analysis [4]. Therefore, this study was aimed to construct a simple plane polariscope using an LCD monitor as a light source and verify the accuracy of constructed polariscope quantitatively by comparing stresses based on the photoelastic method with the strain gauge method.

2. Materials and Methods

2.1 Photoelastic method

The photoelasticity is the method that can analyze the stress based on the light that emit through a transparent material. When stress occurs in the transparent material, it changes the refraction properties of the material. The principle stresses σ_1 and σ_2 in the material change the refractive index into two values. The difference between two values of refractive index was called birefringence. When light passes through the material, it will split into two light speeds. This produces interference of light waves, which generate the fringe pattern in the material when observed by a polariscope. For a plane polariscope, it shows the result by isochromatic fringe and isoclinic fringe pattern. Isochromatic fringe was used to calculate a principle stress difference, and isoclinic fringe was used to calculate the direction of principal stress. For plane stress problem, the principle stress difference can be calculated by Eq. (1) as shown [4].

$$\sigma_1 - \sigma_2 = \frac{Nf_\sigma}{t} \quad (1)$$

where $\sigma_1 - \sigma_2$ is a principal stress difference, N is a fringe order, f_σ is a material fringe value and t is the thickness of specimen.

The conventional plane polariscope consists of three main parts, light source, polarizer and analyzer. In this study, the experiment was set up as shown in Fig. 3. The light source and polarizer were replaced by the LCD monitor. The analyzer was applied from a polarized lens of a digital single lens reflect (DSLR) camera. The

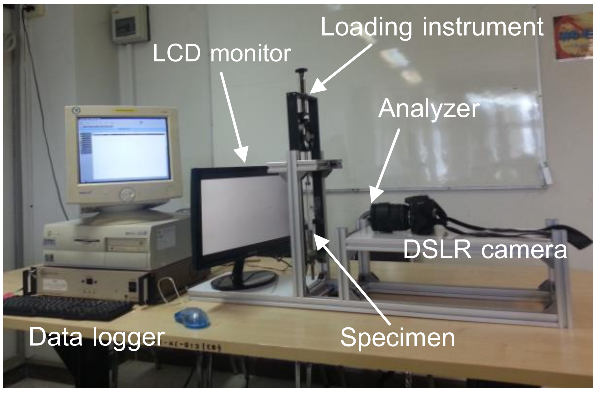

Fig. 3 Experimental set up

isochromatic fringe patterns were recorded using a DSLR camera Nikon D90. An image resolution was 12.3 megapixels.

The specimen used in this study was made of polycarbonate. The specimen was loaded by the loading instrument, which was applied from a load application device of the FL210 photoelastic demonstration equipment by Gunt Company (Fig. 4). The magnitude of force was measured by a dial gauge. One change of scale mark was equal to 5.54 N. In this study, the specimen was tested with five magnitudes of tension force consisted of 277 N, 304.7 N, 332.4 N, 360.1 N and 387.8 N. In the experiment, the specimen was mounted on the loading instrument that was installed between the LCD monitor and analyzer as shown in Fig. 3. The shape of the specimen was rectangular shape with a circular hole at the center. The thickness of the specimen was 3 mm. The size of the specimen was 165 mm long, 34 mm wide, and the circular hole diameter was 15 mm as shown in Fig. 5. The material fringe value (f_σ) of the polycarbonate specimen was calibrated before the experiment. The calibration was carried out using a 4-point bending test of the rectangular plate without the hole [5]. From calibration, the material fringe value was 7,172.15 N/m.

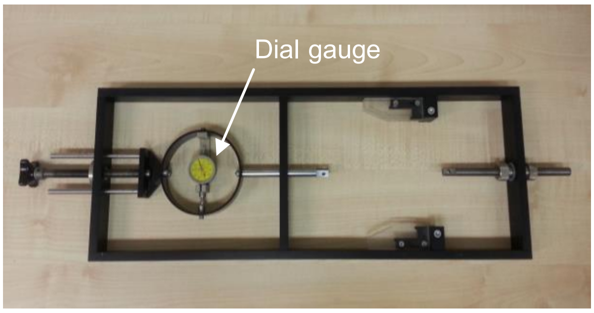

Fig. 4 Loading instrument

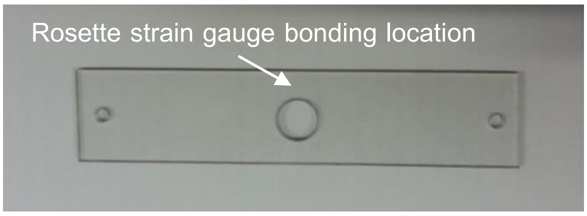

Fig. 5 A polycarbonate specimen

2.2 Strain gauge method

In this study, a rosette strain gauge Kyowa KFG-2-120-D17-11L1M2S was used to measure the strain in specimen during photoelastic experiment. The rosette strain gauge has three strain gauges arrange in 45°pattern as shown in Fig. 6. The location for rosette strain gauge bonding was next to the hole of the specimen (Fig. 5). The rosette strain gauge was connected to Wheatstone bridge circuits and the signals were recorded using a data logger Vishay 5100B.

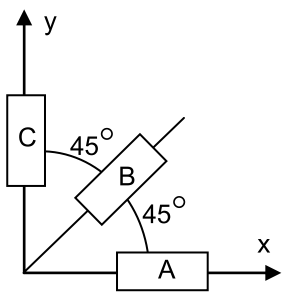

Fig. 6 A 45° strain rosette

The strains measured from three strain gauges ($\varepsilon_A, \varepsilon_B, \varepsilon_C$) were used to calculate the principal stress by Eqs. (2) and (3) as shown [6].

$$\sigma_1 = \frac{E(\varepsilon_A + \varepsilon_C)}{2(1-\nu)} + \frac{E}{2(1+\nu)}\sqrt{(\varepsilon_A - \varepsilon_C)^2 + (2\varepsilon_B - \varepsilon_A - \varepsilon_C)^2} \quad (2)$$

$$\sigma_2 = \frac{E(\varepsilon_A + \varepsilon_C)}{2(1-\nu)} - \frac{E}{2(1+\nu)}\sqrt{(\varepsilon_A - \varepsilon_C)^2 + (2\varepsilon_B - \varepsilon_A - \varepsilon_C)^2} \quad (3)$$

Where E was Young's modulus and ν was Poisson's ratio. The Poisson ratio of polycarbonate was 0.33 [7]. The Young's modulus of polycarbonate was obtained from a tensile testing of dumbbell-shaped specimens (Fig. 7) according to ASTM D638-10 standard [8]. Ten specimens were tested using tensile testing machine Instron 5900 (Fig. 8). The obtained average Young's modulus was 1.585 GPa.

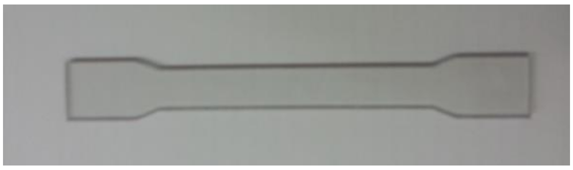

Fig. 7 A dumbbell-shaped specimen

Fig. 8 Tensile testing of the specimens

3. Results and Discussion

The isochromatic fringe patterns were recorded using a DSLR camera and converted to gray scale images as shown in Fig. 9. According to the symmetry of the specimen, the fringe order (N) at the location next to hole on opposite side of the strain gauge location for each loading could be counted for calculation as shown in Fig. 9. The fringe orders were substitute into Eq. (1) to calculate the principal stress differences ($\sigma_1 - \sigma_2$) as shown in Table. 1. It can be observed that the fringe orders did not change when applied force slightly altered. The strains measured from the rosette strain gauge were converted to the principal stress difference using Eqs. (2) and (3) as shown in Table. 2. The principal stress differences between photoelastic method and strain gauge method were compared as shown in Table 3.

Table. 1 The principal stress difference determined by photoelastic method

Force (N)	N	$\sigma_1 - \sigma_2$ (Pa)
277	2.5	5,976,791.7
304.7	2.5	5,976,791.7
332.4	3	7,172,150
360.1	3	7,172,150
387.8	3.5	8,367,508.3

Table. 2 The principal stress difference determined by strain gauge method

Force (N)	$\sigma_1 - \sigma_2$ (Pa)
277	6,438,427.5
304.7	6,471,624.8
332.4	6,489,773.7
360.1	6,513,133.7
387.8	6,543,844.1

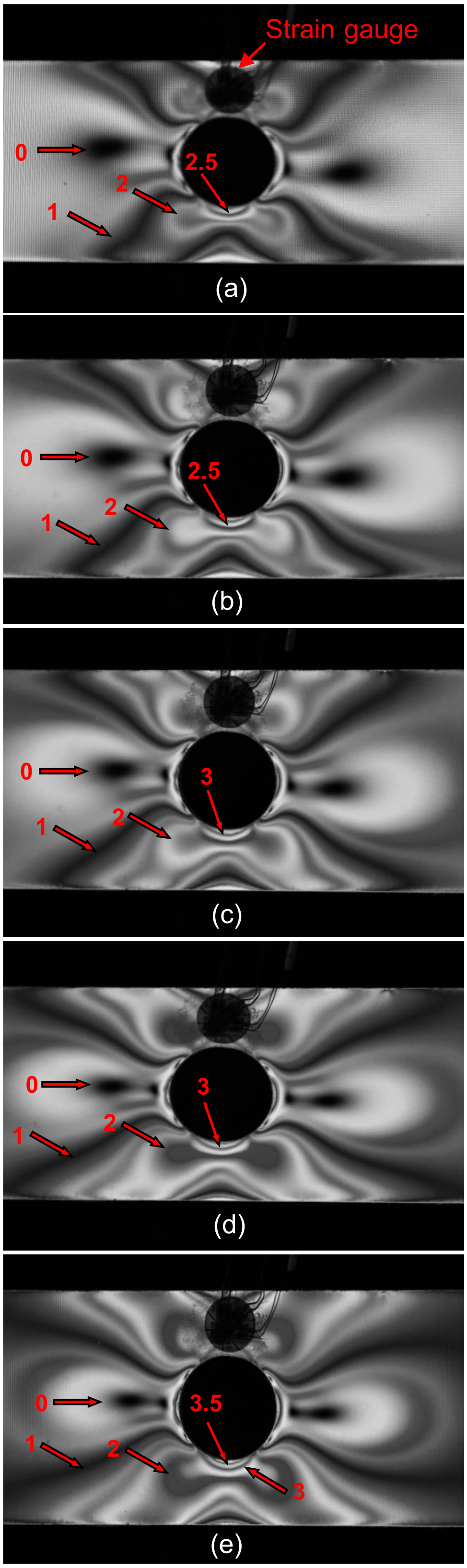

Fig. 9 Isochromatic fringe order of the specimen with tension force (a) 277 N, (b) 304.7 N, (c) 332.4 N, (d) 360.1 N and (e) 387.8 N

Table. 3 Comparison of principal stress differences between photoelastic method and strain gauge method

Force (N)	$\sigma_1 - \sigma_2$ (Pa)		Difference from strain gauge method (%)
	Photoelastic method	Strain gauge method	
277	5,976,791.7	6,438,427.5	7.17
304.7	5,976,791.7	6,471,624.8	7.64
332.4	7,172,150	6,489,773.7	10.51
360.1	7,172,150	6,513,133.7	10.12
387.8	8,367,508.3	6,543,844.1	27.87

4. Conclusion

The test results from photoelastic method and strain gauge method were compared. The principle stress differences measured by strain gauge method were finer than photoelastic method. When consider the percentage of the differences, the average difference was 12.7%. The results suggested the potential of using a simple plane polariscope with light source from an LCD monitor for plane stress analysis.

5. References

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