Elasto-optic Properties Investigation of Photoelastic Materials using Mach-Zehnder Interferometer(MZI)

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Abstract

This paper presents the investigation of elasto-optic material properties using Mach-Zehnder Interferometer (**MZI**). These material properties are investigated by way of the use of a non-contacted test scheme, by applying force on the photoelastic material in the MZI system. The interference signal that changes due to the applied force is detected by a detector, which it is changed optical signal to electronic signal and then displayed in voltage on the oscilloscope. Results of the applied force/stress are plotted against the interference signal intensity, the linear relationship is occurred with the one using Araldite. Results are used for some material properties study. The feasibility study of using such materials for force sensor application are also investigated and discussed.

Keywords: optical metrology, interferometry, photoelasticity

1. INTRODUCTIO

Optical techniques for measurement were widely used for years, the interferometric technique is the one of them that it is popularly used for optical measurement. Such instrument that uses interferometry is known as "**Interferometer**" which has several types of them. MZI is one of such types that is widely employed for optical measurement i.e. optical metrology. Recently, the use of MZI for electro-optic properties of electron-irradiated poly(vinylidene fluoride-trifluoroethylene) copolymer has been investigated, where a relatively good electro-optic effect is reported. Thus, this polymer may be used as a good candidate material for fast speed electro-optic modulator and switches [1]. One project concerning the use of a scanning laser beam in MZI for diffusion coefficient measurement , which the diffusion coefficients are measured and fitted comparing to the theoretical curves [2]. Some works had improved and developed the MZI to be more stabilized [3-4], where the system can be used either with free space or fiber optic systems. The one using fiber optic scheme is more practical work than the one using bulky system because such a system becomes simply and easy to use that it is become a portable instrument. The use of MZI fiber optic scheme is used to investigate the elasto-optic properties of SiON for pressure sensor application [5], while the another scheme is also used for photoelasticity study. The principle of the technique is that the change of the transmitted light signal through such material is observed and measured relatively to the applied pressure/stress [6]

The objective of this work is that we are looking for a simple, economic and compact instrument that can be used to investigate or measure the elasto-optic material properties, for examples, the repeatability, reproducibility and mechanical property of the industrial photoelastic materials. The elasto-optic properties of three different types of photoelastic materials have been selected and investigated by using MZI.

The polycarbonate (PC) is firstly employed in the system that the change in output intensity i.e. phase of traveling light, is observed by the coupling change of two polarization state in the interferometer. The polyvinylchloride (PVC) plate and the Araldite materials are also investigated using the same scheme. The potential of using such materials for sensor application are also investigated and discussed.

2. OPERATING PRINCIPLE

2.1 Photoelasticity

Generally, the optical property of photoelastic material changes when the induced stress is applied on the photoelastic material. This is affected by the changed of molecule position in material which is induced the change in optical path difference (OPD) i.e. phase of light. This phenomenon is caused the change in material birefringence known as "**photoelasticity**". Birefringence is induced on the material in load condition and observed when polarized light is propagated through the material by using a detector. Two components of polarized light with difference speed are induced due to the change of the material structure i.e. molecule in material. This is induced the phase change which is observed in term of output intensity. The phase delay or retardation of light in photoelastic material at a certain position of the principal stress axes, relatively change to the applied stress which is observed and measured.

2.2 Mach-Zehnder interferometer (MZI)

MZI is one of the interferometers that popularly use for fluid flow, heat transfer, and temperature distribution in plasma measurement. Furthermore, the use of MZI either in bulky or fiber optic scheme is now more practical application in measurement, where two beams of light are interfered, and then detected and measured. The interference signal is detected by using a detector, where the signal amplitude is displayed on the oscilloscope. The induced change in optical path difference i.e. phase is observed by the change of output intensity.

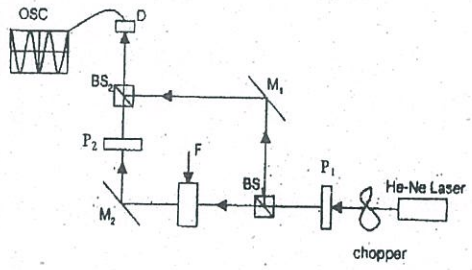


Figure 1 MZI system used in the experiment.

When light from a linearly polarized source e.g. He-Ne laser with wavelength of 632.8 nm, is launched into the MZI system via a beam splitter (BS_1) as shown in Figure 1. Output light is divided into two beams, then propagate to mirror M_1 and M_2, then travel through second beam splitter (BS_2). The direction of **BS_1-M_1-BS_2** is named as a reference beam, while the direction of **BS_1-M_2-BS_2** is employed as measuring arm. The change of optical path differences due to the applied object are caused by the change in output light intensities which are detected and observed. The output intensity is expressed as [4]

$$I = \frac{I_0}{2}[1+\cos(\frac{2\pi\Delta n\Delta L}{\lambda})] \quad (1)$$

I_0 and I is the input and output intensity respectively. Δn is refractive index i.e. birefringence, ΔL is optical path difference and λ is light source wavelength.

When load is applied on the material in MZI, the output intensity is given by

$$I = \frac{I_0}{2}[1+\cos(\frac{2\pi\sigma C_\sigma \Delta L}{\lambda})] \quad (2)$$

By substitution **σ=F/A** in equation (2), thus

(3)

F is the applied force. A and C_σ is the cross section area and the stress optic coefficient of the material respectively.

3. METHODOLOGY

3.1 Material preparation

The available photoelastic materials in this work are popularly used in industry such as polycarbonate (PC), polyvinychloride (PVC) and Araldite. The dimension of sample is considerably small comparing to the applied load and laser beam that is listed in Table 1.

Table 1. Dimension of the photoelastic samples use in the experiment.

Material	Wide (mm)	Length (mm)	Thick (mm)	Section area (A) (mm^2)
Polycarbonate (PC)	11	11	6	66
Polyvinylchloride (PVC)	11	11	4	44
Araldite	4	5	6	30

3.2 Load test set

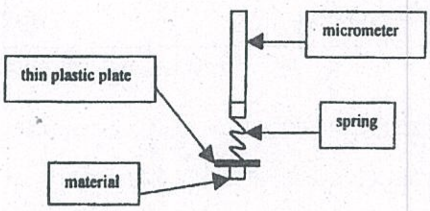
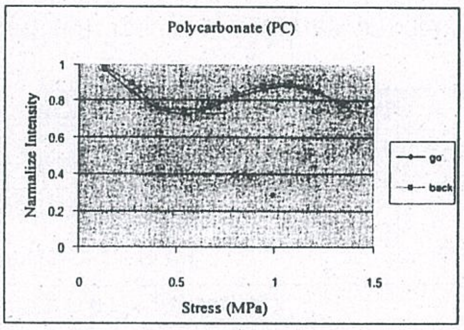


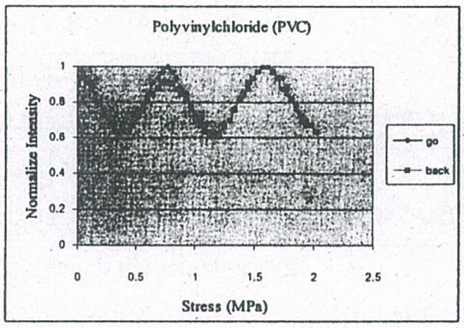
Fig. 2 A load test set schematic diagram.

Load test set is consisted of a standard micrometer that is aligned in vertical axis as shown in Figure 2. The applied external force can be arranged in the direction of principal stress axis, the value of force is carried out by using Hook's law i.e. Force equal to spring constant multiply by spring stretching distance. The smooth contacted point sample and spring can be managed by putting a thin plastic plate on top of the tested material. The calibration masses set can be used to produce the calibration stresses and curved.

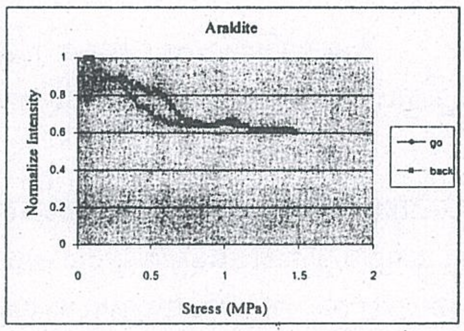
4. EXPERIMENT AND RESULTS



(a)



(b)



(c)

Figure 3 Results of the tested material are plotted between normalized intensities and stress: (a) PC, (b) PVC, and (c) Araldite.

The experimental arrangement is as shown in Figure 1 Light source use is a linearly polarized HeNe laser with output power and wavelength of 4 mW and 632.8 nm respectively.

To avoid the ambiguity of the detected signal and DC noise, a laser beam is chopped before entering into the MZI via a beam splitter (BS_1), then the equal divided signal amplitude is taken care by an input polarizer (P_1). One output beam is traveled along the reference arm, while another beam is propagated through the measurement arm i.e. object beam. The measurement of the change in phase of the object is performed by the second polarizer (P_2) with respect to the input polarizer. The output light form reference and object beams are combined by the second beam splitter (BS_2), then the interference signal is measured by a detector, and then displayed on the oscilloscope.

The measurement is carried out by the way that the reference MZI system is firstly initialized which it is no object is applied into the system, then the output signal is noted for reference data. The tested material is prepared and then pushed into optical system to perform the initial alignment and measurement. The normalized intensity is recorded during the measurement instead of signal amplitude in order to obtain generalized data.

The stress measurement is performed by using the relation as $\sigma = F/A$, where force $F = kx$, A is the material cross section area, k and x is the spring constant and its stretching value respectively. The optical output intensity i.e. amplitude is measured in term of voltage corresponding to the calibration masses set. The load and unload cases are employed in order to investigate the measurement hysteresis. Results of using three photoelastic materials namely PC, PVC and Araldite are investigated and shown in Figure The initial detected output intensities are recorded in term of voltages of 252, 68, and 332 mV respectively. Figure 3(a), the increasing of the applied force i.e. spring stretching, on PC of 0.5 mm is applied through the range of 5 mm on the micrometer corresponding to the applied forces of 9.05 and 90.5 N, and stresses of 0.134 and 1.344 MPa, respectively. Figure 3(b) and (c), the stretching distances of 0.1 and 0.05 mm are applied on the PVC and Araldite which is corresponded to applied forces of 1.8, 0.91 N and 90.5, 45.25 N, and stresses of 0.04, 0.03 MPa and 2.016, 1.478 MPa respectively.

5. DISCUSSION

From equation (2) and Figure 3, the relationship of the plotted values between normalized intensities and applied stresses have shown for PC and PVC materials having sinusoidal oscillation form with different oscillation frequencies. Araldite has shown the shorter oscillation period than the others, where the linear relationship between normalized intensity and applied stress of Araldite is occurred for some certain values. The constant intensity at large force of Araldite sample may be affected from the material elastic or compressive limit i.e. no longer elastic. The slope of Figure 3(c) is declined rapidly due to the small cross section area i.e. large stress, and the Araldite is softer than the other two materials. This is induced the higher oscillation frequency than PC and PVC, which is mean the hardening of material is roughly clarified by the frequency of oscillation. In this study, the highest hardness value of material is PC, and then PVC respectively, while the last one is the Araldite. The measurement hysteresis is also investigated, where the harder material i.e. PC and PVC has shown that the small hysteresis is occurred, while the Araldite sample has shown that the larger hysteresis is obtained either from PC or PVC. A softer material presents a longer relaxation time i.e. longer oscillation time. The linear relationship between normalized intensity and applied stress obtained form Araldite has shown feasibility of using to implement for force/load sensor application.

In conclusion, the experiment set up using MZI may be used to investigate the elasto-optic properties of the other photoelastic materials, where the value of elasto-optic properties may be compared to known samples, and predicted with some certain conditions.

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