Experimental Analysis of Thermal Stress Using Alternative Polariscope

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Abstract: Transmission photoelasticity is an experimental technique widely used for the analysis of stress and strain distribution within a model or prototype, this technique fairly provides the whole field information regarding the major stress concentration zone and gives valuable suggestion for the improvement in the design of component. Photoelasticity is widely used in the field of research and development of components which is to be used in unpredictable loading to improve the life-cycle of the component. In the study of photoelasticity related past work indicates that the effect of rise in temperature due to various reasons based on the kind of loading model have been neglected by the earlier researches. So in the present work photoelastic effect has been calculated over the thermally loaded transparent model (circular disc) using transmission photoelasticity. The optical property of the material is analyzed as a function of temperature, since the stress pattern at higher temperature within the specimen was found to be higher as compared to the stress pattern with constant load at room temperature. The experiments have been carried out on the basis of calibration of the birefringent material used in the photoelastic analysis. An alternative polariscope is developed using economical equipments for industrial purpose, for the analysis of stress field on the designed model.
Keywords : Photoelasticity, Digital photoelasticity, Polariscope and Fringes.

I. INTRODUCTION

Photoelasticity is an experimental technique for the analysis of two dimensional stress field on the testing sample; this method uses optical effect to determine the mechanical stresses and their distribution. Photoelasticity is totally based on the property of some transparent materials that it shows fringes when load is applied on the model and observed through the polarized light.

This effect is the result of refraction of the polarized light by internal deformations due to stresses occurred in the model[1].

The discovery of photoelastic effect is credited to Sir David Brewster who published in 1816 [source] regarding polarization by reflection, on a clear glass when stressed and examined in polarized light exhibited colored patterns.

An early description of the method of photoelasticity was provided by Coker and Felon in 1931[source].

Then in 1937 Oppel introduced the concept of frozen stress photoelasticity, which has facilitated the analysis of three dimensional problems with the use of two dimensional concepts.

This is achieved by initially stress freezing the model and then mechanically slicing the model[source].

The mechanical slicing was replaced by optical slicing with the use of scattered light by Weller in 1939[source].

Analysis of a three dimensional model as a whole was proposed by Aben and in 1979and the technique is known as integrated photoelasticity[source].

In the recent years the development of new synthetic resins possessing desirable photoelastic characteristics, has helped to enlarge applications of the method to a wider variety of problems. In this work calibration of a birefringent material was done and the material stress fringe value was to be found out.

The material was then thermally treated to variety of temperature and loads again material stress fringe value was calculated. It was observed that the material stress fringe value which was considered to constant was varying with the temperature at which it was treated[2][3][4].

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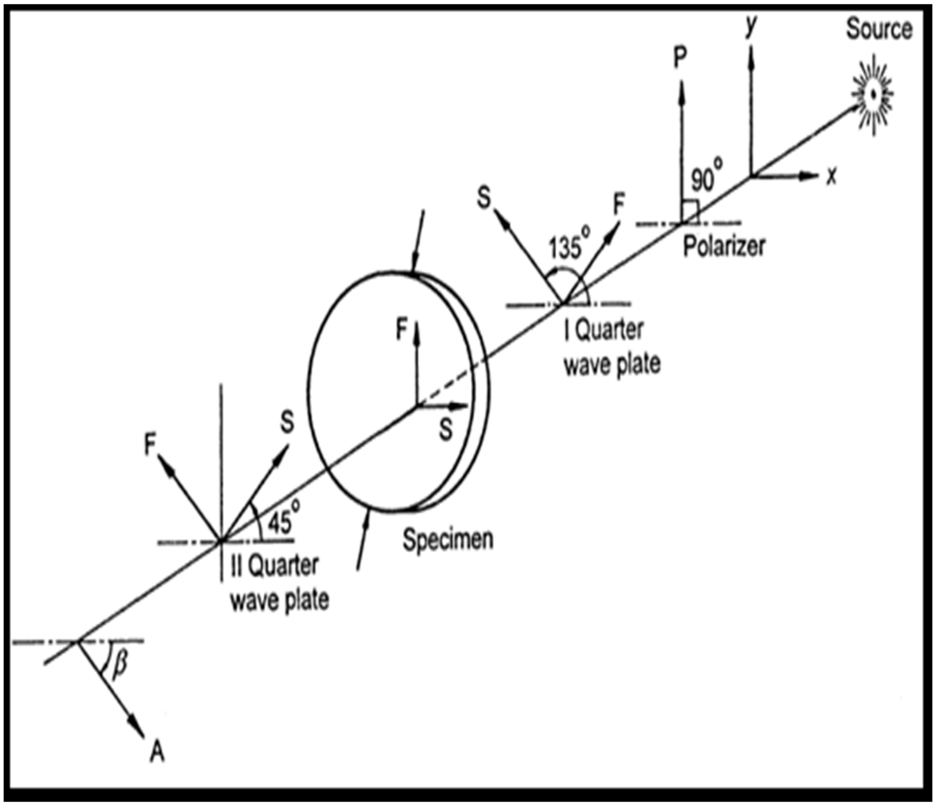

Figure1: Arrangement of a circular polariscope[source]

In the photoelastic stress analysis, first of all calibration of the test material is done to calculate the fringe constant (F_σ) of the material. To determine the fringe constant it is required to find the fringe order (N) using equation 1.

$$N = n \pm \frac{\beta}{180^o} \quad (1)$$

Where n is intermediate fringe order and sign is chosen according to the lower or higher fringe order.
The next step is to find the material fringe constant (F_σ)

$$F_\sigma = \frac{8P}{\Pi DN} \quad (2)$$

Where,
P = load applied on the material
D = diameter of the disc
h = thickness of the disc
Now,
The difference in the principle stresses ($\sigma_1 - \sigma_2$)

$$\sigma_1 - \sigma_2 = \frac{NF_\sigma}{h} \quad (3)$$

II. EXPERIMENTAL SETUP

The following is the list of apparatus used in the experiment for the analysis of circular disc under compressive load:

A. Acrylic sheet (circular disc)
B. Polarizer sheet and quarter-wave plate
C. Light source (Led lamp)
D. Hydraulic press(manual)
E. Water-bath
F. Analyzer
G. Digital camera

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Figure 2: Experimental setup

III. PROCEDURE

The circular disc was calibrated using Tardy's method [source] of compensation and the material stress fringe value was calculated. After obtaining stress fringe value the disc was heat treated at different temperature and the specimen was brought back to room temperature by slow air cooling. Asthe temperature reduced to room temperature, the specimen was loaded in the hydraulic press and load was applied. On the application of external load the fringe pattern was observed, with the determination of fringe order the specimen was calibrated and stress fringe value was calculated for various heat treated specimen at different loads[5][6].

The stress pattern observed due to application of load was captured using a digital camera and using image processing technique the fringe order was determined. Further the load increases the colored fringe pattern tends to spread over the entire region of the specimen[7].

IV. RESULT AND DISCUSSION

A. Observation table

Table 1 Table for different load and difference in principal stress

S.no.	Load in Newton	$(\sigma_1 - \sigma_2)$ in Pa
1	1962	15.736127
2	2158.2	17.309740
3	2354.4	18.883353
4	2550.6	20.456965
5	2746.8	22.030578
6	2943	23.604191
7	3139.2	25.177803
8	3335.4	26.751416

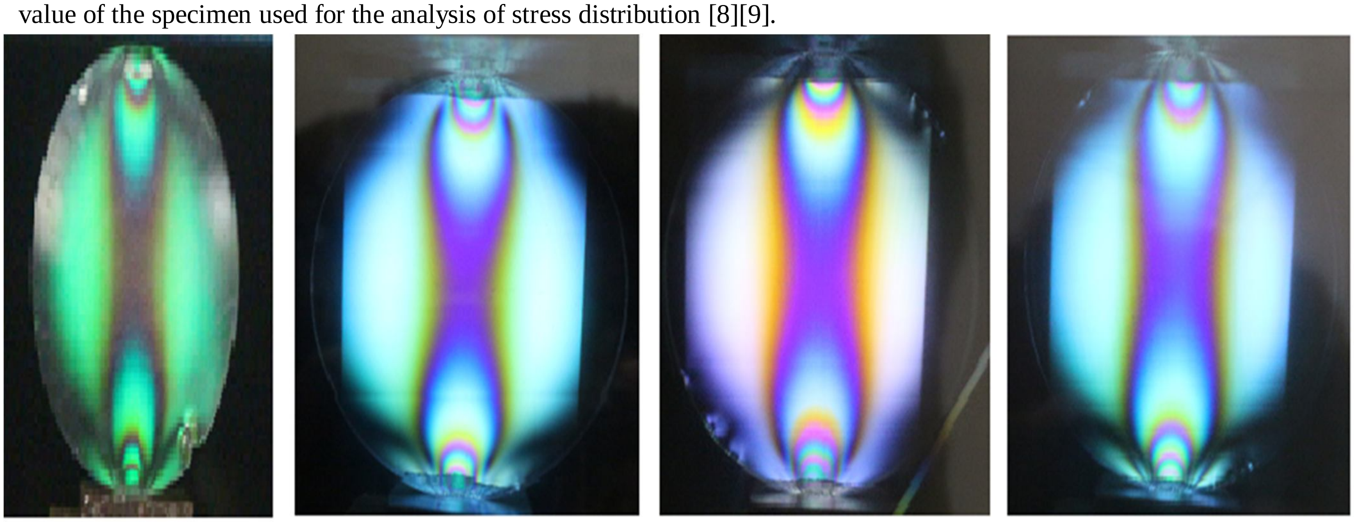
9	3531.6	28.325029
10	3727.8	29.898642
11	3924	31.472254

Table 2: Table for the angular rotation of analyzer for compensation

Load in Newton	Angular rotation of Analyzer (βindegree) at different temperature			
	35°C	40°C	50°C	60°C
1962	-19°	-17°	-14°	-12°
2158.2	-8°	-7°	-4°	-1°
2354.4	2°	4°	6°	9°
2550.6	10°	11°	15°	18°
2746.8	18°	20°	26°	28°
2943	28°	30°	35°	39°
3139.2	37°	39°	44°	47°
3335.4	48°	53°	52°	58°
3531.6	59°	66°	68°	73°
3727.8	72°	77°	8°	87°
3924	83°	87°	95°	99°

1) The value of angular rotation of analyzer (β) is substituted in the formula mentioned below to evaluate the fractional fringe order (δ_N) at the centre of the circular disc.

2) After the determination of fractional fringe order, the actual fringe order (N) is calculated for determination of stress-fringe value of the specimen used for the analysis of stress distribution [8][9].



(a) (b) (c) (d)

Figure 3: Fringe pattern observed at constant load (2354.4 N or 240kg) for different heat treated specimen (a) At 35°C (b) At 40°C (c) At 50°C (d)At 60°C

Formula used

$N = n \pm \frac{\beta}{180^o}$

where, N = Fringe order at any point

n =Fractional fringe order at arbitrary point

Table 3: Table for calculated fringe order for differently heat treated specimen

Load in Newton	Fringe order (N) at different temperature			
	35°C	40°C	50°C	60°C
1962	0.8936	0.9048	0.9216	0.9328
2158.2	0.9552	0.9608	0.9776	0.9944
2354.4	1.0112	1.0224	1.0336	1.0504
2550.6	1.056	1.0616	1.084	1.1008
2746.8	1.1008	1.112	1.1456	1.1568
2943	1.1568	1.168	1.196	1.2184
3139.2	1.2072	1.2184	1.2464	1.2632
3335.4	1.2688	1.2968	1.2912	1.3248
3531.6	1.3304	1.3696	1.3808	1.4088
3727.8	1.4032	1.4312	1.4536	1.4872
3924	1.4648	1.4872	1.532	1.5544

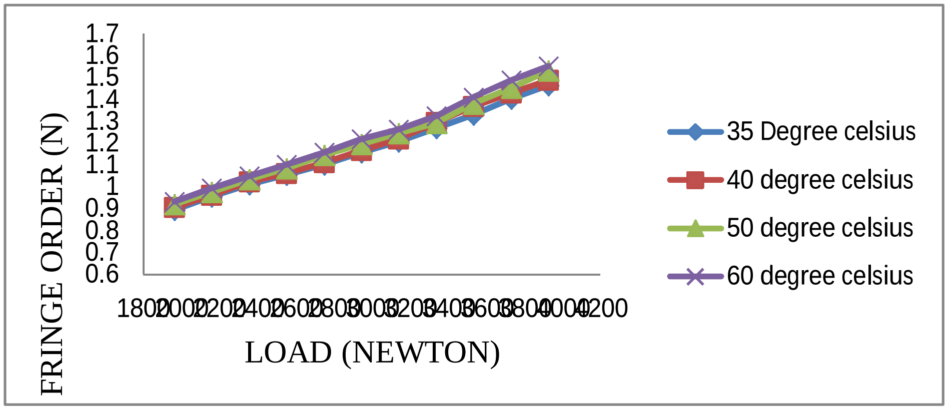


Figure 4: Load vs. Fringe order

The observation of fringe order at the centre of the circular disc is analyzed with the help of tardy's compensation technique in a circular polariscope, it was found that there is increment in the stress field while keeping the load constant at differently heat treated and then air cooled to room temperature (35°C). The specimen was loaded when the temperature was brought down to room temperature. The fringe order was found to be higher for the heat treated specimen as compared to the fringe order calculated of the specimen without heat treatment. It can be fairly be seen from the graph that as the load on specimen increases then the fringe order also tends to increase but for the heat treated specimen the value of fringe order deviates drastically[10].

Table 4: Table for stress-fringe value of material at different temperature

Load in Newton	Stress fringe value (N/mm/fringe) at different temperature			
	35°C	40°C	50°C	60°C
1962	88.04835	86.95845	85.37327	84.3482
2158.2	90.60721	90.07911	88.5311	87.0354
2354.4	93.37026	92.34742	91.34675	89.88576
2550.6	96.85985	96.34891	94.35794	92.91788
2746.8	100.0654	99.05756	96.15224	95.22131
2943	102.0228	101.0445	98.67894	96.86475
3139.2	104.281	103.3224	101.0013	99.65802
3335.4	105.4193	103.1431	103.5905	100.9632
3531.6	106.4522	103.4054	102.5666	100.5281
3727.8	106.5365	104.4522	102.8426	100.5191
3924	107.4276	105.8096	102.7154	101.2352

Table 5: Table of average stress-fringe value for heat treated specimen

S.no	Temperature (in ^oC)	Average stress fringe value (N/mm/fringe)
1	35^{o}C	100.099
2	40^{o}C	98.724
3	50^{o}C	97.01427
4	60^{o}C	95.37972

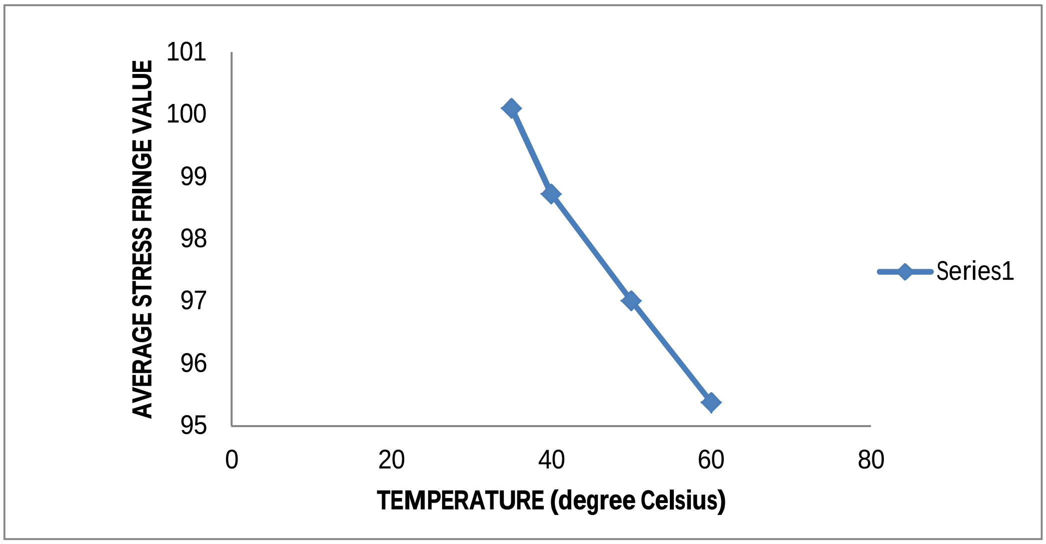


Figure 5: Load vs average stress-fringe value

The difference between the principal-stress was calculated from the analytical formula, the stress at centre of circular disc which is the function of load applied on the specimen and it is found to be constant for the fixed applied load. The fringe order observed and calculated are found to be higher for the heat treated specimen, therefore the stress-fringe value is found to be decreasing as the specimen is heat treated. The average stress-fringe value for the specimen is calculated for different heat treated specimen and a graph is plotted, which shows that the stress-fringe value is a function of temperature and it tends to decrease as the temperature increases[11][12].

V. CONCLUSION

In this research work, the experimentations have been carried-out on transmission photoelasticity on different circular disc of acrylic material using circular polariscope and subsequent calculations have been carried-out with Tardy's compensation technique. This technique is employed for the determination of fractional fringe order at an arbitrary point within the specimen. The fringe order at the center of the circular disc is determined. The stress fringe value of material is calculated for different heat treated specimen. The result shows that there is reduction in average stress- fringe value of the material as the temperature of the heat treated specimen increases. It also shows that the fringe order at a fixed load tends to deviate as the load is increased gradually. Therefore it is recommended that the thermal properties of the acrylic material should also be taken in account for the analysis of stress distribution. Thus taking into account the material stress-fringe value plays a vital role in the analysis of stresses using photoelasticity.

An alternative polariscope has been developed during the experiments, which was capable of providing stress distribution pattern within the model for transmission photoelasticity. The alternative polariscope developed is economical thus it can easily be adopted by the small scale industries and academic institutions for non-destructive testing purpose. The limitation of the alternative polariscope is that it provides near field values which is not highly accurate. However, this polariscope, preliminary stress distribution can easily be evaluated in absence of circular polis cope.

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