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PHOTOELASTIC ANALYSIS OF STRESS CONCENTRATION FACTOR IN RECTANGULAR PLATE WITH NOTCHES & HOLES AND ITS VALIDATION THROUGH ANSYS

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ABSTRACT

Photoelasticity is an experimental method for analyzing stress or strain fields in mechanics. Now-a-days it has become so advanced that it can analyse a 3-dimensional model, this technique is known as integrated photoelasticity. When plane polarized light passes through the model, the state of polarization changes from point to point depending on the principal stress direction and magnitude of principle stress difference. Stress analysis by using polariscopes plays a vital role in advancements in dental sciences, aerospace technology etc. This paper deals with use of polariscope in various fields.

I. INTRODUCTION

Stress is one of the most commonly used terms in mechanical engineering field; it can be defined as internal resisting force per unit cross sectional area resisting that force. Its S.I. unit is N/m^2. In many practical applications determining stress alone is not sufficient, for example: in case, notches are present in a body the value of maximum stress and the average stress over the body are not equivalent. Therefore, it is essential that we introduce a term that gives a comparison between maximum and average stresses; this term is defined as stress concentration factor. It is denoted by $K\sigma$. [12]

II. EXPERIMENTAL METHOD

Experimental approach is easily applicable for complex geometry. They can be directly applied to prototype or models. Several service failures are reported due to stresses introduced during assembly or due to residual stresses developed due to the manufacturing processes. Experimental methods are the best choice to solve such problems and the study is done on the prototype. One of such experimental method is photoelasticity. [13]

Introduction to photoelasticity:

- Light is used as a sensor.
- The equipment used for visualization of stress field is known as polariscope.
- Photoelasticity basically provides information of difference in principal stresses and the orientation of principal stress direction at a point.

Physical principle:

Certain non-crystalline transparent materials, notably some polymeric materials are optically isotropic under normal conditions but, become doubly refractive or birefrigent when stressed. This effect persists when the loads are maintained but vanishes almost instantaneously or after a brief interval of time depending on the material and conditions of loading. This is the principle characteristics on which photoelasticity are based. This phenomenon of artificial or temporary birefringence was first observed by Brewster in 1816.

The circular polariscope is used to determine the isoclinics (orientation of principal stress) and isochromatics (difference in principal stresses) in birefringent materials. [14]

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Fig 1: Circular Polariscope.

III. LITERATURE REVIEW

D.H. Morris et al. [1]: The objective of this research was to develop a method for photoelastic stress analysis using the optical properties of transparent material. The selection 14 and characterization of material is of paramount importance. In general, it was desirable that the material be able to undergo large plastic strains while, at the same time, exhibits a good level of optical response.

P. M. Pathak et al. [2] studied photoelastic fringe contours and validation of Finite element methods; it was found that an appropriate discretization scheme for modeling was very important in evaluating the intended parameters accurately. The discretization of model was restricted due to constraints on computer resources, discretization was optimized.

The discretization of the model should be fine near the stress concentration zone and elsewhere it could be coarser in order to obtain precised results.

Ahmad Loqman et al. [3]: This research analysed the stress concentration factor was carried out. The specimens are fabricated with edge notches, multiple edge notches and holes. The stress concentration factor value is compared between the theoretical values and the experimental results. The stress distribution in cracks and notches is compared to deduce the significance of stress concentration factor for the cracks. From several experiments it was observed that the different type of specimen cut from photoelastic specimen gave different fringe numbers at different loads.

Fang Li [4] investigated an experimental infrared transmission technique to obtain full stress components of residual stresses in a thin multi-crystalline silicon wafer and to meet the need of photovoltaic industries, to measure residual stress for large cast silicon wafers. Photoelastic technique is used to calibrate the stress optic coefficients for different grain orientations and stress orientation.

Tae Hyun Baek et al. [5] studied the photoelastic fringe patterns are obtained through a circular polariscope with variation in the optical arrangements and they were processed with image processing techniques in a personal computer.

Rabah Haciane et al. [6] has done stress analysis in the neighborhood of contact zones which helped in improving the design and durability of the mechanical component using photoelasticity. The experimental analysis and a numerical solution for a three dimensional contact problem of a sphere rolling over a plane surface, under a normal load is compared.

S.B. Shinde et al. [7]: Photoelasticity is whole field technique which works on the property "birefringence" of transparent material. Birefringence means transparent material shows two refractive indices before and after loading. This paper describes the use of photoelasticity in various fields of science.

Nalla Santosh Kumar et al. [8]: Photoelasticity is an experimental method to determine the stress distribution in an elastic material having optical property. Now a days large numbers of photo elasticity experiments are based on the principle of light polariscope. The load frame is an important part of the experimental setup of polariscope to perform the experimental stress analysis.

J.R. Lesniak et al. [9]: This paper reviews how the re-conceptualization of photoelasticity has made it more accessible to the authors and contributed to the modernization of photoelastic imaging. The Grey Field Polariscope (GFP) uses new methods of: polariscope configuration, data acquisition/imaging techniques, sample preparation, and image analysis in 16 a coordinated combination of traditional, innovative, and newly implemented methods that have revolutionized the technology.

Jon R. Lesniak et al. [10]: This paper describes a polariscope that has a single rotating lens and a digital camera for proper acquisition of image data. Software analysis is used to interpret the data obtained from image and depicts the magnitude of shear strain and direction of principal strains.

Touahir et al. [11] investigated the stresses developed in a birefringent cylinder loaded perpendicularly to its longitudinal axis were determined experimentally and numerically. The problem could have been encountered in various machinery components and in manufacturing processes; the moving part induces stresses particularly in the neighborhood of the contact zones.

IV. METHODOLOGY

Stress concentration around the discontinuities is the major cause of failure of many structures. Experimental analysis can be performed in photoelastic bench. The shape and size of the discontinuity is varied. The additional discontinuity has been incorporated in the model and its effect has been analyzed.

Stress developed in a specimen is independent of material properties, whereas strain and deflection depend on the properties of the material used [15]. Therefore, the stress distribution in every material will be similar. The specimen that can be used in polariscope has to be made up of a transparent material. The property that the material should exhibit is that it should be anisotropic in nature. When the load is applied for the purpose of stress analysis, the material should be strong enough to withstand the applied load. The specimen should not buckle or fracture during stress analysis. Epoxy and polyurethane were used to make the specimen earlier but the results obtained were not satisfactory. Therefore, at last Perspex sheets were used to make the specimen.

To perform the experiment the value material fringe constant needs to determined. Therefore, a circular disc is used to determine the value of fringe constant and it is equal to 8 kg/cm.

Following specimens were used in the experiment:

1. Calibration of circular disc (Model - 1) under compression: Diameter of disc = 7 cm & thickness of circular disc = 0.6 cm.

Fig. 2: Model – 1

Fig. 3: Fringe formation in Model - 1 under compression observed in polariscope using white light.

2. Rectangular plate with semicircular notch (Model - 2): Size of plate = 18 cm X 5 cm & Size of notch, d = 2 cm.
3. Rectangular plate with semicircular notch (Model - 3): Size of plate = 18 cm X 5 cm & Size of notch, d = 2.4 cm.
4. Rectangular plate with two semicircular notches (Model - 4): Size of plate = 18 cm X 5 cm & Size of notch, d = 2 cm.

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5. Rectangular plate with semicircular notches and a hole at the centre (Model - 5): Size of plate = 18 cm X 5 cm, Size of notch, d = 2 cm & Size of hole, d_h = 1.8 cm.
6. Rectangular plate with semicircular notches, a hole at the centre and two small holes between the notches (Model - 6): Size of plate = 18 cm X 5 cm, Size of notch, d = 2 cm, Size of hole, d_h = 1.8 cm and d_s = 1 cm.
7. Rectangular plate with V-Notch (Model - 7): Size of plate = 18 cm X 5 cm, Size of notch, h = 1 cm and W_n = 1 cm.
8. Rectangular plate with V-Notch and a hole at the centre (Model - 8): Size of plate = 18 cm X 5 cm, Size of notch, h = 1 cm, W_n = 1 cm and d_h = 1.8 cm.

V. RESULTS

Once the experiment is performed, all the results are validated with the help of ANSYS 16.2 Workbench platform software.

After calculating the value of stress concentration factor in the above mentioned specimens the following results and variations in the validation were found:

Table 1: Comparison between values of Kσ in various models.

Model	Kσ exp.	Kσ ansys	Variation (%)
2	4.58	4.14	9.46
3	4.87	3.99	17.55
4	3.71	3.10	15.27
5	2.86	2.32	18.63
6	2.66	2.34	11.78
7	5.19	6.11	18.50
8	4.63	5.76	24.29

After analysing the different models in Circular Polariscope, the following results can be drawn:

- It is observed that perspex is the best suited material for experiment in photoelastic bench.
- On comparing, we found that the concentration of stress in V notch is more as compared to that in semi-circular notches due to its geometry.
- From the analysis it is observed that the value of stress concentration factor decreases by imposing additional discontinuities in various plates and discs. All the results obtained are validated with the help of ANSYS software and the variation is considerably low.
- It is found that the magnitude of stress concentration factor increases when the size of notch is increased.

VI. CONCLUSIONS

- The machinability is easy.
- In case of V notch the geometry of the notch is such that a stress is more around a point therefore, stress concentration factor is more as compared to that in semi-circular notch for same plate.
- As the size of discontinuity increases, the magnitude of stress concentration factor decreases.
- By introducing additional discontinuities around the main hole or notch, stress concentration factor decreases as stress flow lines become smoother.
- Then various discontinuities were provided on the specimen and its effect on the stress concentration factor was noted.
- The experimental results are validated with the help of ANSYS software.
- The results obtained from the software were considerably low and hence can be considered correct.

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