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Stress Analysis Using Photoelasticity Technique – A Review

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Abstract: Photoelasticity is a non-destructive testing technique of visualizing of stress on a model subjected to load, due to the property of material called as birefringence or double refraction. The crystalline psolid have a property of birefringence that is change in refractive indices of the material on application of load. The change of refractive indices generates fringe pattern on the axis perpendicular to the application of load. The fringe pattern thus obtained is analyzed and calculations of stresses within the model are analyzed. This review paper provides the extent to which photoelasticity technique has been explored in various field of science and research. The objective of this paper is to provide a suitable understanding of the technique and the extent of research work done in this field. A literature search was conducted, using keywords photoelasticity, non-destructive testing, principle stress and fringe pattern. The article and research paper were shortlisted for reading and data analysis, articles related to photoelasticity and stress measurement techniques. This paper gives the review of photoelasticity in various fields of research.
Keywords: Photoelasticity, Structural analysis, Principle stress, Non-destructive testing and Fringes.

I. INTRODUCTION

Photoelasticity is an experimental technique of analysis for stress and strain, for the members having complicated geometry, complicated loading conditions or both. The experimental technique is quiet suitable for such cases rather than the analytical methods considering mathematical solution which is time consuming and cumbersome for the analysis. Photoelasticity is totally based on the property of the crystalline solid transparent material which shows fringes when the load is applied on the model and observed through a polarized light. This effect is the result of refraction of the polarized light by the diffraction of light due to the internal deformation of model due to the application of external load. The fringes give all stress distribution and allow the measurement of their direction and their magnitude at any point within the model. The fringes are obtained due to the property of material called as birefringence, since the refractive index of material changes by the application of external load on the material[1][2][3].

An optical system is required for the experiment in photoelasticity called as polariscope. A polariscope consist of various elements given as light source, polarizer, quarter-wave plates and analyzer. The birefringent property of the material leads to the formation of fringe patterns that depend on the external load applied on the specimen. The fringe obtained is observed and captured with a high resolution CCD camera and saved in a computer. The fringe patterns are analyzed to obtain information about stress of the specimen. Fringe patterns obtained in the polariscope consist of broad fringe bands with different width and different color of fringe depends upon the source of light being used. In this paper, image processing techniques with digital and high speed computers are reviewed for better analysis of fringes in photoelasticity. Image sharpening technique makes it easier to locate maximum or minimum in the fringes[4][5][6].

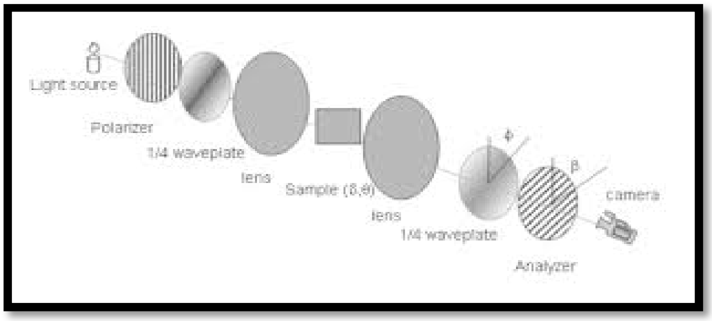

Fig. 1 Arrangement for circular polariscope

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Photoelastic technique is used to study a prototype made of transparent material, having similar properties to as that of a model. The prototype model is subjected to similar loading condition to as that of the actual work load conditions, which take to a deformation. Polariscope used in photoelasticity allows the establishment of the light propagation plane and therefore, the difference between the two components of main stress as well as the direction of main stress[7].

A. *Analytical Approach*

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)[8][9][10].

$$N = n \pm \frac{\beta}{180^o} \tag{1}$$

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)

$$F_\sigma = \frac{8P}{\Pi DN} \tag{2}$$

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

$$\sigma_1 - \sigma_2 = \frac{NF_\sigma}{h} \tag{3}$$

II. RESEARCH WORK IN VARIOUS FIELDS USING PHOTOELASTICITY

P. M. Pathak et al. 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 précised results. The development in automatic mesh generation helped in solving the problems with complicated geometry more easily. The theory of elasticity provides closed form solution[12][13][14].
The model was discretized based on the number of elements in the model 40 elements and 140 elements. It was made clear that the result improved as the number element increased from 40 to 144 elements near the stress concentration zone and there was slight improvement near the boundaries. As the number of element increased the shape of the contours are not smooth and thus it was reported that the slight change in stress can be observed and can be easily traced. From this paper the deviation of theoretical result was found to be 40.4% for 40 elements and 1.6% for 144 elements. The author concluded that this approach for the complex problem can be easily adopted for rapid modeling and prototyping. The plotting of fringe contours from finite element results has made the comparison quiet simple and less time consuming.

Rabah Haciane et al. 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 plan surface, under a normal load is compared. The experimental analysis with the same load was conducted on a regular polariscope with a three dimensional model. The stress field in the model is locked with the help of stress freezing technique. The stress frozen model is mechanically sliced and the stress field is then determined, on a regular polariscope. The sliced element is used for the comparison with the finite element solution. The isochromatics and isoclinic fringes are compared with the simulated ones. The author concluded that the stress decreases along the vertical axis of symmetry as we move away from the contact area[15][16][17].

Ahmad Loqman et al. investigated the stress concentration factor was carried out. The specimens are fabricated with edge notches, multiple edge notches and holes. The stress concentration factor (K) 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. The specimen with surface discontinuities produces variation in the fringe patterns

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at constant load. As the load increases on a specimen the fringe number increases. The author concluded that variation in the experimental result from the theoretical values is due to the residual stresses generated due to machining process tends to cause deviation in the fringe pattern at same load for different specimen with variation in stress concentration factor[18].

Rupali Patil et al. gave a review on the analysis of bell crank lever using photoelasticity and the component was analyzed in finite element method. The bell crank lever is subjected to variety of load and at different orientation of the lever but the study shows that the failure of the component is mainly due to bending action of the component. With the help of photoelastic analysis it is easier to analyze the stress distribution within the component when subjected to load and one is capable of observing stress on the component and one can work on the improvement of the design of component to avoid failures[19].

The results obtained from the experimental photoelasticity and the analytical finite element method analysis it is clear that both the techniques are in a close agreement with each other and maximum failure and stress concentration occurs at maximum bending surface. The stress can be easily calculated by observing the number of fringe pattern and using empirical equations, for the complicated problems of arbitrary geometries. The experimental technique provides the results which are close to reality.

Tae Hyun Baek et al. 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. The image processing technique majorly discuss about fringe sharpening, fringe multiplication and 8-step phase measuring. 8-step phase measuring technique is used to separate isoclinics and isochromatics. The work briefly describes various techniques and the significance and focusing on more digital technique for reduction in processing and highly reliable and less time consuming techniques. Varieties of fringe patterns are obtained due to rotation of optical arrangement such as II-quarter wave plate and analyzer in the polariscope. This shows the impact of optical arrangement of the system, thus with the help of digital recording system, it is easier to distinguish in the change in fringe patterns[20].

T. Lalitha et al. investigated the stresses developed in composites using experimental and analytical method. The stresses induced in a circular disc under compression load is studied and compared with the results obtained from analytical and simulation studies. A compression test was conducted on the disc with the help of photoelastic principles and polariscope, experimental setup to calculate compressive stresses. The value of stresses from the experiment was compared with the simulation results, obtained from ANSYS software. It was observed that the experimental stress values are tuning the stress values of disc obtained through the ANSYS software. The author finally concluded that the variation in the stresses is due to the modeling error that is proper selection of element and the correct values of material properties of the disc[21].

Bhimaraju et al. studied the design of multi-leaves to withstand the large loads than that of the existing single leaf spring suspension system. The model of designed leaves was analyzed for stress distribution at various points through polariscope and software analysis. The results of both the methods are compared with the stresses obtained by the analysis software. From the analysis it was concluded that the graduated leave in the multi-leave spring helps in reducing the stresses developed in the master leaves, the load carrying capacity of the suspension system increases. As the number of leaves increases in suspension system, the shock transmitted to the vehicle decreases. The drawback of the experimental technique was that it requires more concentration in analyzing fringes obtained during analysis[22][23][24][25].

Fang Li 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. A new polariscope system has been designed and built for the analysis of residual stresses in the silicon wafers. The orientation of grain was characterized by light intensity of the images captured by an infrared camera instead of x-ray diffraction. With the help of new polariscope system, the error was reduced to 1MPa by linearly calibrating the camera and subtracting the system pattern from the residual stress measurement. The author studied the thermal transient state using finite element method, a thermal model was built and to calculate the thermal stresses induced by the light source, a structural model was built[26][27][28].

A. Bilek et al. 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

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manufacturing processes; the moving part induces stresses particularly in the neighborhood of the contact zones. Stress freezing technique was used to lock the stress field inside the birefringent cylinders. Two slices were mechanically cut, one along the load direction and other one 10mm away from the load direction. The analysis of stress field developed between orthogonal cylinders in contact by using Photoelasticity and Finite element analysis. The isolated slice of a three dimensional model was analyzed. The author concluded that the STRESSES and photoelastic fringes could be captured and calculated for complicated geometries[29].

III. RESULT AND DISCUSSION

Photoelasticity has been widely used in the field of automobile and aeronautics to solve the problems generated in contact zone and assembly of components in a machine. The residual stresses generated in the component due to machining, they play vital role in the life span of the component thus photoelasticity as a tool provides data that is capable for the prediction of failure of component. Earlier photoelasticity was restricted to two dimensional problems, the model being studied was considered to be of negligible thickness but with the advancement of technology this technique has been improved far better than other experimental techniques and is now capable for the analysis of three dimensional models. With the help of stress freezing technique it is quiet simpler to analyze the stress distribution in the model[30].

In polariscope, the slight changes in the arrangement of the elements causes change in the fringe pattern, that is with the help of circular polariscope the fringes obtain are the isochromatics fringes and the isoclinic fringes are eliminated. The isoclinic fringe signifies the direction of the principle stress and the isochromatics fringes signifies the values of the principle stress difference in the model. The color of fringe pattern depends upon the color of light used as a source.

The multi-leave spring was capable of carrying higher loads as compared to single leaf suspension system. The shock transmitted to the vehicle tends to decrease as the number of graduated leaves increases. The principle stresses that are developed in the leaf springs can be visualized with the help of polariscope and the design of the suspension system can altered based on the load carrying capacity of the suspension system.

IV. CONCLUSIONS

The following conclusion can be drawn from various articles and research papers:

A. The experimental technique is capable of measuring the internal stresses effectively in the indeterminate structures with complicated geometry as well as complicated loadings.
B. Photoelastic technique is quiet simpler and less cumbersome for the problems of the model with arbitrary shape as compared to that of analytical solution and mathematical equations which are time consuming.
C. This technique provides reliable full-field values of the difference between the principle normal stresses in the plane of the model.
D. The method is adaptable for both static and dynamic investigation.
E. Photoelasticity provides uniquely the value of non-vanishing principle normal stress along the perimeters of the model, where the stresses are generally larger.
F. With the help of digital photoelasticity it is quiet easier and very less time consuming to capture and process the image of the fringe pattern.
G. Photoelasticity and other analytical method gives closed form solution which shows that the technique is reliable and worth adopting for analysis.

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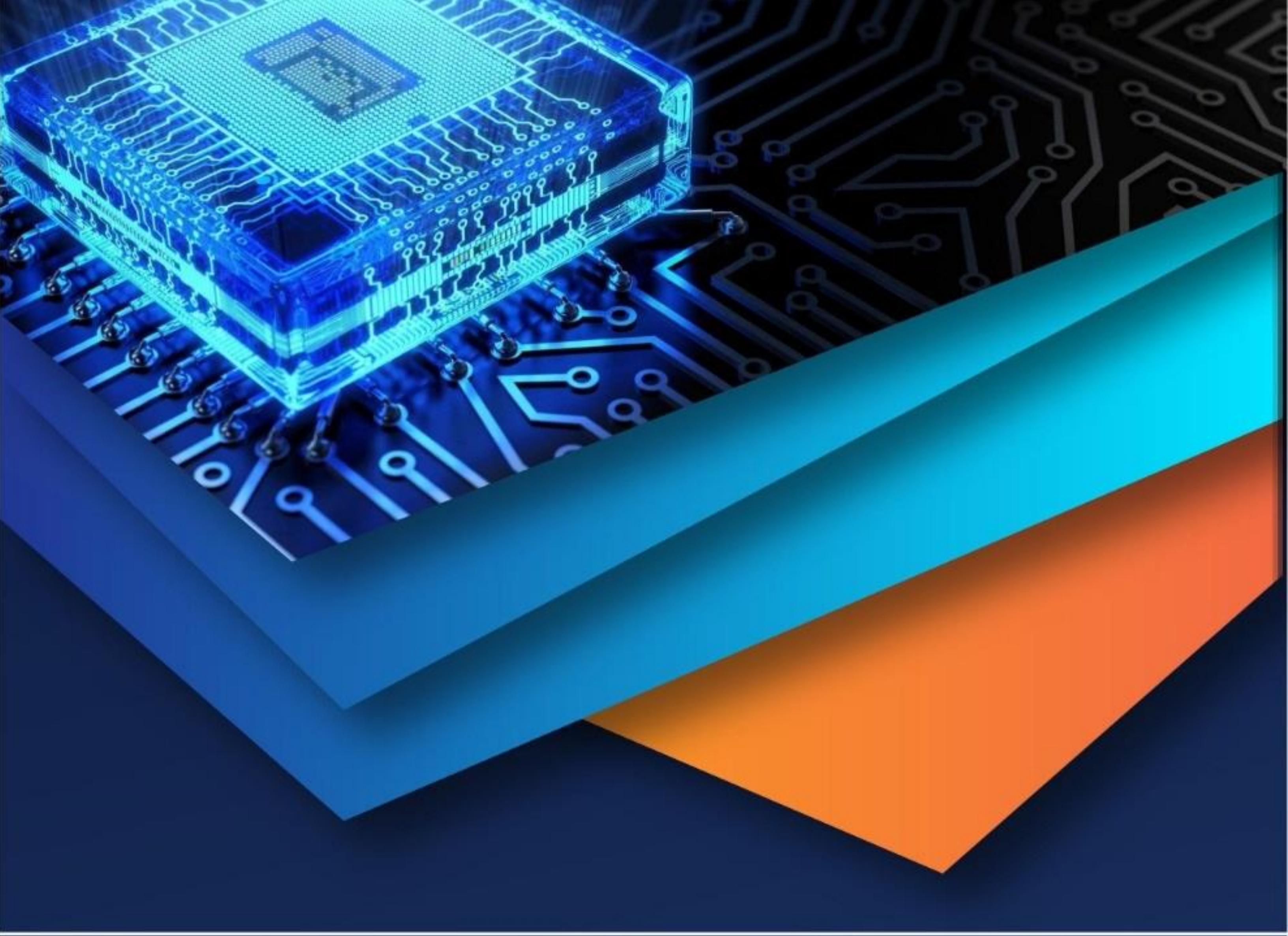

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