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Visualization of Stress Patterns for Stepped Rectangular Specimens Using Experimental Photoelasticity Method and Finite Element Analysis

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Abstract: *In the fields of mechanics and materials science, photoelasticity is a reliable experimental method that provides a visual evaluation and analysis of the distribution of stress in materials that are transparent or translucent. This non- destructive testing technique uses the special property of materials known as birefringence or double refraction to visualize stress on a model under load. The process involves building a physical model that mimics real-world structures, applying mechanical stress to the model, and carefully choosing a suitable photoelastic material that exhibits birefringence. The material undergoes birefringence when it is under stress, which causes changes to its optical characteristics. As a consequence, different stress levels are reflected in the pattern, which makes it easier to identify stress concentrations and possible failure areas and offers insights into how materials behave under varied circumstances. In the current study a photoelasticity unit was used to evaluate the stepped rectangular specimen under four different stresses. Next a comparison was made between the experimental analysis results and ANSYS simulation (Finite Element Analysis). Because of its intuitive user interface, the software functions as a virtual laboratory by enabling simulations with user-defined problem parameters that are tailored to the users circumstances.*

Keywords: Isochromatic and isoclinic fringes, Polarization, Photo elasticity, Polari scope, Stress, Jones calculus

I. INTRODUCTION

The experiment can be easily set up because photoelasticity only requires simple optics.

Photoelasticity essentially provides contours of constant principal stress/strain difference (isochromatic fringes) and constant principal stress/strain direction (isoclinic fringes). It could be applied in the transmission or reflection modes[1-3]. Many challenges may be examined only by looking at the fringe field's entire field nature. Fringe density is a useful statistic for identifying areas of concentrated stress and potential material removal sites to bring the weight closer to its ideal level. The isochromatic and isoclinic values at each time point must be obtained in order to decrease quantitative data.

Any interferometry approach requires the ability to order the fringes. Seeing the common fringe patterns for a range of issues is one of the easiest ways to do this. This can be simply accomplished by utilizing Polari scope to simulate fringe patterns [4]. Due to the use of simulation, it is ideally suited for performing actual experiments as well FEA simulation. The software not only provides the theoretical values of fringe order and isoclinic value as recorded in a standard polariscope testing unit, but it also simulates solutions based on the Theory of Elasticity [5]. This feature facilitates the quick application of compensation approaches at any place of interest and the learning of fringe ordering. Babinet-Soleil and Tardy are the two techniques of compensation available in the software [6]. The student may comprehend the significance of ascertaining the isoclinic angle at the site of interest initially and the heuristic information that is retrieved from the fringe fields for data interpretation since the fringe fields are realistically reproduced using Jones calculus [7]. This particular knowledge can help one to appreciate the intricacies in the development of digital Photoelasticity. Several experimental techniques have employed the carrier fringe method to enhance the fringe field information [8].

An additional feature of the software allows it to add carrier fringes to any chosen model at any angle and with different densities [9]. The simulation introduces a basic wedge-type carrier, the parameters of which are user-definable. Applications for carrier fringes include data extraction from weak birefringent materials, such as glass. In order to conduct a photoelastic experiment, need to make the models out of birefringent materials that are capable of satisfying a set of fundamental prerequisites [10]. It is essential that the polariscope be transparent to the light that is being observed through it, and this transparency can be lost for one of two reasons: (1) a drop in the indexes of refraction of the constituent materials, or (2) trapped air. In both instances, there is a change in the characteristics of the photoelastic medium, which results in the dispersion of light and, as a consequence, a reduction in the material's transparency [11]. Another factor that is taken into account is the potential for the material to be affected by "the border effect," which is a phenomenon that is associated with the water absorption and evaporation that occurs in plastic materials. This phenomenon causes changes in the dimensions of the model, which in turn causes changes in the internal stresses [12].Aphotoelastic constant is a representation of the photoelastic sensitivity to produced stresses on the model, which is a particularly relevant property. When the material is loaded, a highly elastic module will ensure that the material will not change shape [13]. Because of the connection between these two qualities, the photoelastic constant and the elasticity module, there is a third property that needs to be taken into consideration. This value, which is known as the figure of merit, measures how sensitive certain resins. In a perfect world, the value of the figure of merit should likewise be as high as is humanly possible, and it should remain stable during the examination [14]. In a perfect world, the model materials would behave in clinical settings just like the real thing, just like what the researcher hopes to duplicate. When it comes to models that are used to replicate dental tissues, the qualities of these models should be quite similar to those connected to enamel and dentin [15]. These structures are in charge of receiving the efforts that are exerted during chewing, and the stresses that are created are communicated to the dental support tissues. When simulating supporting tissues, such as the alveolar bone in this example, the photoelastic material used in the simulation must, at the very least, be able to function within the bounds of its elastic capacity. In addition to this, it offers a photoelastic response that is most consistent with the load intensity that is imposed on photoelastic models, and more specifically, from "loads that best simulate a genuine condition"[16]. And because it is impossible to faithfully reproduce all of the factors that act in the oral medium, at the very least, a material should be used that is capable of providing the photoelastic answer that is most compatible with the load intensity that is being imposed on the photoelastic models when they are being subjected to the stresses. In order to ensure that the fringes that can be seen on the polariscope are distinct and welldefined, which will allow the results to be extrapolated to the clinical state. Photoelastic study of a composite model built with HY951 as the infill material was explored by Rao [17]. The stress distribution for a photoelastic chip tool interface was investigated by Chandrasekaran and Kapoor [18] for a range of rake angles, from -10 to 20 degrees. The photoelasticity technique was used to review the stress analysis by Jain and Kumar [19]. Using photoelsticity, Jones and Hozos [20] demonstrated the stress distribution on a flat plate with an oval hole. Using photoelastic and finite element methods, Shete et al. [21] conducted a comparative analysis of the stress distribution of an internal combustion engine piston. Using various mesh types, Mekalke et al. [22] investigated the impact of increased loading on a pre-stretched plate with a circular hole investigated Shrivastava and Chandrakar [23].

II. METHODOLOGY

2.1Selecting the Material:

Many polymers exhibit sufficient birefringence to be used as photo elastic specimen material. However, such common polymers as polymethylmethacrylate (PMMA) and polycarbonate may be either too brittle or too intolerant of localized straining. Homalite-100 has long been a popular general purpose material. Another good material is epoxy, which may be cast between plates of glass, but this procedure is seldom followed for two-dimensional work. Since polystyrene is clear, rigid, brittle and moderately strong we selected polystyrene.

2.2 Making a Template:

If you need to create several pieces of the same shape, it's a good idea to start by machining a template out of metal. This template serves as a guide for making multiple Photoelasticity specimens with identical shapes. To ensure smooth machining and avoid any issues, it's recommended to undercut the template by approximately 0.050 inches. This undercutting should extend through about half of the template's thickness from one side. This precaution is taken to prevent contact with the router bit during the machining process, ensuring precise and consistent replication of the desired shape for all the specimens.

2.3 Drilling the specimen:

If the specimen has holes, such as those used for load-application points using pins, then these holes should be drilled carefully with a sharp bit with plenty of coolant, such as ethyl alcohol, kerosene, or water; otherwise, unwanted fringes will develop around the edge of the hole. The specimen should be backed with a sacrificial piece of similar material to avoid chipping on the back side of the specimen as the drill breaks through. A series of 2 or 3 passes of the drill bit through the specimen, with coolant added each time, will minimize heat induced fringes.

2.4 Machining the specimen:

If the specimen is machined "from scratch," care must be taken to take very light cuts with a sharp milling cutter to avoid heating the specimen unduly along its finished edges. A coolant, such as ethyl alcohol, kerosene, or water, should be used to minimize heating. If a template is used, then a bandsaw with a sharp, narrow bandsaw blade is used to rough out the shape of the specimen. A generous allowance of about 1/8 in. should be marked on the specimen all around the template edge, since the blade will heat the material and nick the edge. Then a router with a high-speed carbide router bit, preferably with fine multiple flutes, should be used to fabricate the edge of the model. A succession of two centering pins—the first having a diameter larger than that of the router bit, and the second one the same size—should be used so that excess material can first be removed quickly, and then in a very controlled manner, leaving the specimen with the same dimensions as those of the template.

2.5 Loaded specimen viewing:

Once the specimen has been removed from the template and thoroughly cleaned, it is ready for loading and analysis using a polariscope. The polariscope is an optical instrument essential for viewing the fringes induced by the stresses in the material. for effective observation, the elements of the polariscope need to be arranged in a way that allows light to propagate perpendicular to the plane of the specimen. If a loading frame is required to apply stress to the specimen, it should be positioned between the first element(s) and the last element(s) of the polariscope.

When it comes to lighting, the use of monochromatic light is recommended for producing the sharpest fringes. However, the light source doesn't necessarily need to be coherent, and it may or may not be collimated as it passes through the specimen. This flexibility in the type of light source provides practical options for experimentation and analysis in stress visualization.

2.6 Recording the fringe patterns:

For digital recording, use a camera or imaging system attached to the polariscope to capture images of the fringe patterns.

2.7 Calibrating the material:

The sensitivity of a photo elastic material is denoted by its fringe constant, represented as fringe constant f_σ. This parameter establishes a relationship between the value N associated with a particular fringe, the thickness (h) of the specimen in the light-propagation direction, and the difference between the principal stresses ($\sigma_1 - \sigma_2$) in the plane normal to the light- propagation direction. The relationship is expressed as in equation 1.

$$\sigma_1 - \sigma_2 = N * f_\sigma / h \ldots\ldots(1)$$

To determine the value of f_σ, an experiment is conducted using a model of simple geometry subjected to known loading. A common calibration specimen for this purpose is the disk in diametral compression. Through this experimental process, researchers can ascertain the fringe constant, allowing for accurate interpretation and analysis of stress distribution in photo elastic materials.

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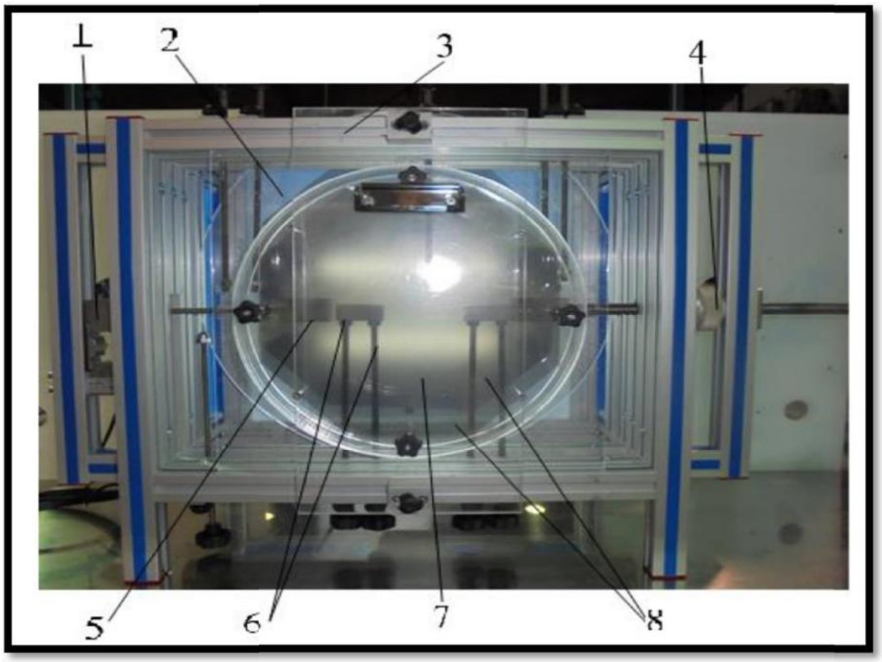

Figure1: Photo Elasticity Unit (1. E-C: load cell, 2. P-D: translucent diffusion plate, 3. S-A: translucent supporting surface, 4. T2: force screw, 5. M1: clamp and screws to fasten the specimens.6. T1: screws to apply pressure on the specimens, 7. D-C: discs with grid in between, 8. P: double effect polarizing filters)

2.8 Interpreting the fringe patterns:

Two types of patterns can be obtained: isochromatic and isoclinic. These patterns are related to the principal stress differences and to the principal stress directions, respectively shown in figure1

III. CALCULATION OF STRESS IN PHOTO ELASTIC MATERIAL

Formula Used:

$\sigma = N * f(\lambda) / e$ Where: N = Fringe Order $f(\lambda)$ = Fringe factor (const.)

e = Thickness of Material

Material Used: Polycarbonate

Fringe factor for polycarbonate = 13.15 N/mm

Thickness of Material Used: 5mm

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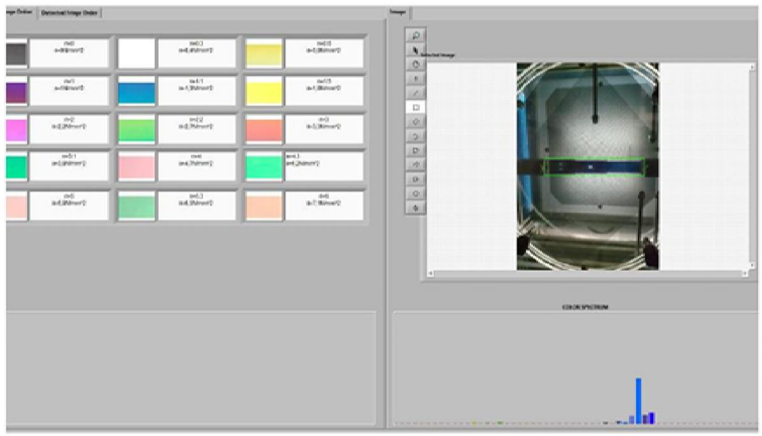
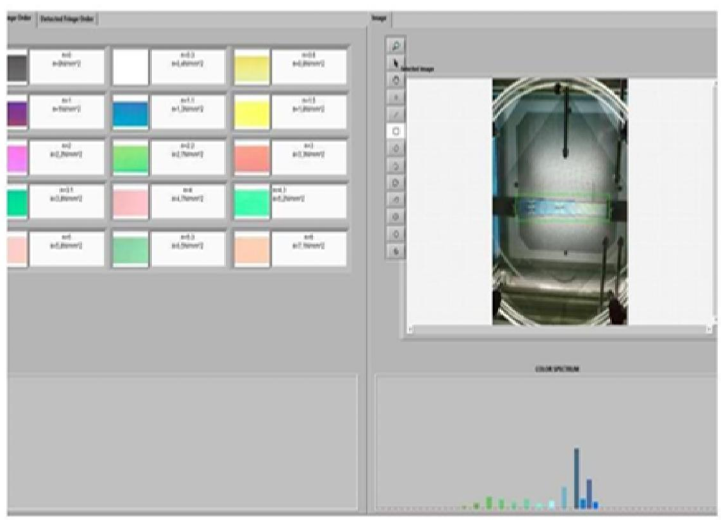
3.1 Data collected for Stepped Rectangular specimen from Photoelasticity unit



Tensile Load :- 50N

N	Color	Force (N)	Stress σmax (N/mm^2)
1	●	50	2.63

At load 50N



Tensile Load :- 100N

N	Color	Force (N)	Stress σmax (N/mm^2)
1.1	●	100	2.893

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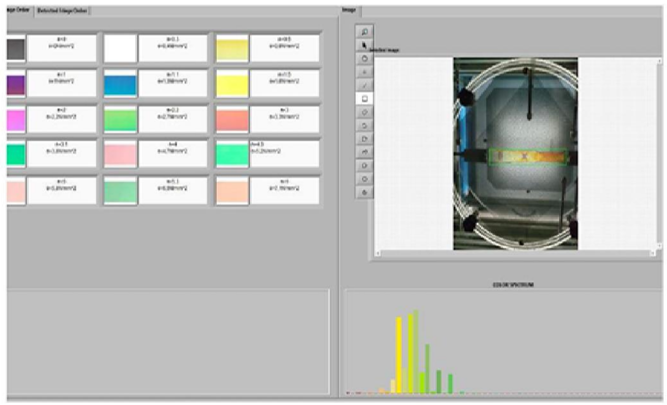
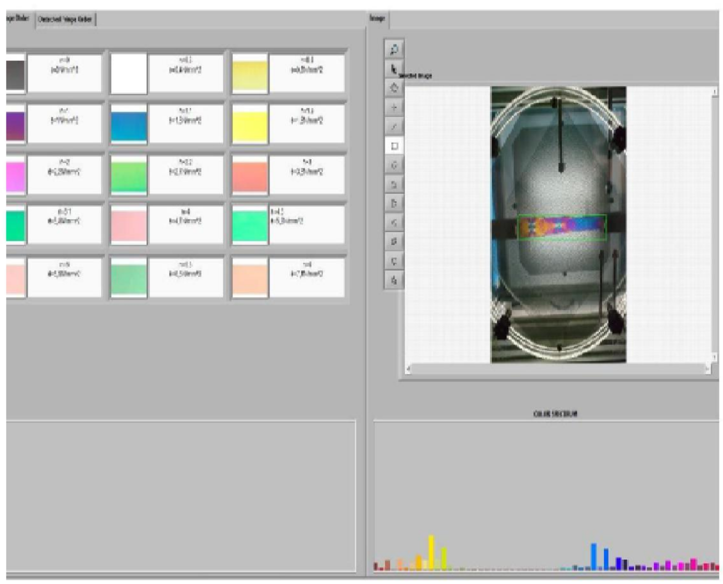
At load 100N



Tensile Load :- 150N

N	Color	Force (N)	Stress σmax (N/mm^2)
1.5		150	3.945

At Load 150 N



Tensile Load :- 200N

N	Color	Force (N)	Stress σmax (N/mm^2)
3		200	7.89

At Load 200 N

Figure 2: Experimental readings at different loading condition.

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3.2 Modeling and analysis using ANSYS:

We have been using two specimens of EFO kit we are develop the design and simulation using Ansys software and applying different force and check a various stress at location and make graphs for check the various stress.

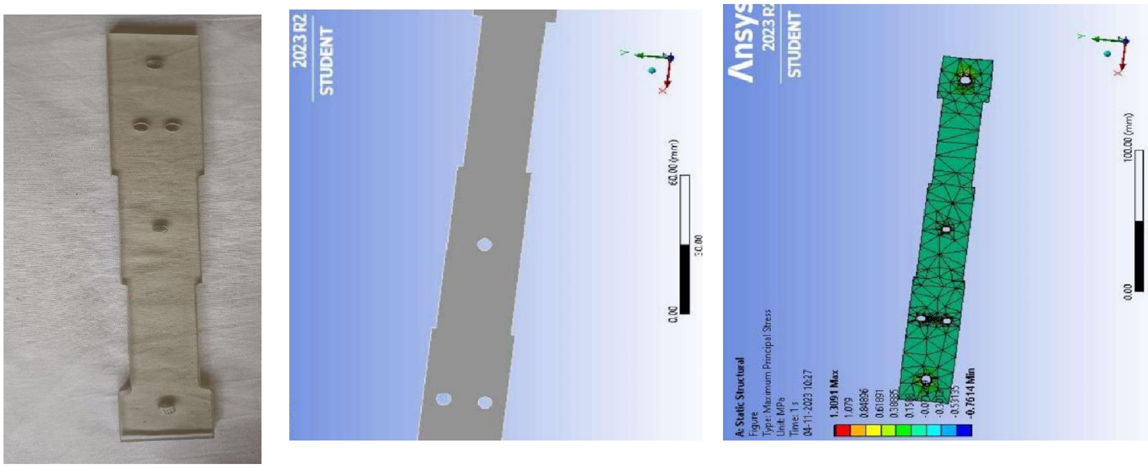

Figure 3: ANSYS GUI to interpret the result at different loading conditions

When a loaded photoelastic specimen (or photoelastic coating applied to an ordinary specimen) is combined with other optical elements and illuminated with an ordinary light source, it displays fringe patterns related to the difference between the principal stresses in a plane normal to the light propagation direction.

IV. RESULTS AND DISCUSSIONS

The findings consistently demonstrated stress patterns in polycarbonate specimens through the application of both photoelasticity and ANSYS simulations.

The fringe patterns observed during the experiments closely matched the simulated stress distribution. Some minor discrepancies were noted, which can be attributed to factors such as material heterogeneity or assumptions made in the simulation model.

The specimen of stepped rectangular has been tested with the help of photoelasticity unit under four different loads. The results obtained are compared with the results obtained by ANSYS simulation. At lower loads, the results obtained from ANSYS closely align with the experimental findings. For instance, at 50N, the stress values derived from ANSYS simulation and experimental measures are 1.603 N/mm² and 1.578 N/mm² respectively.

At 100N, the stress values from ANSYS simulation and experimentation are 2.878 N/mm² and 2.893 N/mm², respectively. However, at higher loading conditions, the experimental results deviate more significantly from the ANSYS simulation outcomes.

At 200N, for example, the percentage deviation reaches more. This higher deviation in experimental results at higher loads is attributed to the progressive deformation of the internal structure of the material shown in table 1.

The increased deviation observed in experimental results at higher loads can be attributed to the progressive deformation of the internal structure of the material.

In summary, the comparative analysis emphasizes the reliability of both experimental and computational methods, underscoring the importance of integrating these approaches for a comprehensive understanding of stress in materials shown in figure 5.

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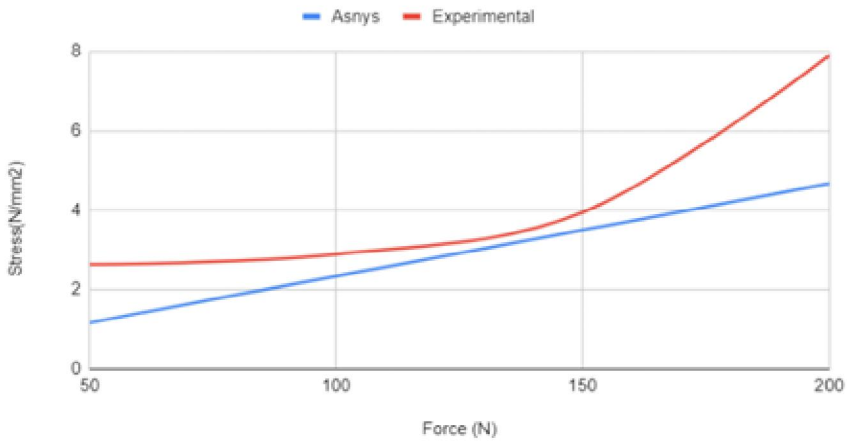

Figure 4: Tensile stress analysis on stepped rectangular specimen

Force	Ansys stress(N/mm2)	Experimental stress(N/mm2)	Percentage Deviation
50	1.1665	2.63	1.4635
100	2.341	2.893	0.552
150	3.4	3.945	0.545
200	4.666	7.89	3.224

Table 1: Tensile stress test data

V. CONCLUSION

This experimental method excels in determining internal stresses within structures that pose challenges due to their intricate shapes or exposure to complex loads. It serves as a formidable tool for comprehending the intricate workings of forces within structures that are both uniquely shaped and subject to diverse complexities. offers accurate full-field values of the principal normal stress difference in the model's plane; it uniquely provides the value of the nonvanishing principal normal stress along the model's perimeter, where stresses are typically highest; it provides full-field values of the principal stress directions, also known as stress trajectories; it can be used for both static and dynamic investigations; and it only requires a minimal investment in tools and materials for routine work. In contrast, the photoelastic technique proves to be a simpler and less cumbersome alternative for addressing issues related to models with arbitrary shapes, offering a more efficient solution compared to analytical methods and time- consuming mathematical equations. Digital photoelasticity greatly simplifies and accelerates the capture and processing of fringe patterns in images, streamlining the entire process of acquiring and analyzing intricate patterns compared to traditional methods. The technology's efficiency makes it a valuable choice for adoption in analysis alongside other analytical methods like photoelasticity, which provides closed- form solutions, demonstrating its reliability.

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