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Integrated Analysis of Stress Patterns in Transparent Polycarbonate Specimens: A Comparative Study between Photoelasticity and FEA Simulation for Compact Circular Testing

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Abstract

Photoelasticity stands as a robust experimental technique within the realms of mechanics and materials science, offering a means to visually assess and analyze stress distribution within materials possessing transparency or translucency. This method, a non-destructive testing approach, involves the visualization of stress on a model subjected to a load, leveraging the unique property of materials known as birefringence or double refraction. The procedure entails the careful selection of a suitable photoelastic material exhibiting birefringence, the creation of a physical model replicating real-world structures, and the application of mechanical stress to the model. Under the influence of stress, the material experiences birefringence, inducing alterations in its optical properties. The resulting pattern reflects various stress levels, facilitating the identification of stress concentrations, potential failure points, and providing insights into material behavior under different conditions. In present research work, The compact circular specimen underwent testing using a photoelasticity unit, subjected to four distinct loads. The outcomes from this experimental analysis were then compared with the results obtained through ANSYS simulation.

Keywords: *Polarization, Photo elasticity, Polari scope, Stress, Isochromatic and isoclinic fringes.*

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1. INTRODUCTION

PhotoelasticityIn order to ascertain how stresses are distributed across a material, one experimental method known as photo-elasticity can be utilized. David Brewster, a Scottish physicist, was the first person to describe the photoelastic phenomenon in 1816. E.G.Coker and L.N.G Filon of the University of London made significant contributions to the phenomenon throughout the early decades of the twentieth century[1-4]. The photoelasticity method is an important instrument for detecting the critical stress sites in materials that have intricate geometries, complicated loading conditions, or both. When using mathematical approaches becomes challenging or impossible, this approach is employed. The method of photoelasticity is not overly complicated and provides reasonably accurate pictures of stress distribution in both planes and abrupt discontinuities in a member. This is helpful information for determining the critical stress points in a part and the factors that contribute to stress concentration in irregular geometries [5-7].

The word "photo," which refers to the application of light beams and optical qualities, is where the term "photoelastic" comes from. The word "elasticity," on the other hand, refers to the study of stresses and deformations in elastic members. This technique makes use of the birefringent feature that is shown by a number of optical materials. The primary benefit of utilizing this method is the contemporaneous visualization of the stresses generated in the loaded models, which is only possible provided the stresses in question are capable of being calculated and photographed[8]. On the other hand, one of the limitations of the method is that it requires the use of models that are as accurate to representations of reality as they can be. This is due to the fact that the materials is utilised to build the models differ from the materials that are being copied [9]. An appropriate selection of the resin, taking into consideration the requisite qualities of a material in order for it to be categorized as photoelastic, is then the primary fact that attests the reliability of the approach [10].

In order to conduct a photoelastic experiment, you will need to make the models out of birefringent materials that are capable of satisfying a set of fundamental prerequisites. 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 [11-13]. 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 [14].

A photoelastic 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 [15]. 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 are. 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. The existence of intrinsic strains, also known as residual stress, is something that can frequently be seen within photoelastic resins. Keeping in mind that photoelastic materials are involved, the stresses in question will cause interference with the results, rendering the extrapolation of those results erroneous [16-17].

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. 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"[18] 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 well-defined, which will allow the results to be extrapolated to the clinical state [19-21].

2. METHODOLOGY

2.1. Selecting the material –

Numerous polymers possess adequate birefringence to be employed as specimen material for photoelasticity. Nevertheless, popular polymers like polycarbonate and polymethylmethacrylate (PMMA) could be excessively brittle or too insensitive to localized straining. Homalite-100 is a widely used general purpose substance that has been around for a while. Epoxy is another excellent substance that may be cast between glass plates, however two-dimensional work rarely uses this technique. Since polystyrene is clear, rigid, brittle and moderately strong we selected polystyrene.

2.2. Making a template-

Starting with a metal template that has been machined is a smart choice if you need to make multiple parts with the same shape. This template can be used as a guide to create many identically shaped specimens of Photoelasticity. In order to minimize problems and guarantee flawless machining, undercutting the template by around 0.050 inches is advised. This undercutting should start from one side and continue through approximately half the thickness of the template. This safety measure keeps the specimens from coming into touch with the router bit while it is being machined, guaranteeing accurate and reliable reproduction of the intended shape in each specimen.

2.3. Drilling work on the specimen-

If there are any holes in the specimen, such those used for load-application points with pins, they should be thoroughly drilled using a sharp bit and lots of coolant, like kerosene, water, or ethyl alcohol, to prevent undesired fringes from forming around the edge of the hole. To prevent chipping on the rear side of the specimen when the drill breaks through, it is recommended to place a sacrificial piece of similar material behind the specimen. Heat-induced fringes can be reduced by running the drill bit through the specimen two or three times, adding coolant between passes.

2.4. Machining the specimen-

When machining a specimen "from scratch," extreme caution must be used to prevent overheating the specimen's completed edges by making tiny incisions with a sharp milling cutter. To reduce heating, use a coolant, such as water, kerosene, or ethyl alcohol. If a template is utilised, the specimen's shape is roughed out using a bandsaw equipped with a narrow, sharp bandsaw blade. A generous tolerance of around 1/8 in. should be marked on the specimen all around the template edge, as the blade will heat the material and cause the edge to nick.

The model's edge should then be constructed using a router and a high-speed carbide router bit, ideally with fine multiple flutes. To remove excess material quickly and carefully, two centering pins should be used in succession. The router bit's diameter should be greater than the first centering pin's, and the second one should be the same size. As a result, the specimen's dimensions will match 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. An optical tool that is necessary to see the fringes caused by the stresses in the material is the polariscope. The polariscope's components must be positioned so that light can travel perpendicular to the specimen's plane in order for observation to be effective. If a loading frame is needed to exert tension on the specimen, it ought to be positioned halfway between the polariscope's initial and final elements.

When it comes to lighting, the use of monochromatic light is recommended for producing the sharpest fringes. The light source need not be coherent, though, and it is allowed to travel through the specimen without necessarily being collimated.

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 –

A photoelastic material's sensitivity is indicated by its fringe constant, or f_σ. The relationship between the specimen's thickness (h) in the direction of light propagation, the value N linked to a particular fringe, and the difference between the principal stresses is defined by this parameter ($\sigma_1 - \sigma_2$) in the direction of the plane normal to the light propagation for actual direction. This relationship is expressed as in terms of equation (1)

$$\sigma 1 - \sigma 2 = - N * f\sigma / h \ldots\ldots\ldots\ldots.(1)$$

To find out the value of f and σ, an experiment is carried out with a basic geometry model under known loading. A common calibration specimen for this purpose is the disk in diametric compression. Through this experimental process, researchers can ascertain the fringe constant, allowing for accurate interpretation and analysis of stress distribution in photo elastic materials.

2.8. Interpreting the fringe patterns-

Two types of patterns can be obtained: isochromatic and isoclinic. Figure 1 illustrates these patterns in relation to the primary stress directions and differences, respectively.

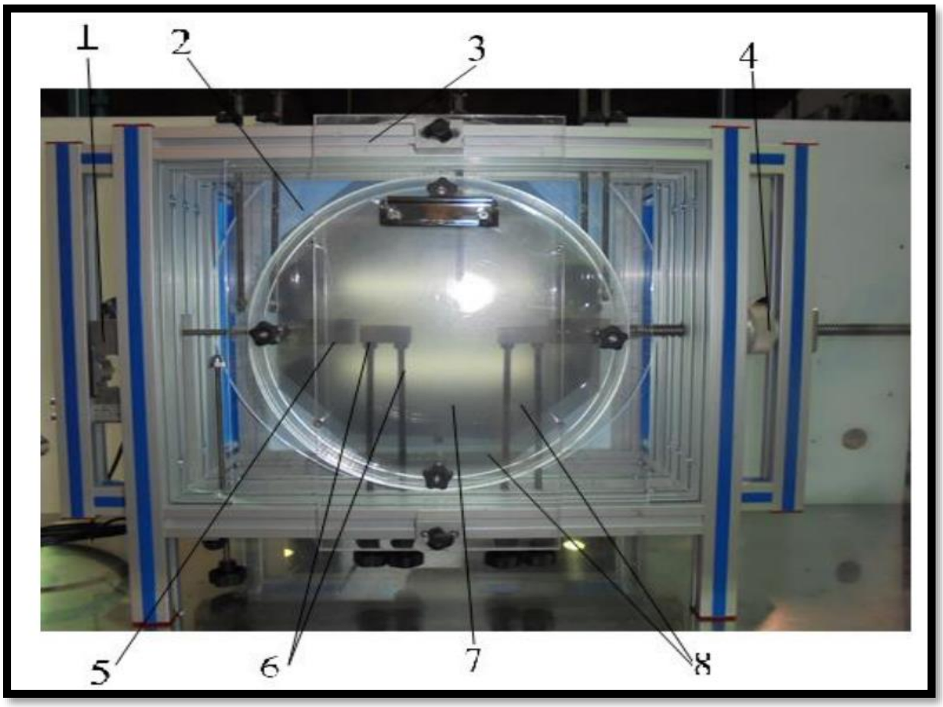


Figure1: Photo Elasticity Unit

(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)

3. **CALCULATION OF STRESS IN PHOTO ELASTICMATERIAL**: -

Formula Used: - σ = N * f(λ) / e [21]

Where: N = Fringe Order

f(λ) = Fringe factor (const.)

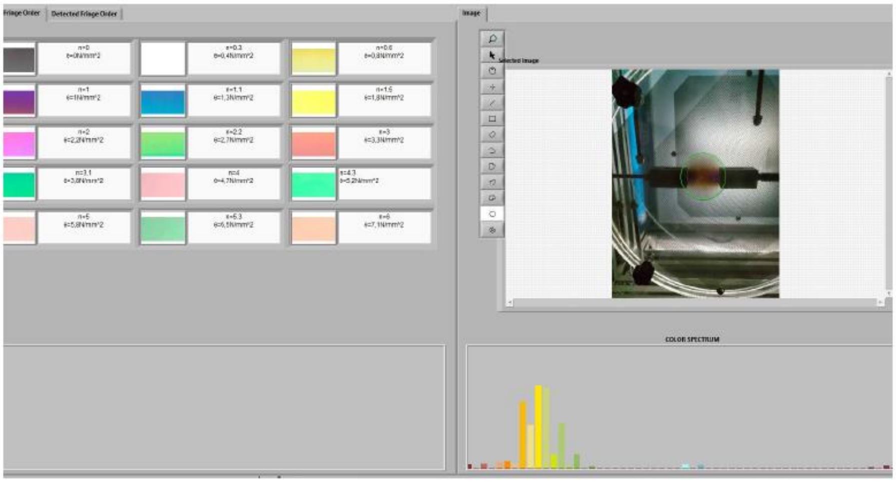
e = Thickness of Material

Material to be Used: - Polycarbonate

Fringe factor for polycarbonate = 13.15 N/mm

Thickness of material used: - 5mm

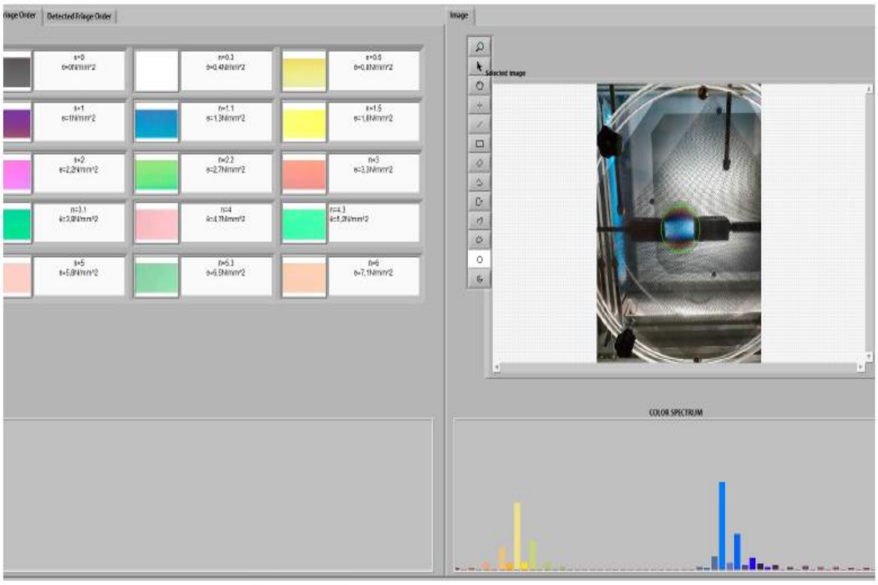
3.1. Data collected for Compact circular specimen from Photo elasticity unit



Tensile Load :- 50 N

N	Color	Force (N)	Stress σmax (N/mm^2)
0.6		50	1.578

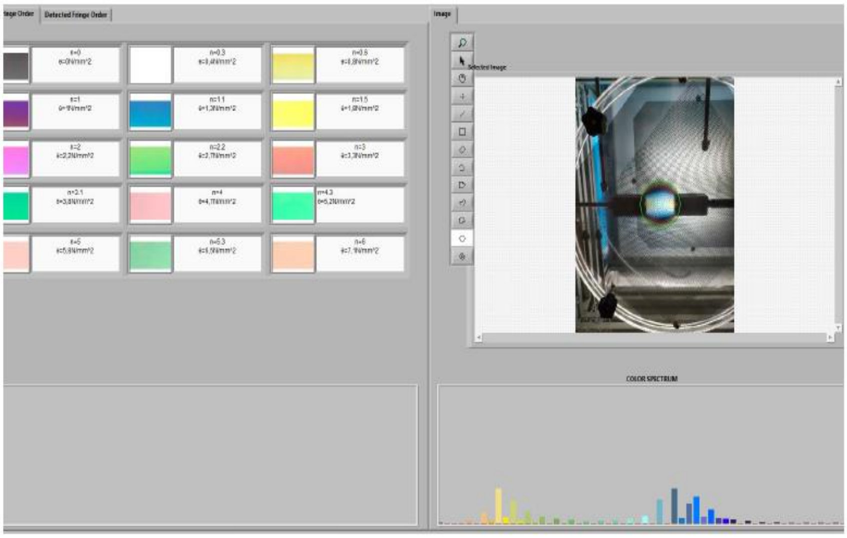
(a) at load 50N



Tensile Load :- 100 N

N	Color	Force (N)	Stress σmax (N/mm^2)
1.1		100	2.89

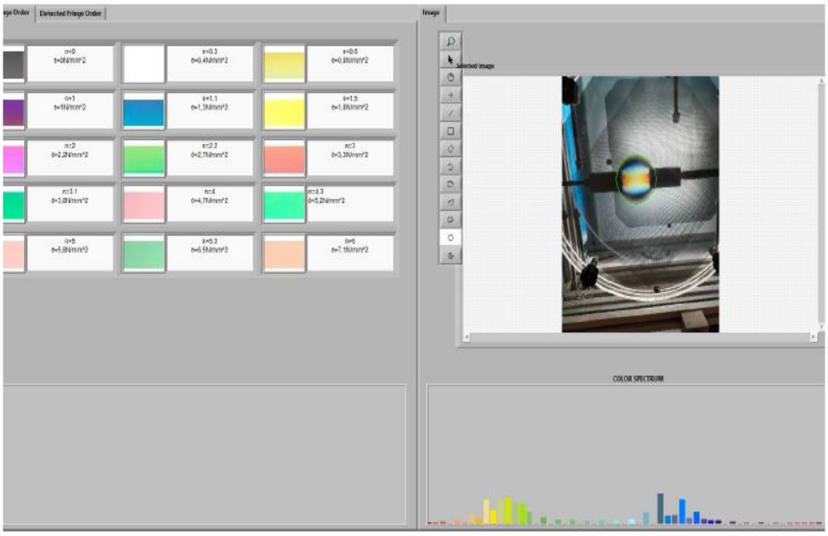
(b) at load 100N



Tensile Load :- 150 N

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

(c) at Load 150 N



Tensile Load :- 200 N

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

(d) at Load 200 N

Figure 2: Experimental Readings at different load

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.

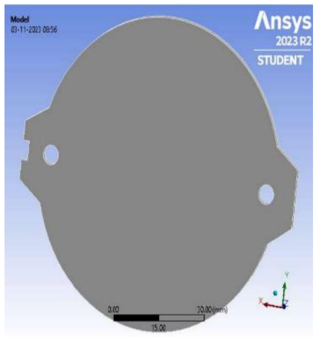
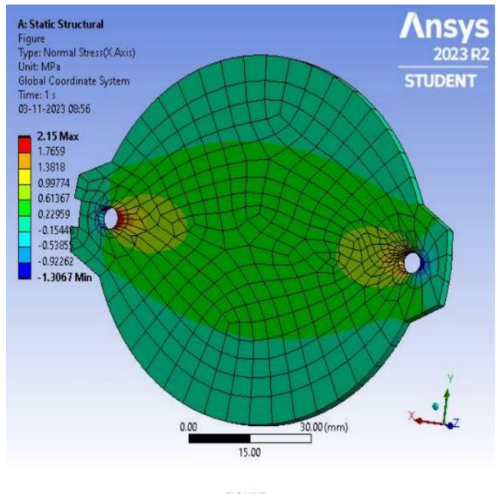
Actual Specimen	3-D Design of Specimen	Ansys Stress
		

Figure 3: Finite Element Analysis for Rectangular Specimen with Arc Feature

4. RESULTS AND DISCUSSIONS: -

The findings consistently demonstrated stress patterns in polycarbonate specimens through the application of both photo elasticity 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 compact circular has been tested with the help of photo elasticity unit under four different loads. The outcomes are contrasted with the ANSYS simulation's outcomes.

The experimental data and the ANSYS results at lesser loads correlate well. For instance, at 50N, the stress values derived from ANSYS simulation and experimental measures are 1.879 N/mm² and 1.578 N/mm² respectively, with a percentage deviation of 19.07%.

Similarly, At 100N, the stress values from ANSYS simulation and experimentation are 2.375 N/mm² and 2.89 N/mm², respectively, with a percentage deviation of 17.82%.However, at higher loading conditions, the experimental results deviate more significantly from the ANSYS simulation outcomes.

At 200N, for example, the percentage deviation reaches 39.77%. 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.

Table 1: Tensile stress test data Rectangular Specimen with Arc Feature

Force (N)	Ansys Stress (N/mm^2)	Experimental Stress (N/mm^2)
50	1.1879	1.578
100	2.3750	2.890
150	3.5630	3.945
200	4.7514	7.890

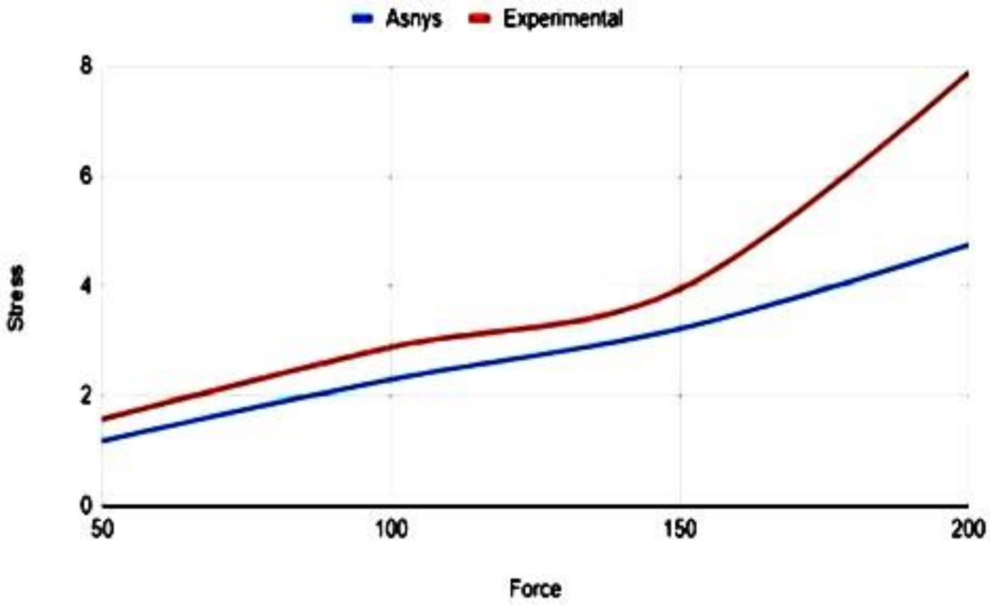


Figure 4: Tensile stress analysis on compact circular specimen

5. CONCLUSIONS

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. In contrast, the photo elastic 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 photo elasticity 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 photo elasticity, which provides closed-form solutions, demonstrating its reliability.

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