STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 12, Issue 3, 2024
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Research JoPC

# Using FEA Simulation and Photoelasticity Techniques to Observe Integrated Stress Pattern for Transparent Polycarbonate Rectangular Specimen having Arc Feature

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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 visualise 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 photo elastic 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 compact circular specimen under four different stresses. Next, a comparison was made between the experimental analysis's results and those from the ANSYS simulation.*

**Keywords:** Polarization, Photo elasticity, Polari Scope, Stress, Isochromatic and Isoclinic Fringes.

## INTRODUCTION

One of the experimental method for figuring out how stresses are distributed in a material is known as photo-elasticity. Scottish scientist david brewster was the first to describe the photoelastic phenomenon in 1816 [1, 2, 3]. In the early decades of the twentieth century, E.G. Cooker and L.N.G. Filon from the University of London made important contributions to the phenomena. A valuable tool for identifying the key stress locations in materials with complex geometries, demanding loading circumstances, or both is the photoelasticity approach [4, 5]. When using mathematical approaches becomes challenging or impossible, this approach is employed. Photoelasticity is an easy-to-use technique that yields fairly realistic images of the distribution of stress in both planes and abrupt discontinuities inside a member. Finding a part's essential stress spots and the elements that lead to stress concentration in irregular geometries are made easier with the use of this knowledge [6]. (Anon., 2009–2016)

The term "photoelasticy" derives from the word "photo," which describes the application of light beams and optical properties. The study of stresses and deformations in elastic members is what is meant to be understood by the term "elasticity".

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Received Date: January 01, 2024
Accepted Date: March 06, 2024
Published Date: April 18, 2024

**Citation:** Om Prakash Sondhiya, Roopesh Tiwari. Using FEA Simulation and Photoelasticity Techniques to Observe Integrated Stress Pattern for Transparent Polycarbonate Rectangular Specimen having Arc Feature. Journal of Polymer & Composites. 2024; 12(3): 55–63p.

This method exploits the birefringent property displayed by certain optical materials [7]. (from James F. Doyle and James W. Phillips' 1989 publication).

The main advantage of this approach is the real-time display of the stresses produced in the loaded models; however, this is only achievable if the stresses in question can be measured and captured on camera. However, one drawback of the approach is that it necessitates the employment of models that are as true to real-world representations as possible. This is so because the materials being replicated are not the same as the materials used to build the replicas [8]. The main factor confirming the approach's dependability is thus the suitable choice of resin, which takes into account the characteristics of a material required to be classified as photo elastic [9, 10, 11].

You must construct the models out of birefringent materials that can meet a number of essential requirements in order to carry out a photoelastic experiment. The polariscope must be transparent to the light passing through it in order to be used for observation [12, 13]. This transparency can be lost due to one of two things: (1) a decrease in the constituent materials' indices of refraction, or (2) trapped air. Both cases include a modification of the photoelastic medium properties that lead to light dispersion and, consequently, a decrease in the material's transparency [14–19].

The possibility that the material may be impacted by “the border effect,” a phenomenon related to the water absorption and evaporation that happens in plastic materials, is another consideration. The model's dimensions alter as a result of this phenomena, and the internal tensions alter as a result [20]. One particularly important property is the photo elastic sensitivity to induced stresses on the model, which is represented by a photo elastic constant [21]. A highly elastic module will prevent the material from changing shape as it is loaded [22, 23]. Because of connection between the photo elastic constant and the elasticity module, there is an additional property that needs to be considered. In an ideal world, the figure of merit's value would also be as high as is humanly possible and would hold steady throughout the assessment. Photo elastic resins frequently exhibit the presence of intrinsic stresses, commonly referred to as residual stress. The stresses in question will interfere with the results, making the extrapolation of those results incorrect, given that photoelastic materials are involved [24].

In an ideal environment, the model materials would exhibit clinical behaviour that is identical to the real thing—that is, behaviour that the researcher is trying to replicate [25, 26]. Regarding dental tissue models, the properties of these models need to be quite close to those associated with enamel and dentin. These structures are responsible for absorbing the force applied during chewing and relaying the resulting stresses to the tissues supporting the teeth [27, 28, 29, 30]. At minimum, the photo elastic material employed in the simulation needs to be able to work within the parameters of its elastic capacity while simulating supporting tissues, such the alveolar bone in this case. Moreover, it provides a photo elastic response that most closely matches the intensity of the load applied to photo elastic models, i.e., from “loads that best simulate a genuine condition” [31]. Since it is impossible to accurately replicate every variable that affects the oral medium, a material that can, at the very least, provide a photo elastic response most compatible with the load intensity being applied to the photo elastic models when they are under stress should be used [32]. To guarantee that the polariscope's discernible fringes are clear and well-defined, enabling the results to be extrapolated to the clinical condition.

## METHODOLOGY

### Selecting the Material

There are numerous polymers possess adequate birefringence to be employed as specimen material for photo elasticity. However, common polymers like polycarbonate and polymethylmethacrylate (PMMA) might be too brittle or too insensitive to localized straining. Homalite-100 is a widely used different purpose material that comes in different thicknesses and is available in large, optically-quality sheets. More recently, PSM-1 has been available, and it has great fringe sensitivity and machining capabilities. Epoxy is another excellent material that can be cast between glass plates, though twodimensional work rarely uses this technique. Since polystyrene is clear, rigid, brittle and moderately strong we selected polystyrene.

**Making a Template**

Starting with a metal template that has been machined is a good idea if you need to make multiple pieces with the same shape. 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.

**Drilling the Specimen**

If there are any holes in the specimen, like those used for load-application points with pins, they should be carefully drilled using a sharp bit and plenty 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 back 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.

**Machining of the Specimen**

When machining a specimen "from scratch," extreme caution must be used to prevent overheating the specimen's finished 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 utilized, the specimen's shape is roughed out using a bandsaw equipped with a narrow, sharp bandsaw blade. Since the blade will heat the material and cause the edge to nick, a generous allowance of approximately 1/8 in. should be marked on the specimen all around the template edge. 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 first centering pin should have a diameter larger than the router bit, and the second one should be the same size. This will leave the specimen with the same dimensions as the template.

**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. 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 needed to exert stress on the specimen, it ought to be positioned halfway between the polariscope's initial and final elements (Figure 2).

When it comes to lighting, the best fringes should be produced with monochromatic light. The light source need not be coherent, though, and it is allowed to pass through the specimen without necessarily being collimated. This variety in light source types offers useful alternatives for testing and analyzing stress visualization.

**Recording the Fringe Patterns**

Utilize a camera or imaging device that is fastened to the polariscope to take digital pictures of the fringe patterns.

**Calibrating the Material**

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

$$\sigma_1 - \sigma_2 = N * f\sigma/h$$

To determine the value of σ, the experiment is conducted by using a model of simple geometry subjected to known as simple 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.

### 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 below Figure 1.

### CALCULATION OF STRESS IN PHOTO ELASTICMATERIAL

Formula Used:- .σ = N * f(λ)/e

Where: N = Fringe Order

f(λ) = Fringe factor (const.)

e = Thickness of Material

Material Used: - Polycarbonate

Fringe factor for polycarbonate = 13.15 N/mm

Thickness of Material Used: - 5 mm

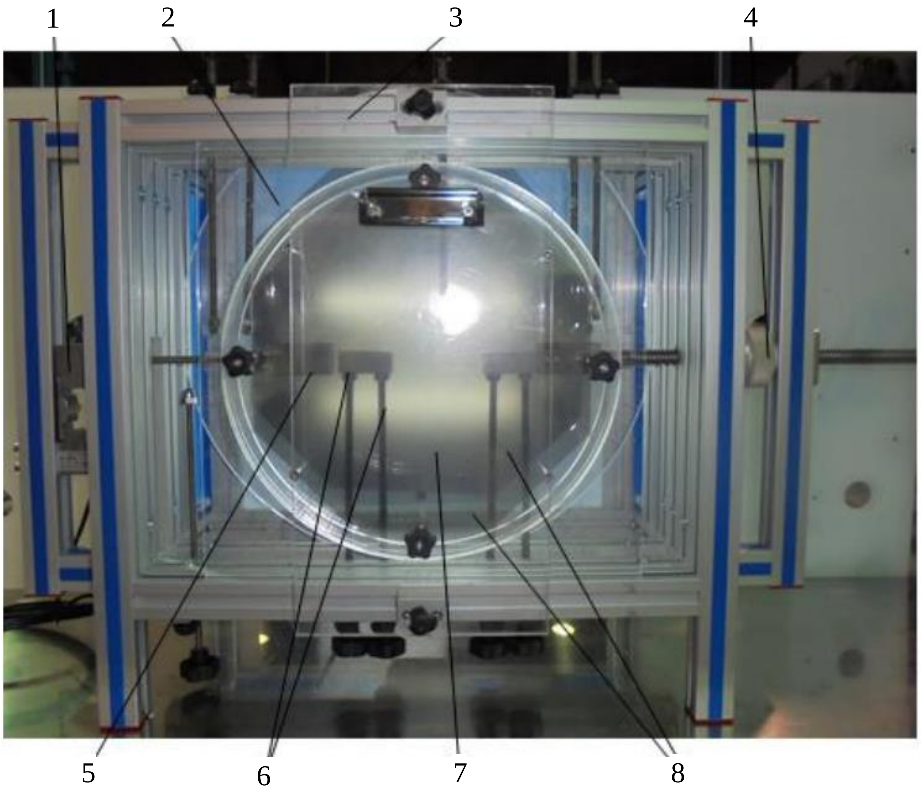


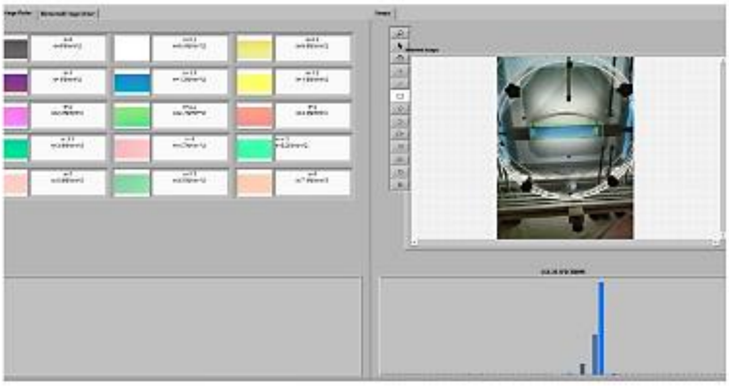

**Figure 1.** Representation of Photo Elasticity measurement test rig (1. E-C: load cell unit, 2. P-D: translucent diffusion plate assembly, 3. S-A: translucent supporting surface plates, 4. T2: force or load screw, 5. M1: clamp & screws to fasten specimens. 6. T1: screws for applying pressure on the specimens, 7. D-C: discs, 8. P: double effect polarizing filters) [Source: Experimental setup at IET-DAVV, Indore]

**Data Collected for Compact Rectangular specimens arc feature.**

Tensile Load :- 50 N

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

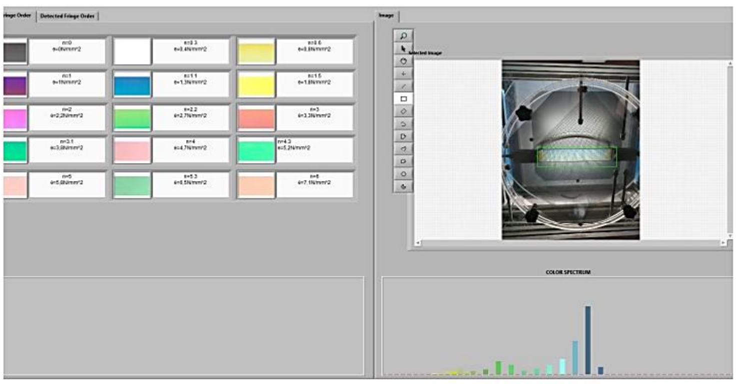
(a) At load 50 N



Tensile Load :- 100 N

| N | Color | Force (N) | Stress σmax (N/mm^2) |
|---|---|---|---|
| 1.1 | ● (blue) | 100 | 2.89 |

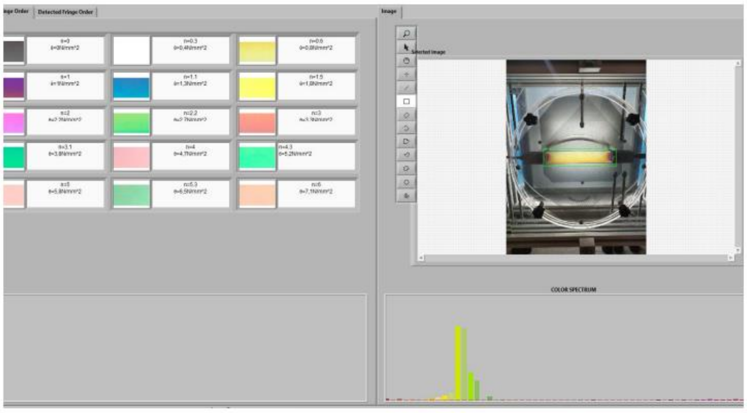
b) At load 100 N



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) |
|---|---|---|---|
| 2.2 | | 200 | 5.786 |

(d) At load 200 N

**Figure 2.** Experimental Readings for Rectangular Specimen with Arc Feature with different loading condition [Source: Experimental setup at IET-DAVV, Indore].

**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.

**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 Rectangular Specimen having Arc Feature has been tested with the help of photoelasticity unit under four different loads. The outcomes are contrasted with those from the ANSYS simulation.

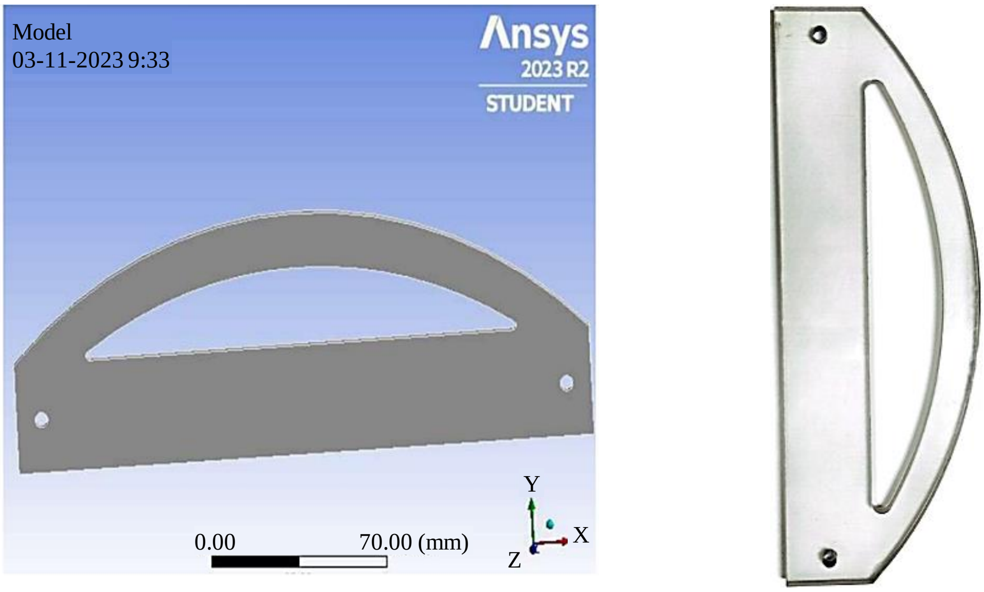
The ANSYS results are in good agreement with the experimental results at lower loads. The stress values obtained from ANSYS simulation and experimental measurements, for example, are 1.3356 N/mm² and 1.985 N/mm² respectively.

Similarly, at 100N, the stress values from ANSYS simulation and experimentation are 2.489 N/mm² and 2.89 N/mm² respectively.

Similarly, at 150N, the stress values from ANSYS simulation and experimentation are 4.008 N/mm² and 3.945 N/mm² respectively.

Similarly, at 200N, the stress values from ANSYS simulation and experimentation are 5.342 N/mm² and 5.786 N/mm²respectively.

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 Table 1.




(a) 3D model of Rectangular Specimen (b) Actual Test Polycarbonate Specimen

**Figure 3.** Modelling for Rectangular Specimen with Arc Feature.

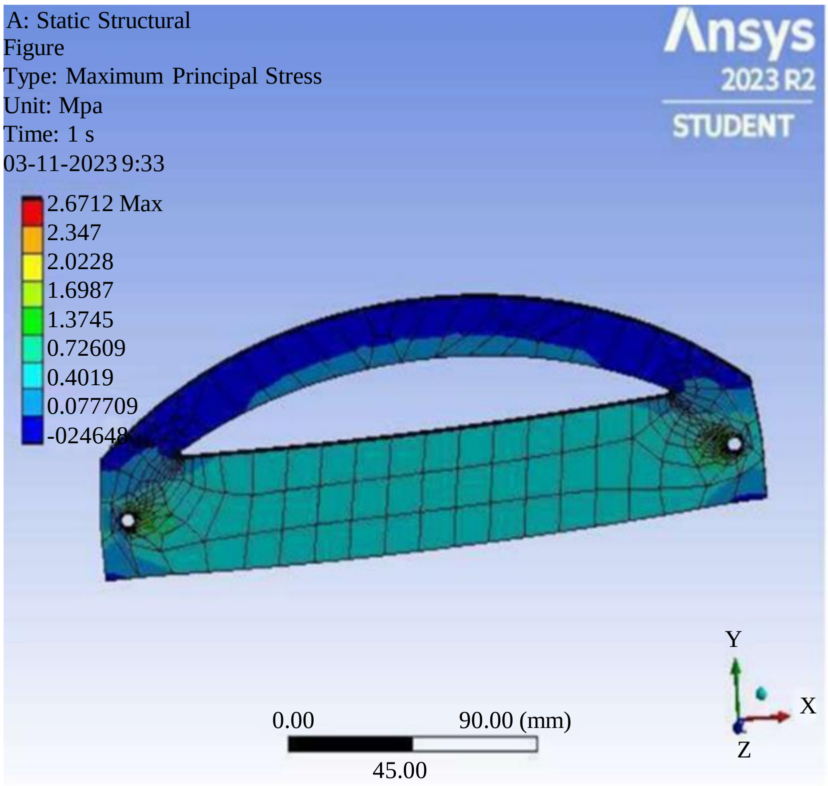



**Figure 4.** Finite Element Analysis for Rectangular Specimen with Arc Feature.

**Table 1.** Tensile stress test data [Source: Testing data form experimental setup].

| Force (N) | Ansys Stress (N/mm$^2$) | Experimental Stress (N/mm$^2$) |
|---|---|---|
| 50 | 1.3356 | 1.985 |
| 100 | 2.4890 | 2.890 |
| 150 | 4.0068 | 3.945 |
| 200 | 5.3420 | 5.786 |

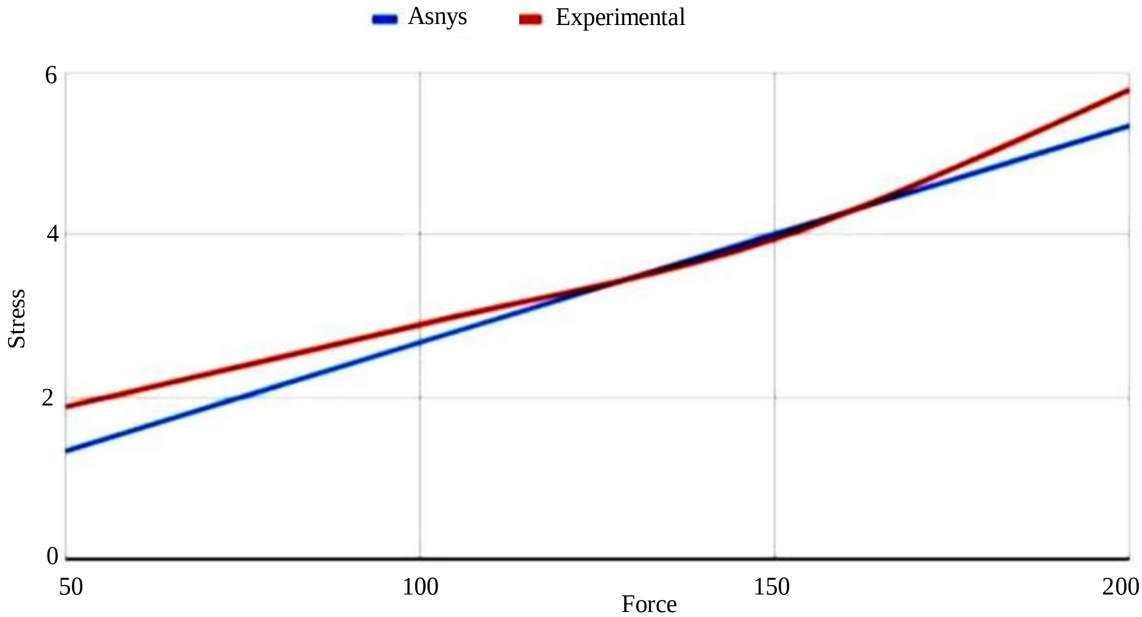



**Figure 5.** Tensile stress analysis in rectangular specimen with arc.

## 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 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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