Experimental and Finite Element Analysis of Circular Disc under Diametrical Compression Loading

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ABSTRACT

This paper presents the experimental estimation of stresses in the epoxy based material for varying weight percentage of alumina particles using Photoelasticity method and validating the results using ANSYS. The study deals with the stress distribution within the diametrical disc under compression loading which uses the property birefringence. Photoelasticity method used to calculate the stresses for the intricate shapes models where the analytical solutions are too complex. The significance of the method is to do the variety of stress analyses and even for routine use in design, particularly before the advent of numerical methods, such as for instance finite elements or boundary elements.

Keywords: Birefringence, Polariscope, Epoxy.

I. INTRODUCTION

Determination of stresses inside the material which are under loading is most important factor as per design considerations. There are several methods for the stress analysis which gives the behavior and the distribution of stresses in the material. There are basically two methods

- Experimental
  - Brittle lacquers.
  - Strain gauges.
  - Photoelasticity.
  - Photoelastic coatings.

- Analytical
  
First two methods, because of their complexity and some error in results they are not used. The photoelastic coating is the method which uses the brittle coating of photoelastic material on the metallic materials to calculate the stress distribution inside the material. The photoelasticity method is widely used to calculate the stresses inside the transparent material by the property of birefringence which is the property of transparent material, when the ray of monochromatic light passes through the photoelastic material it will deviates in two fringes which gives the direction of two principle stresses.

A. Introduction to Photoelasticity

Photoelasticity is an experimental method to determine stress distribution in a material. The method is mostly used in cases where mathematical methods become quite cumbersome. Unlike the analytical methods of stress determination, photoelasticity gives a fairly accurate picture of stress distribution even around abrupt discontinuities in a material. The method serves as an important tool for determining the critical stress points in a material and is often used for determining stress concentration factors in irregular geometries. The method is based on the property of birefringence, which is exhibited by certain transparent materials. Birefringence is a property by virtue of which a ray of light passing through a birefringent material experiences two refractive indices. The property of birefringence or double refraction is exhibited by many optical crystals. But photoelastic materials exhibit the property of birefringence only on the application of stress and the magnitude of the refractive indices at each point in the material is directly related to the state of stress at that point. Thus, the first task is to develop a model made out of such materials. The model has a similar geometry to that of the structure on which stress analysis is to be performed. This ensures that the state of the stress in the model is similar to the state of the stress in the structure.

When a ray of plane polarized light is passed through a photoelastic material, it gets resolved along the two principal stress directions and each of these components experiences different
The difference in the refractive indices leads to a relative phase retardation between the two component waves. The magnitude of the relative retardation is given by the stress optic law:

\[ \sigma_1 - \sigma_2 = \frac{N}{h} f_\sigma(t) \]

Where \( N \) is the fringe order, \( f_\sigma(t) \) is the material fringe value, \( h \) is the specimen thickness, \( \sigma_1 \) is the first principal stress, and \( \sigma_2 \) is the second principal stress. The two waves are then brought together in a polariscope. The phenomena of optical interference take place and we get a fringe pattern, which depends on relative retardation. Thus studying the fringe pattern one can determine the state of stress at various points in the material.

II. EXPERIMENTAL

A. Material and sample preparation

A circular disc of epoxy containing centric circular and non-circular holes with varying percentage of alumina if prepared by open mould technique. The materials used for specimen preparation are epoxy resin and stoichiometric quantity of hardener (HYD951) was added into the epoxy in which the alumina particles are reinforced percentagewise.

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Dia(mm)</th>
<th>Thickness(mm)</th>
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<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>5</td>
</tr>
</tbody>
</table>

B. Experimentation

1. Plane Polariscope

The setup consists of two linear polarizer’s and a light source. The light source can either emit monochromatic light or white light depending upon the experiment. First the light is passed through the first polarizer which converts the light into plane polarized light. The apparatus is set up in such a way that this plane polarized light then passes through the stressed specimen. This light then follows, at each point of the specimen, the direction of principal stress at that point. The light is then made to pass through the analyzer and we finally get the fringe pattern.

The fringe pattern in a plane polariscope setup consists of both the isochromatics (the locus of the points along which the difference in the first and second principal stress remains the same) and the isoclinic’s (the locus of the points in the specimen along which the principal stresses are in the same direction). The isoclinic’s change with the orientation of the polariscope while there is no change in the isochromatics.

![Fig. 1: A circular disc of epoxy containing centric circular and non-circular holes](image)

![Fig. 2: Plane Polariscope](image)
III. PARTICLE CALCULATIONS
A. Volume Of Component = 9822 mm$^3$
B. Percentage of reinforcement = 1%, 3% and 5%.

Volume of reinforcement for 1% = \( \frac{1 \times 9822}{100} = 98.22 \text{mm}^3 \)

Volume of reinforcement for 1% = \( \frac{3 \times 9822}{100} = 294.66 \text{mm}^3 \)

Volume of reinforcement for 5% = \( \frac{5 \times 9822}{100} = 491.1 \text{mm}^3 \)

Volume of one Alumina particle = \( \frac{4}{3} \pi r^3 = \frac{4}{3} \times 0.5^3 = 0.52 \text{mm}^3 \)

Number of particle for 1% reinforcement = \( \frac{98.22}{0.52} = 189. \)

Number of particle for 3% reinforcement = \( \frac{294.66}{0.52} = 567. \)

Number of particle for 5% reinforcement = \( \frac{491.1}{0.52} = 945. \)

IV. FINITE ELEMENT ANALYSIS
A. Modeling
The 3D modeling done in Solid works-12 with respective dimensions. The below sketch shown the same,

Fig. 3: Disc with alumina reinforcement (1 %)

Fig. 4: Disc with alumina reinforcement (3 %)

Fig. 5: Disc with alumina reinforcement (5 %)

B. Finite Element Analysis

1. Plain Epoxy
The 3D specimens are modeled in Slid-Work then imported into ANSYS. The properties of epoxy (\( E = 3416 \) Mpa, \( \mu = 0.33 \)) are given. The specimens are meshed with, Brick 8 node, plane 185 elements. The uniform pressure is applied on the upper diametric edge by selecting proper nodes on that edge. The other side is constrained with UX and UY degrees of freedom. Method is repeated for the different pressure values to get the different fringes pattern and the critical stress pattern. The Von-misses stress distribution is obtained as shown below

Fig. 6: Von-misses stress for pressure 6.41 Mpa
Fig.7: Von-misses stress for pressure 8.91 Mpa

Fig.8: Von-misses stress for pressure 12 Mpa

2. Epoxy Disc with Centric Circular and non-circular holes
   To check the stress concentration and fringe deviation through the different centric holes geometries (circular and non-circular) the following analysis for the same is done and shown below, all the analysis is done at pressure value of 8.91 Mpa and the radius of hole is 10mm. By calculating the perimeter of circle and equating same with the perimeter of other centric geometries and hence generating the holes.

Fig.9: Von-misses stress of Centric Circular hole

Fig.10: Von-misses stress of Triangular hole

Fig.11: Von-misses stress of Rectangular hole
From the above analysis it is found that maximum value of stress is obtained for rhombus holes at centre followed by rectangular hole then circular and last triangular. This is because of the direction of application of pressure.

3. Epoxy Disc with alumina particle reinforcement

The modeling shown above (fig.3,4,5) are the geometries showing the reinforcement of alumina particle percentage wise i.e. 1%, 3%, 5% and shape assumed to be spherical. Alumina particle assumed to be nano particles, when the pressure is applied on the disc (nodal pressure) the internal resistance is found to be very high as the percentage of particle increases. The von-misses diagram for reinforcements are shown below.

The fringes pattern obtained from the analysis of epoxy disc with alumina particle reinforcement is not sharp and clear, it is because of internal resistance offered by alumina particles which leads to separation of each fringe striking the particle.

V. VALIDATION OF ANSYS RESULTS WITH EXPERIMENTAL RESULTS

The experimental results are obtained with different specimens loaded under a load of 20 kg. Different principle stress values are obtained for plain epoxy disc and epoxy with alumina particle reinforcement. The disc kept under diametric compression between load cells and gradually increase the load up to 20 kg and for this load calculates the principle stresses by using the
photoelastic equations. The following table and graph shows the experimental results and Ansys results both.

### Table 2: Principle Stress

<table>
<thead>
<tr>
<th>% Of Alumina</th>
<th>Experimentally $\sigma_1$ (Mpa)</th>
<th>Ansys $\sigma_1$ (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.4</td>
<td>4.7</td>
</tr>
<tr>
<td>1</td>
<td>5.687</td>
<td>4.98</td>
</tr>
<tr>
<td>3</td>
<td>6.7</td>
<td>9.57</td>
</tr>
<tr>
<td>5</td>
<td>6.9</td>
<td>13.56</td>
</tr>
</tbody>
</table>

![Graph showing major principle stress vs alumina particle %](image)

**Fig.16: Major Principle Stress v/s Alumina particle %**

For plain epoxy and 1% alumina the experimental and Ansys results are nearly matched but for 3% and 5% reinforcement the values showing so much of variation this is because for experimental work the alumina particle assumed to be nano-particle and for Ansys the particles considered as micro-particle because of some modeling restrictions. But it is found that the variation of Major principle stress in experiment and Ansys is nearly same i.e. there is large variation between 1% and 3% in both condition.

### VII. CONCLUSION

From the experimental results after calculating the stresses by applying the birefringence expression it is seen that the value of stresses obtained experimentally are matched with the FE analysis results i.e. ANSYS results. So this experimental method will help to determine the stresses in the material which is not possible analytically.

### VIII. REFERENCES


