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Stress Analysis of Different Types of Beam of Polycarbonate using FEA and Photo-Elasticity

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Abstract*— Cantilever and simply supported beams are undoubtedly most commonly used structural elements. So, it is very important to find out the points on these beams at which the maximum stress occurs i.e. the failure points. Failure of beams can be avoided by making some modification around these points. The objective of this research paper is to find these points of maximum stress and calculate the value of stress at these points. In current case, a comparative study between experimental and simulated fringes was used to compare the stresses developed in the beams. A comparison was also made between experimental and simulated values of the difference in principal stresses to validate the FEA solution.

Keywords: Photoelasticity, Birefringence, Isochromate, FEA, Stress concentration.

I. INTRODUCTION

Stress evaluation is an essential function in an engineering discipline. Stress analysis is the evaluation of the effects of loads on physical body. Stress analysis is the base of the engineering design of any system. Photoelastic fringes acquired experimentally with circular polariscope can assist designers to determine the stress field developed in the components. A finite element analysis using ANSYS software was used to simulate fringes and stresses developed in the beam model. Several studies have been conducted, experimentally [1-4, 6, 7, 8] as well as numerically [5].

Rao [1] studied photoelastic analysis of a composite fabricated model with HY951 as infill material. Chandrasekaran and Kapoor [2] studied the stress distribution for a photoelastic chip tool interface for a varying range of rake angles from -10 to 20 degree. Jain and Kumar [3] reviewed the stress analysis using photoelasticity technique. Jones and Hozos [4] presented the distribution of stress in a flat plate having an elliptical hole using photoelsticity. Shete et al. [5] carried out a comparative study of stress distribution of an internal combustion engine piston using photoelastic and finite element techniques. Mekalke et. al. [6] studied the effect of additional loading on a pre-stretched plate with circular hole using different types of meshes. Chandrakar and Shrivastava [7] presented the scope and applications of photoelasticity technique in different domains of science and research. Dongare and Kailash [8] studied the effect of bending stresses generated on a helical gear using photoelastic technique. Chandrashekhara and Jacob [9] analyzed the composite model of wall supported on beam using photoelasticity.

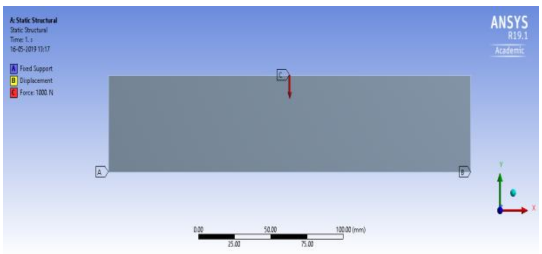
The objective of this research work is to study the patterns of distribution of stress in different type of beams of polycarbonate with rectangular cross-section using finite element method and validate the results experimentally using polariscope.

II. METHODOLOGY OF STRESS ANALYSIS

Finite element method is used for carrying out the stress analysis of Polycarbonate model and results are verified by photo elasticity theory. To do finite element analysis, a virtual beam model similar to the polycarbonate beam model is prepared in ANSYS 19.1 and the results of stress analysis are compared against the experimental results on polariscope.

2.1 Finite Element Analysis (FEA)

Nowadays, Finite Element Method is the most commonly used tool for calculating numerical solution of various engineering problems. For the stress analysis of the polycarbonate model of beams the outer geometry or profile of the model is drawn in ANSYS 19.1. Element type and properties of material are fed, and the model is meshed. Smart size option is used for meshing and the global size of element is taken as 3. Constraints and loads are applied to the meshed model as depicted in the **Figure 1** and solution is generated for this finite element model. Maximum shear stress patterns are thus obtained as shown in **Figure 2**.



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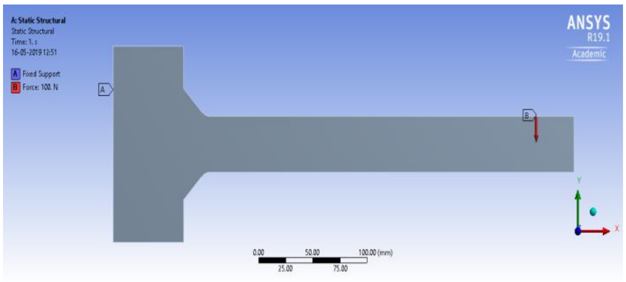


(b)

Fig.1 (a) and **(b)** Applied loading and constraints on beam

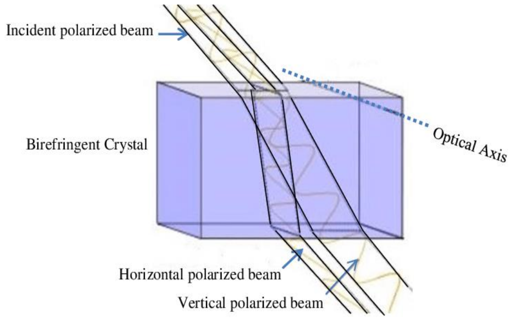
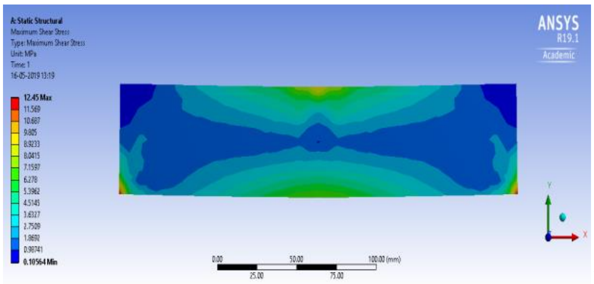
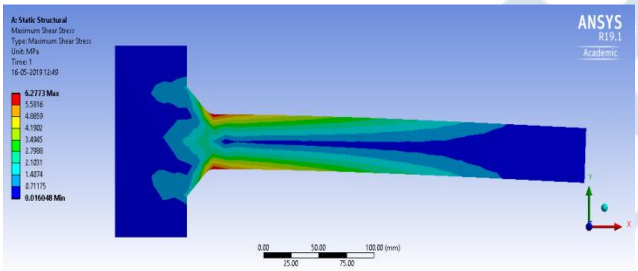


Fig. 3: Birefringence



(a)



(b)

Fig.2 (a) and (b) Maximum shear stress distribution

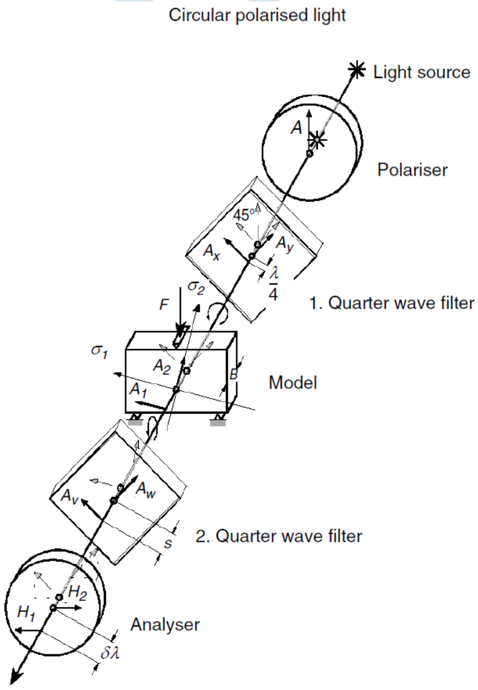


Fig. 4: Photoelastic Beam Path

2.2 Photo Elasticity:

Birefringence, the double refraction of light in a transparent material which is often the property of anisotropic materials, but under mechanical load isotropic materials act as anisotropic materials as their structure is altered. Refractive index of the material depends on the induced stresses. Anisotropy can be understood by an example, let us consider if the compressive strain is being applied in x-direction, then the molecular structure in the x-direction gets compressed. Hence the medium becomes optically denser and causes an increase in refraction index in that direction. On the other side, in the y-direction, the material experiences a positive lateral strain, due to which the molecular structure opens. Hence the medium becomes optically thinner results in decreased refraction index. In case of tensile strain and lateral contraction, the effect on refractive index gets reversed.

Generally, the refractive index remains constant in most of the homogeneous transparent materials. But in case of those transparent materials that behave like non-homogeneous on the application of stresses or strain, i.e. Photoelastic materials, the refractive index becomes a function of the principal stress or strain:

$n_1 = f(\sigma_1)$

$n_2 = f(\sigma_2)$

If a light vector 'A' that is linearly polarized, is passed through a transparent material at a point *P*, and 1-1 and 2-2 are the direction of principal stresses (Fig. 4), the oscillation vector gets bifurcated into polarized vectors *A1* and *A2* which oscillate in the planes 1-1 and 2-2 respectively. If *v1* and *v2* are the velocities of *A1* and *A2* then the time required by these vectors to pass through the transparent body having *th* thickness comes out to be th/v_1 or th/v_2 respectively.

Hence path difference or relative delay between two vectors is given by:

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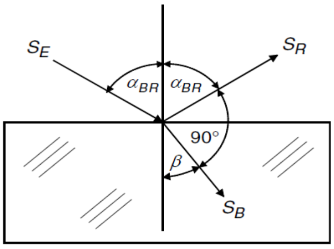


Fig. 5: Brewster’s Law

$\delta = c.th/v_1 - c.th/v_2 = th.\,(n_1 - n_2)$

According to Brewster’s law: “The relative change in the refractive index is directly proportional to the difference in the principal stresses.”

$(n_1 - n_2) = k\,(\sigma_1 - \sigma_2)$

where *k* is a proportionality factor that depends on the wavelength of used light and physical properties of material. It gives idea about photoelastic sensitivity of the material.

If we combine the above equations, we obtain the main equation in photoelasticity:

$\delta/(th.k) = (\sigma_1 - \sigma_2)$

III. DESCRIPTION

3.1: Set-up Layout:

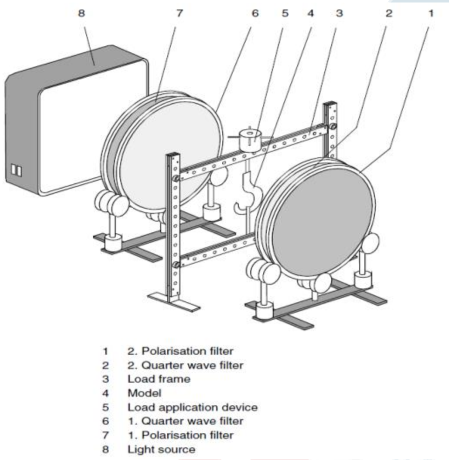
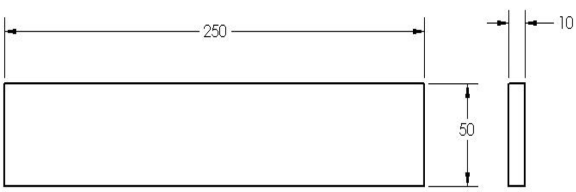


Fig. 6: Schematic Illustration of Experimental System

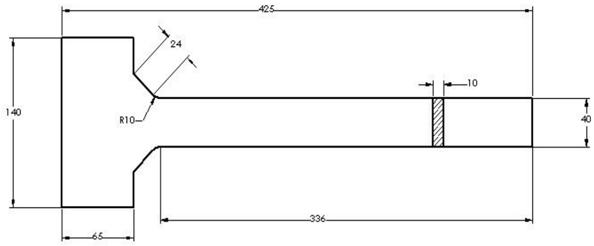
3.2: Specimen Properties:

- Material : Polycarbonate (MAKROLON)
- Young’s Modulus : 2350 MPa
- Proportionality Factor, k : 1/7

3.3: Specimen Dimensions:



(a)



(b)

Fig.7: Dimensions (in mm) of the **(a)** simply supported beam and **(b)** cantilever beam

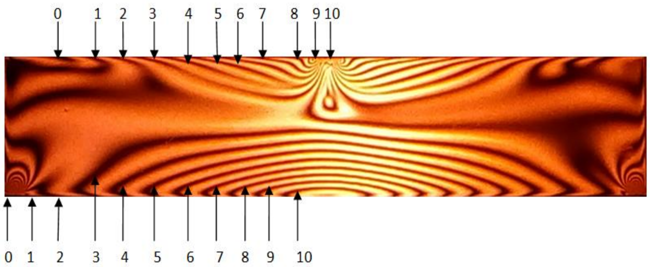


Fig.8 Stress field with fringe order identified for simply supported beam

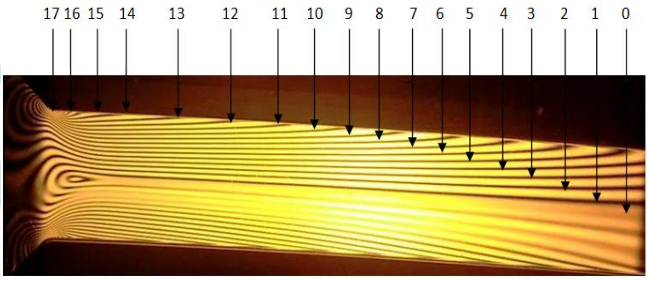


Fig.9 Stress field with fringe order identified for cantilever beam

You can see the isochromatic images. Start at an unloaded and thus tension-free point i.e. in simply supported beam - the unloaded corner. This is the "zero-th" order isochromate. In this way you count to the 10th order and have thus located the highest tension.

The stresses values in the material can be calculated with the formula

$\delta/(th.k) = (\sigma_1 - \sigma_2)$.

For ‘delta’ enter the order number as 10.

For ‘*th*’ enter the material thickness as 10mm.

k(Lambda) is the reciprocal of the photoelastic constant: k(Lambda)= 1/7 N/mm.

$(\sigma_1 - \sigma_2)$ corresponds to σ_{max}

Thus, the highest tension is 10/(10mm*1/7 N/mm) = 7 N/mm^2

Each Isochromate shows a line of equal tension or compression with n*7/10 N/mm^2.

For example, the 4th order isochromate shows the tension line for 4*7/10 N/mm^2 = 2.8 N/mm^2.

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IV. RESULTS

For the simply supported and cantilever beam of rectangular cross-section, stresses induced during finite element analysis are compared with that of photo elasticity experiment. For the poly carbonate model of Simply Supported and cantilever beam, the results are given below: As shown in **Figure 8**,

(i) For Simply Supported Beam:

Shear stress value at the supports obtained from ANSYS = 7.6 N/mm^2 (as supports are at around 10 mm from the edges, we have considered the average value of stress in that region i.e. (7.1597+8.0415)/2 = 7.6 N/mm^2) while that obtained from photoelastic experiment = 7 N/mm^2 from Fig. The simulation results are closely in agreement with a small percentage error of 8.57 %.

(ii) For Cantilever Beam:

The maximum shear stress value calculated from ANSYS = 6.28 N/mm^2 while that obtained from photoelastic experiment = 5.85 N/mm^2 from Fig. The simulation results are aligned with the experimental values with a small percentage error of 7.35 %.

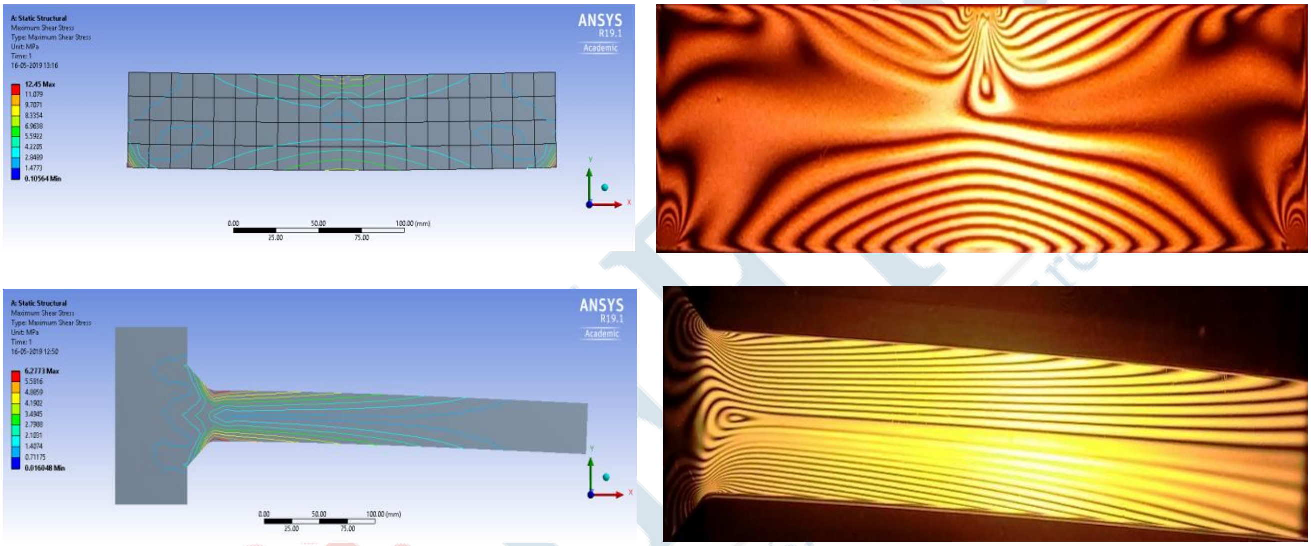

Fig 8. Stress field with fringes for Simply Supported and cantilever beam of polycarbonate **(a)** using FEM (ANSYS); **(b)** using Polariscope.

The variation in the results is due to the fact that it is difficult to determine the magnitude of the stress on the plane of the closest edge and therefore the value of 5.85 N/mm^2 may not be accurate in the case of cantilever beam. Figure 9 shows the location of the high stress on the adjacent beam model as found in the ANSYS software. Also, in the case of simply supported beam it is difficult to apply loads at the edges while doing the experiment but in ANSYS, the loads are applied at the edges. In experiment we have given supports at around 10 mm from edges. So, while calculating the value of stress from ANSYS we had to take the average stress value in that region.

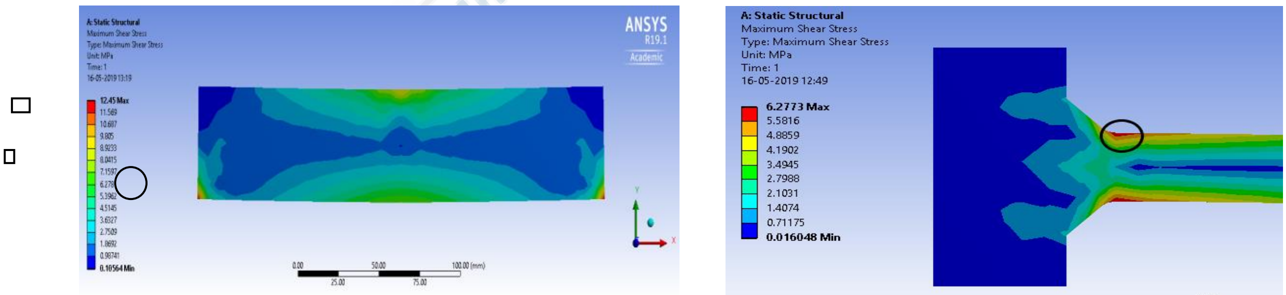

Fig 9. Variation due to limitations

The above results ensure that the FEA method is well established and can be used for more complex and accurate models. Therefore, in the second phase of the study, the statistical analysis was designed for a specific model of the beams and the results were validated from the ANSYS.

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V. CONCLUSIONS

A comprehensive study is a step towards establishing a FEA process, by confirming results, for measuring stresses in the beam. By reducing the failure of the beams to limit stress, their size and areas may be the most important.

In current research work, a photoelasticity test with a polariscope was performed on different beams made of polycarbonate. Test stress scores are also compared to the simulation results found in the ANSYS software. Apparently, the values from ANSYS are aligned with the results from experimental study. The process and simulation models used in this paper are useful for researchers who are willing to work on the stress analysis of complex geometric objects.

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