Application of Photo Stress Method in the Analysis of Stress Around a Notch

Mr. Sandesh S. Awati
M.E. Design Engineering
Department of Mechanical Engineering
PVPIT Budhgaon, Sangli, India

Mr. Ravindra D. Patil
Associate Professor
Department of Mechanical Engineering
PVPIT Budhgaon, Sangli, India

Mr. C.G. Harge
Associate Professor
Department of Mechanical Engineering
PVPIT Budhgaon, Sangli, India

Mr. A. S Patil
Assistant Professor
Department of Mechanical Engineering
PVPIT Budhgaon, Sangli, India

Abstract

The presented paper aims at the analysis of stress fields which occur while applying loads to a photo elastically coated notched sample. The analysis was done by means of Photo Stress method using reflection Polaris cope and digital video camera. On the notched sample subject to loads by eccentric tension we determined the differences of principal normal stresses in specified point at loads 3 kN, In addition, we determined the value of principal normal stress at the edge of the sample during load of 4 kN and 5 kN which was later compared with numerical solution in FEA method ANSYS software. On the photo elastically coated sample we observed maximum elongation of the coating, too. And also by changing the composition of notch specimen do the same and compare the above mention results.

Keywords- Stress, Photo elasticity, Visual inspection, Photo spectrometer

I. INTRODUCTION

Determination of stress is one of the common practices in industries. The point of maximum stress determines the location of failure. To determine the stress we can use strain gauge method or photo elasticity method.

Photo elasticity is a non-destructive experimental technique for stress and strain analysis. The term photo elasticity reflects the nature of this experimental method; photo implies the use of light rays and optical techniques, while elasticity depicts the study of stresses and deformations in elastic bodies. Through the photo-elastic coating technique, its domain has extended to inelastic bodies too.

Photo elasticity can be employed to wide verity of problems including experimental solution for two-dimensional and three-dimensional geometry, multiple-component assemblies, static, elastic, dynamic loading and inelastic material.

Photo elastic analysis is widely used for problems in which stress or strain information is required for extended regions of the structure. It provides quantitative evidence of highly stressed areas and peak stresses at surface and interior points of the structure and often equally important, it discerns areas of low stress level where structural material is utilized inefficiently.

To validate the results of photo elasticity method, we can use either analytical or numerical method. As the numerical method gives visualization of the results, it is commonly used for validation.

"Finite Element Method is a method of piecewise approximation in which the approximating function is formed by connecting simple functions, each defined over a small region". In recent decades with development in mathematics and computers, very efficient FEA software's were developed (like ANSYS, NASTRAN, MARC, LS-DYNA etc.). These software's in combination with high computational powered work stations (computers) are working very efficiently The Design process compromises of things (design may change several time from designers mind till it comes to actual practice). Such as manufacturability, maintainability, reliability, factor of safety, cost, size and shape. Selecting best design is mere permutation and combination. Hence design may change according to person working as designer. As it is compromise of many things, there will be always chance for optimization. Hence there is no exact answer to any design or related question codes giving flexibility of using different design approaches and technology by stating that the code is not a handbook and cannot replace education, experience and use of engineering judgment, also it suggests for using of FEA software in many situations, in traditional design process; design activity is carried out by using formulae developed by researchers or code formulae. This formulae change with change in loading, size, shape, location, material etc. Method of design by formulae is unable to account nonlinearity (such as loading non linearity, material non linearity, geometrical nonlinearity, contact nonlinearity) in design. To account non linearity; rigorous calculations are necessary which will be time consuming process and possibility of many errors.

II. PROBLEM DEFINITION

The property of offering visual cues while encountering stresses needs to be validated for precise calibration of equipment's. The Finite Element Analysis methodology is being considered as an alternative methodology for validation of the results. The magnitude and the sensitivity of the change in stress levels needs to be verified for seeking credibility of the results. The problem here is to correlate the results determined by two different methodologies. The current testing equipment uses strain gauges for checking stresses. This calls for fixing a strain gauge over the component with an adhesive. The strain gauge cannot be reused. Also, the variability in the results determined by this method (using strain gauge) needs to find an alternative answer.

III. RELEVANCE

Measurement of stress typically involves conventional methods using strain gauges. This work shall be pursued for offering research work in an alternative method using 'Photo elasticity'. While a coat of specified material is applied on the test specimen, the stresses on the same can be visualized as a spectrum of colours, each colour is indicating a particular level of stress induced. The process of validation for this method is sought through development of Finite Element Methodology. This numerical methodology shall be compared for results with the Experimental data and vice-versa. The concurrence of the results shall offer validation for this dissertation work. Photo Spectrometer shall be used for conducting test while applying specified loads to the specimen fetching the stresses at the visual locations on the specimen. On the notched sample subject to loads by eccentric tension we determined the differences of principal normal stresses in specified point In addition, we determined the value of principal normal stress at the edge of the sample during load by using reflection Polaris cope, which was later compared with numerical solution using FEA.

IV. LITERATURE REVIEW

A brief review of some selected references on various types with application of photo elasticity is presented below:

Lazzarin et al. [1]. In the presence of sharp (zero radius) V-shaped notches, the notch stress intensity factors (N-SIFs) quantify the intensities of the asymptotic linear elastic stress distributions. They are proportional to the limit of the mode I or II stress components multiplied by the distance powered 1 ki from the notch tip, ki being Williams Eigen values. When the notch tip radius is different from zero, the definition is no longer valid from a theoretical point of view and the characteristic, singular, sharp-notch field diverges from the rounded-notch solution very next to the notch. Nevertheless, NSIFs continue to be used as parameters governing fracture if the notch root radius is sufficiently small with respect to the notch depth. Taking advantage of a recent analytical formulation able to describe stress distributions ahead of rounded V notches, the paper gives a generalized form for the notch stress intensity factors, in which not only the opening angle but also the tip radius dimension is explicitly involved. Such parameters quantify the stress redistribution due to the root radius with respect to the sharp notch case.

Wang et al. [2]. they demonstrated the dynamic stress concentration are being increasing critically in variety of micro fluidic channels and other devices with sharp corners and edges. The Finite Element Method (FEM) is widely used as a numerical simulation system. Additional Photo elasticity is one of the more widely used experimental methods for verification of the FEM models.

This has been done widely for static loading situations. In this paper dynamic Stress Concentration Factors are determined numerically using FEM and experimental using a novel dynamic photo elastic system. They have found that the results from the finite element analysis resemble closely the experimental patterns recorded.

Frankovskyet al. [3]. The main aim behind this paper is the latest means of stress state determination in structure parts while taking advantage of isoclines field. The field is scanned photographically and examined through computer technology. For such purposes, computer programs for Photoelast and Photo stress testing were developed to automate the separation of stresses from the field of isoclines.

Frankovsky et al. [4]. The Presented paper aim at the analysis of stress fields which occur while applying loads to a photo elastically coated notched sample. The analysis was done by means of Photo Stress method using Reflection Polaris cope and digital video camera. On the notched sample subject to loads by eccentric tension, he determined the differences of principal normal stresses in specified point at loads 3 kN, 4.5 kN, 6 kN, 9 kN and 12 kN. In addition, they determined the value of principal normal stress at the edge of the sample during load of 12 kN, which was later compared with numerical solution in programme SolidWorks.

Frankovsky et al. [5]. The application of Photo Stress method in stress analysis of a rotating disc of a constant thickness, which was made of a photo elastic material PS-1A. Isoclinic fringes were observed on the rotating disc using linear polarized light at revolutions 5000 RPM. Observations were carried out under angle parameter 0 º to 90 º with 10 º increase. A set of isotactic lines of I and II was made from the set of obtained isoclinic lines. During gradual increase of rotations of the rotating disc up to 17000 RPM, and with circular polarized light, they observed the distribution of colourful isochromatic fringes on the rotating disc. The field of isochromatic fringes, gained experimentally, at 15000 RPM was compared with the field which was gained by means of a numerical analysis.

V. CONCLUDING REMARKS

Following outcomes can be drawn from the above literature review of notch specimens in different loading condition:

a) Some report have pointed that, this photo elastic technique applied here confirms FE predictions where the former has shown to agree with the analytical solution to the known stress concentration arising from a hole in a plate, photo elastic bench from the simpler plane geometry of a strip in tension, as used here, or for a beam in four-point bending. Following its validation, this preliminary study shows that photo elasticity is a useful experimental technique for providing a full stress field around slots subjected to bi-axial loadings. In particular, when slots are aligned with applied stress axes their straight boundaries distribute tangential stress uniformly in tension and compression. A maximum concentration in stress usually occurs within the end radii, their precise positions depending upon the slot orientation.

b) Several studies have been reported, in the Use of Photo Stress method, we were able to determine the difference of principal normal stresses in a particular point at various values of loading force. The correctness of experimentally gained data was verified through determination of one of principal normal stresses on the free edge of photo elastically coated notched sample. This measurement was verified by means of numerical simulation in program FEA. Stress value σ1 determined by means of Photo Stress method. The difference of stress values is 3.6%, what implies that the experimental measurement was relatively precise.

c) Some reports have pointed that in the presence of sharp notches (where the notch root radius is null) subjected to mode I loading conditions, the notch stress intensity factors KvI are recognized as parameters suitable for controlling the static behaviour of brittle materials and the fatigue crack initiation phase of structural materials. When the notch root radius is different from zero, the characteristic, singular, sharp-notch field diverges from the round notch solution very next to the notch. As the notch root radius q increases, the usefulness of KvI rapidly decreases.

VI. OBJECTIVES OF THE STUDY

Objectives of this dissertation work are:

1) To study the Literatures related to dissertation work and collect the important information regarding the same.
2) To introduce the use of photo elastic principles in stress analysis.
3) To select test specimens made up of metal alloy for experimentation.
4) Use the stress distribution in notched specimens to find the material fringe constant.
5) To Measure the stress concentration in every notched specimen.
6) Compare these results with experimental and analytical methods.
7) Validate the Result

VII. SCOPE OF WORK

The above work illustrates the field of Photo elasticity. Few researchers have worked on various types of notches. One of them used V type of notch and compared the results taking into account two methods, one with a straight apex and another with a circular apex of notch.

After this, one researcher has worked with notch having circular apex. He found that the notch sensitivity factor value was higher as compared to the conventional notch.

This work investigates the stress analysis of notch specimen by using Reflection Polaris cope. In this work, three various specimens of Notch will be taken. The experimentation will be carried out on these three specimens by varying the amount of carbon percentage in Notch specimen material. The above mentioned results will be further compared with FEA method.

VIII. EXPERIMENTAL INVESTIGATION

A. Experimental Set Up

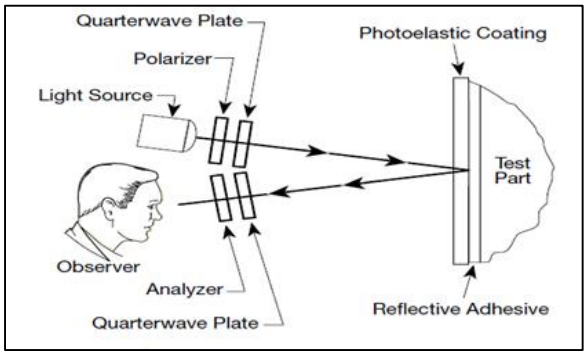

Fig. 5.1: Schematic representation of Experimental Set up (Reflection Polaris cope).

Fig. 5.1 shows the different components of Experimental set up (Reflection Polaris cope). The determination of stress fields around the notch was done by means of Photo Stress method on steel samples of 12 mm thickness. The shape and dimensions of the sample are depicted in Figure 5.2. The sample was cut from a steel plate with photo elastic coating PS-1A. The cutting technology used is called Wire Cutting. Steel has only small volume of carbon and its biotitic microstructure secures its high toughness and ductility level. Photo elastic coating PS-1A of 2.05 mm was chosen while following systematic selection methodology. The coating was applied to the surface of the notched sample by two-component adhesive PC-1. Photo elastic coating PS-1A is highly sensitive and hence allows us to use it in elastic as well as in elastic-plastic areas. It is delivered as a plane plate with reflective layer. Material characteristics of the PS 1A photo elastic coating used are listed in Table 4.1.

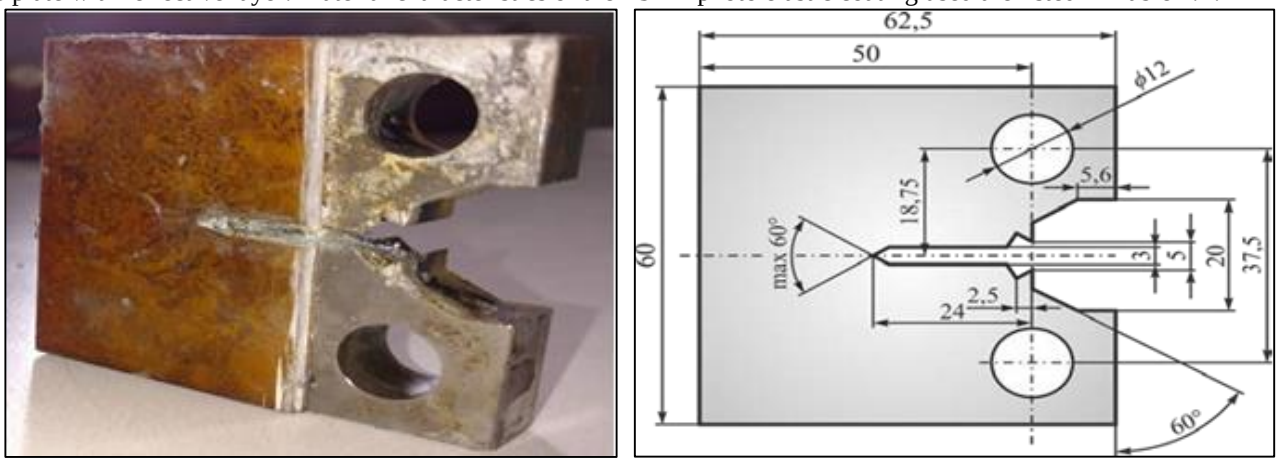

Fig. 5.2: Shape and dimensions of analysed notched sample

Load Specification Experimental measurement was done on a tearing UTM machine Figure 5.3. While loading the sample with eccentric tension. In order to fulfil the conditions of static loading the movement of the machine jaws was set to 0.5 mm/min.

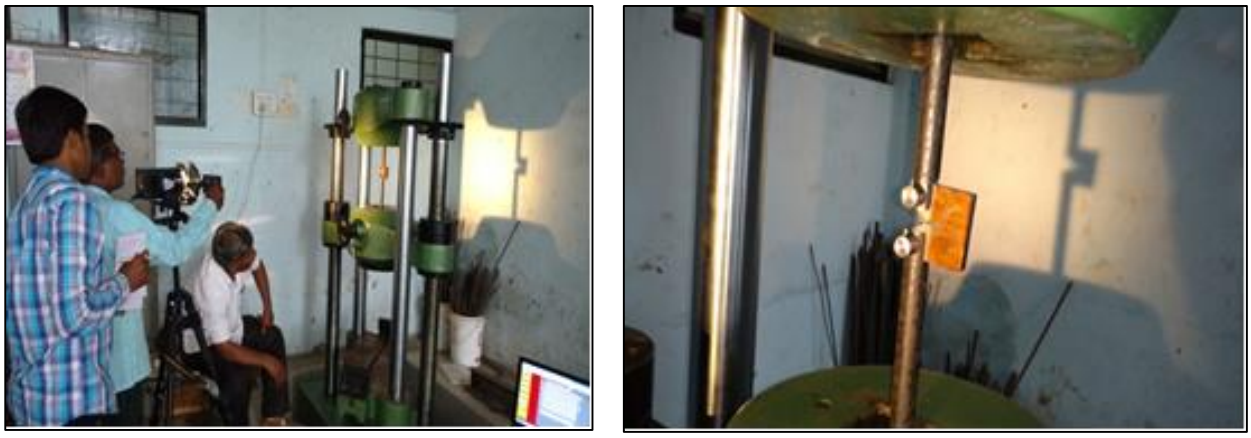

Fig. 5.3: Tearing UTM machine with reflection Polaris cope LF/Z-2

Reflection Polaris cope LF/Z-2 with usual source of white light Figure 5.3 was used to observe isoclinic and isochromatic fringes which occur when loading the notched sample. Compensator 832 was used to read order values of isochromatic fringes in pre-selected points. The compensator was based on the principle of null balance. Digital video camera was used to record isochromatic fringes during gradual loading of the sample. The relation of force F in kN to elongation f in mm was a direct outcome of the tearing machine software Figure.

Table 1: Material characteristics of photoelastic coating PS-1A Photoelastic coating PS-1A

Strain-optic coefficient K [-]	*0.150*
Modulus of elasticity E [MPa]	*2500*
Poisson's ratio μ [-]	*0.38*
Elongation A [%]	*5*
Maximum usable temperature [ºC]	*150*

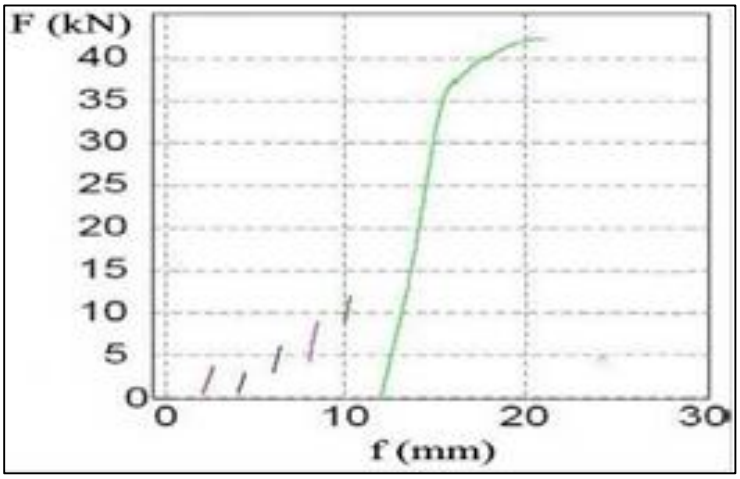

Fig. 5.4: Notch opening in relation to loading force [7]

The relation of force F in kN to elongation f in mm was a direct outcome of the tearing machine software. The relation in Figure consists of a number of curves. The light green curve represents force distribution while loading the sample until crack. The notch opening increased without increasing force. The cause of this effect is that after fastening the sample in the device both surfaces had to fit firmly and adjust to each other. The short curves in the initial part of the diagram (red, blue, brown, violet, dark green) represent force distributions during analysis of isoclinic and isochromatic fields while applying loads 3 kN, 4kN and 5kN.

B. Experimental Procedure

The experimental test carried on Reflection Polariscope.

The steps of Experimental work are as given below:

1) Light source emits light waves vibrating in infinite number of planes.
2) Polarization Filter (Polarizer): Restricts the vibration of light waves to a single plane.
3) Polarizer: Second polarizer used to analyse polarized light passed through material in testing. Doubly refracting lights which passed through the birefringent are resolved by analyzer. Speed difference in the refracting lights causes that a certain colour from the light disappears (wave shift).
4) The speeds of the refracted lights are directly proportional to the principal stresses σ1 and σ2, major and minor principal stresses, respectively and also stress depend on the colours of fringe pattern shown in bellow figure 5.5.

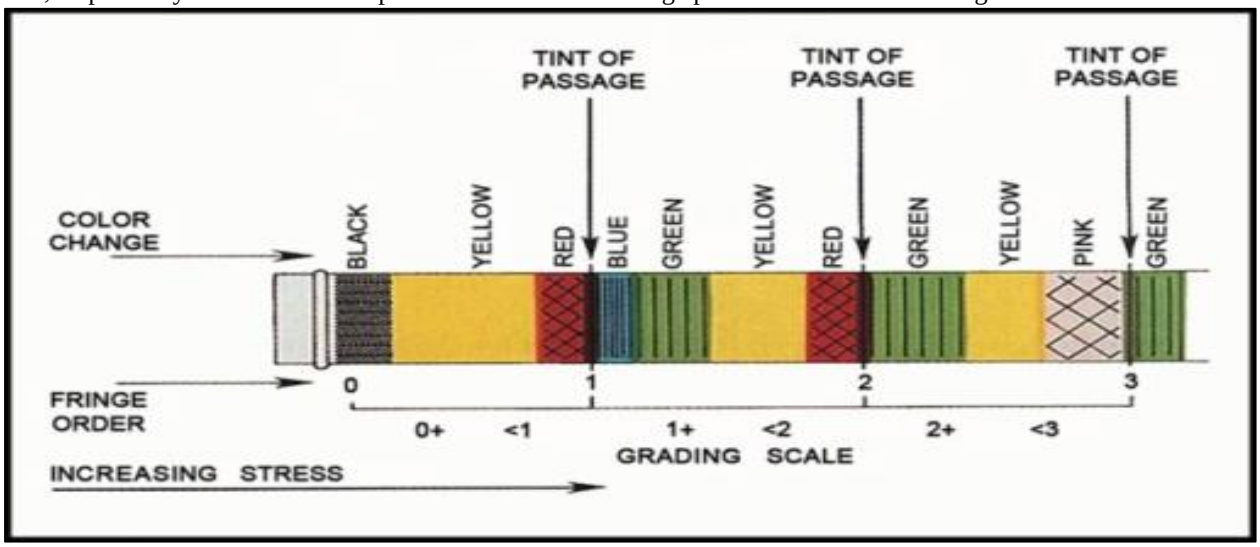

Fig. 5.5: Colours of fringe pattern shown


Fig. 5.6: Loading Position

Stress depends on the colours of fringe pattern and on that we get the value of Fringe order (N) of respective material. Values of N for different material at different loads 3kN, 4kN and 5kN as shown in following figures.

1) Experimental Result Ma

a) Material:-Mild Steel

Fig. 5.7: Load 3kN (N=0.59) (M.S)

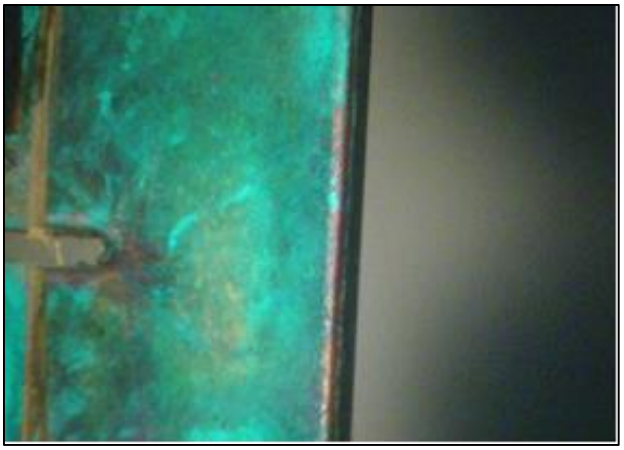

Fig. 5.8: Load 4kN (N=0.76) (M.S)

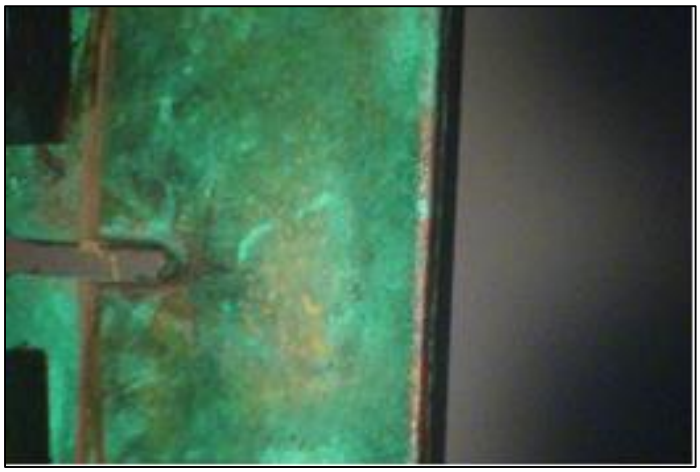

Fig. 5.9: Load 5 kN (N=0.95)(M.S)

b) Material EN8

Fig. 5.10: Load 3kN (N=0.65) (EN8)

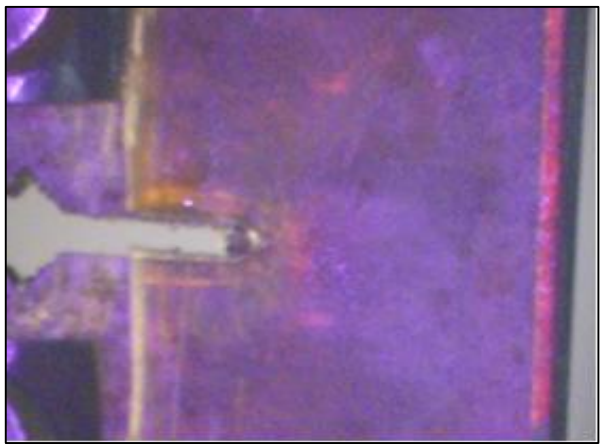

Fig. 5.11: Load 4 kN (N=0.69) (EN8)

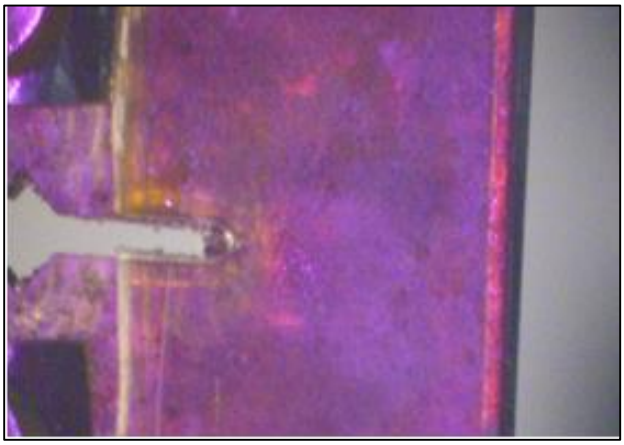

Fig. 5.12: Load 5kN (N=0.87) (EN8)

c) Material D3

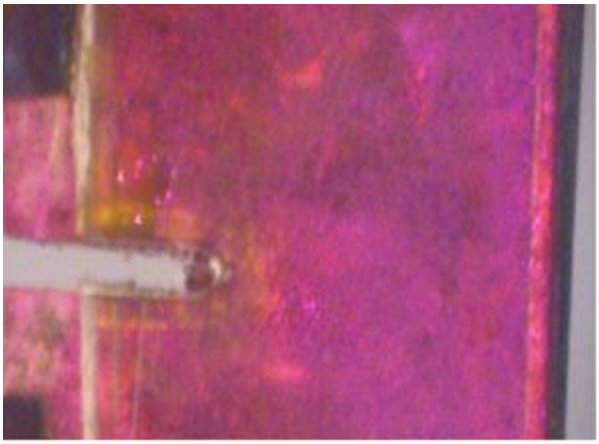

Fig. 5.13: Load 3kN (N=0.52) (D3)

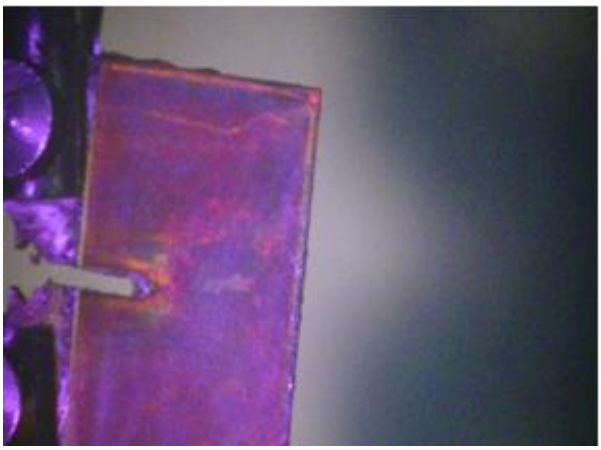

Fig. 5.14: Load 4 kN (N=0.87) (D3)

Fig. 5.15: Load 5 kN (N=1.15) (D3)

Listed in Table 5.2 are isochromatic fringe orders N at point 1 under loading force F, 3 kN, 4 kN and 5 kN and differences of principal normal stresses find out.

2) Observations

Table 2: Fringe orders and difference of principal normal stresses at individual loads

Material	*Measurement no.*	*Force(kN)*	*Fringe Order N*	*($\sigma_x - \sigma_y$) MPa*
Mild Steel	*1*	*3*	*0.59*	*82.24*
	2	*4*	*0.76*	*105.93*
	3	*5*	*0.95*	*132.41*
EN8	*4*	*3*	*0.52*	*80.724*
	5	*4*	*0.69*	*107.11*
	6	*5*	*0.87*	*135.05*
D3	*7*	*3*	*0.65*	*96.84*
	8	*4*	*0.87*	*129.62*
	9	*5*	*1.15*	*156.441*

3) Sample Calculations

For Material Mild Steel
Load 3 KN

$$\sigma x - \sigma y = \frac{E}{1+\mu} Nf \quad (1)$$

Where,
$\sigma_x - \sigma_y$ = principal stresses in test part surface
E = elastic modulus of test part
μ = Poisson's ratio of test part
1ST we find out value of f,

$$f = \frac{\lambda}{2tck} \quad (2)$$

Where,
f = (fringe value of coating)
λ= wavelength (in white light, 22.7 × 10-6 in or 591 nm or 5.91 × 10^{-4} mm)
t_c = thickness of coating = 2.mm
K = strain optical coefficient of coating = 0.15

$$f = \frac{\lambda}{2tck}$$

$$= \frac{5.91 \times 10-4}{2 \times 2.05 \times 0.15}$$

f = 9.61×10^{-4}
Now,

$$\sigma x - \sigma y = \frac{E}{1+\mu} Nf \quad (3)$$

Where,
E= Elastic modulus =190 GPa
μ = Poisson's ratio = 0.31
N = Fringe Order = 0.59
f = 9.61×10^{-4}

$\sigma x - \sigma y = \frac{1.9\times105}{1+0.31} \times 0.59 \times 9.61\times10^{-4}$
$(\sigma_x - \sigma_y) = 82.24$ MPa

As it is known from the theoretical background, biaxial stress state requires additional measurement to determine individual values of principal normal stresses. For these purposes we use separation methods. However, there are cases when the equation (3) can be transformed to the following form:

$$\sigma_y = \frac{E}{1+\mu} \; Nf \qquad (4)$$

One of these cases requires free unloaded edge of an object subject to analysis. In each point of such edge we find one principal normal stress, which is non-zero tangential to the edge, and another zero normal stress. In an experimental way we used a compensator with null balance to specify the isochromatic fringe order on the notched sample at loading force 3 kN Figure 5.7 Its value was N=0.59. Using the relation (4) we subsequently determined the value of principal normal stress 82.54Mpa.

Numerical stress analysis was done in programme ANSYS in order to verify previously gained value of principal normal stress σ in point. Principal normal stress in point determined by computer ANSYS Software has the value 80.10Mpa. The difference between principal normal stress σ gained in an experimental way and numerically is 2.6%. As a result, we can state that the experimental measurement was relatively precise. This way of verification is easily applicable in everyday practice.

IX. VALIDATION

The validation shall be pursued using FEA Method. For this, ANSYS software shall be engaged for recording the stresses on the standard test-piece. The reading shall be noted while the test piece is subjected to pre-determined load. The results of the Test shall be assessed in relation to the results achieved using Reflection Polari scope. A good concurrence of the results for these two differing methodologies shall indicate a favourable assessment towards validation of the thesis work.

REFERENCES

[1] P. Lazzarin , S. Filippi , "A generalized stress intensity factor to be applied to rounded V- shaped notches", Journal of Solids and Structures , Vol. 43, (2006), pp 2461–2478.
[2] Wenjing Wang, a,Li Kai, Randy Gu, AnandAsundi, "Dynamic Stress Concentration – a Hybrid Analysis",Onal Conference on Optics in Precision Engineering and Nanotechnology .Physics Procedia,Vol.19, (2011),pp 220–226.
[3] P. Frankovskya, O. Ostertaga, E. Ostertagovab, "Automation of experiments in Photo elasticity", Procedia S
[4] Peter Frankovsky, PavolZubko, Oskar Ostertag, WładysławPapacz, Martin Smida, "Application of Photo Stress Method in the Analysis of Stress Fields Around a Notch", American Journal of Mechanical Engineering,Vol.1, No. 7,(2013), pp 329-334.
[5] P. FRANKOVSKY, F. TREBUNA "Application of Photo Stress method in stress analysis of a rotating disc", Original Scientific Paper METABK, Vol.53 (4), (2014), pp 541-544.
[6] Alberto Sapora, Pietro Cornetti, Alberto Carpinteri "Analytical Stress Intensity Factors for cracks at blunted V-notches" Procedia Materials Science 3 (2014) 738 – 743, Science Direct.
[7] Introduction to Stress Analysis by the Photo Stress Method, Micro-Measurements Document Number: 11212, Tech Note TN-702-2, photostress@vishaypg.com
[8] How to Select Photoelastic Coatings Tech Note TN-704-2 micro measurement Document Number:11213 www.micro-measurements.com, Revision:04-Aug-2015

Books Referred

[9] Experimental Stress analysis by, Dally Riley
[10] Experimental Stress analysis by, Shrinath
[11] Experimental Stress analysis by, Sadhu singh

Website Referred

[12] photostress@vpgsensors.com (Accessed on date 10/04/2016)
[13] www.micro-measurements.com (Accessed on date 15/5/2016)
[14] photostress@vishaypg.com (Accessed on date 25/5/2016)