Innovative Systems Design and Engineering www.iiste.org
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol 2, No 3

Photoelastic Analysis of Bending Strength of Helical Gear

Bhosale Kailash C. (Corresponding author)
SRES College of Engineering, Kopargaon.
Dist- Ahmadnagar (Maharashtra) India.-423603
Email: bhosale_kailash@yahoo.co.in

A.D.Dongare ,
Pravara Rural Engineering College, Loni.
Tal- Rahata. Dist- Ahmadnagar (Maharashtra) India.-413736.
Email: addongare@indiatimes.com

Abstract:

Photoelastic stress analysis is a technique that provides us with a complete (full-field analysis) stress distribution over an entire object/structural member of interest. It is based on the property of some transparent materials to exhibit colorful patterns when viewed with polarized light. These patterns occur as the result of alteration of the polarized light by the internal stresses into two waves that travel at different velocities. This phenomenon of double refraction is known also as birefringence. The patterns that develop are related to the distribution of the internal stresses and are called the photoelastic effect.

Keywords: Photoelasticity, Circular Polariscope, Helical Gear, Bending Strength.

1. Introduction:

Photoelasticity is one of the major experimental techniques for analyzing stress or strain distributions in loaded members. A stress freezing method is used to find out fringe pattern of the model. With the development of computers, the traditional areas of application of photoelasticity have been partially replaced by modern numerical techniques. However, developments in lasers, fiber optics, image analysis, and data acquisition continue to extend the range of applications, for example in fracture mechanics, so that the use of the photoelastic technique is still increasing instead of decreasing in stress or strain analysis.

In this work bending strength of helical gear is found out with the help of three dimensional photoelasticity. A helical gearbox with 2.2 kW power transmitting at 760 rpm and Number of Teeth = 30mm, Pitch circle Diameter = 60mm, Module = 2mm, Pressure Angle =20°, Helix Angle = $12^0 54'$, Addendum = 64mm, Base circle Diameter = 56.38mm, Dedendum = 55mm

2. Three-Dimensional Photoelasticity

In practice, many problems are three dimensional in nature. Thus, techniques in three-dimensional photoelasticity are rapidly developing. Among the most powerful of these is the frozen-stress method. Certain photoelastic model materials, such as epoxy resins, exhibit the frozen-stress phenomenon. This phenomenon occurs when the material is heated to its stress annealing (or stress freezing) temperature, stressed (usually by dead-weight loads) after the temperature has reached its equilibrium in the material, and then cooled slowly to room temperature with the loads still applied. The optical response, related to the mechanical stress, remains fixed in the material after the removal of the loads at room temperature.

Furthermore, the optical response is not disturbed even when the material is cut into thin slices. This phenomenon forms the basis of the frozen-stress method, widely employed in three-dimensional photoelasticity.

4. Experimental Analysis

As the accuracy of photo elastic model has got the major effects on the results obtained, the preparation of the model bears its own importance in the whole problem of photo elastic stress analysis. Considering all requirements of a good photo elastic model, one would come to know that preparation of a model is a sort of technique which needs not only great care, but a lot of experience and practice. Following are the steps in casting three dimensional photo elastic models.

(a)Pattern making : To cast 3-dimensional model, it is necessary to make pattern either of wood or metal. Cost factor is affects the material for pattern.

(b)Preparation of rubber mould : The rubber mould was made out of "SYLARTIVI-12", Silicone rubber vulcanizing at room temperature as shown in Figure1.1.

Figure 1. A rubber mould of helical gear

Figure 2. Casting of Araldite

(c)Model casting: The model is prepared out of epoxy resin AY-103 araldite mixed with HY-951 hardener as shown in figure 1.2.

(D)Loading: A loading frame is prepared to load the gear which is casted.

5. Process:

After mounting a model on a loading frame, a model alongwith loading frame is placed in a stress freezing oven. The calibration disc is also placed in a separate loading frame and kept inside stress freezing oven. A stress freezing oven (Hanyoung Make) having "PX 09" process controller is used for stress freezing purpose. Temperature rise rate is kept 10^0 C/hr up to soaking temperature of 80^0C, the soaking time was kept 4 hrs and cooling rate was kept 2^0C/hr. 3.4 shows a typical stress freezing cycle. The model was loaded initially. The total stress freezing cycle is observed to be of 38 hrs.

6. Slicing

Generally in three- dimensional photoelasticity, the analysis is performed on slices cut from the model after stress-freezing. The model is sliced to remove the planes of interest which can then be examined individually, to determine state of stress existing in that particular plane or slice. The slice preparation involves three steps, viz. layout, cutting off the slices and flattening the slice surface

The slices are cut by employing milling machine with high speed (1500 rpm) and slicing saw of 1mm thickness. Sufficient amount of cutting oil is spread at the time of cutting as coolant. Slice thickness was kept 3mm. After cutting the slices, the surface of each slice was finished manually with the help of zero number polish paper. SAE- 40 oil was used as a lubricant.

7. Material Fringe Value

The material fringe value (F) is defined as number of fringes produced per unit load. The material fringe value is the property of the model material for a given wavelength (λ) and thickness of the model (h). Here the circular disk subjected to dimensional compressive load is employed as a calibration model.

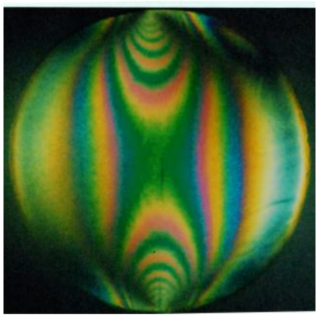

Figure 3. Fringe pattern of calibration disc

A) Procedure To Find Material Fringe Value:

The circular disc of diameter 55 mm and thickness 6mm was used to find material fringe value. This circular disc was loaded under compression by special fixture as shown in fig. 5.7. A compressive load of 2Kg was applied to find material fringe value. This circular disc was also subjected to same stress freezing cycle as that for the model.

Viewing through dark-field of circulated Polar scope, locked isochromatic fringe pattern was observed. By using following equation, the material fringe value (F_{σ}) at critical temperature were found out.

$$F_{\sigma} = \frac{8 \times P}{\pi \times D \times N}$$

P =Load applied = 2Kg = 19.60 N

D=Diameter of disc = 55mm

N= Fringe order observed at the center of the disc = 2.66

Substituting these values in above equation.

$$F\sigma = \frac{8 \times 2 \times 9.81}{\pi \times 55 \times 2.66} = \mathbf{0.34\ N/mm}$$

8. Stresses Developed In Slices

At root of marked tooth (that is in point contact) on the each slice, the isoclinic and isochromatic fringes were observed by using plane and circular Polariscope. All the values of fringe orders were noted down.

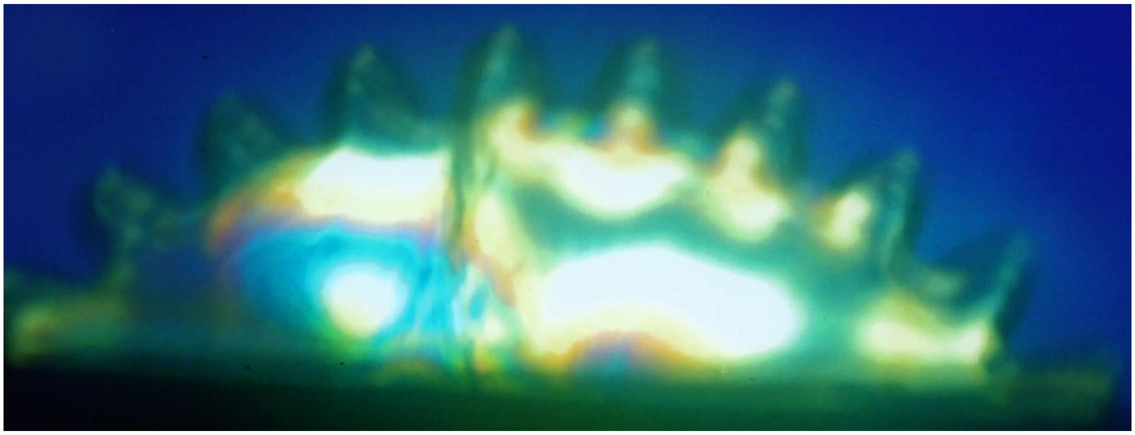

Figure 4. Fringe patterns of slices

The stresses developed in each slice at root of marked tooth point have been calculated as follows.

Specimen Calculations: Slice No.1

N_1= 1+0.36 = 1.36 N_2 = 2- 0.62 = 1.38

Fringe order(N),

N=fσ × D/h N = 1.37

Material fringe value = 0.34 N/mm.

Slice thickness = 3mm

$$\sigma_1 - \sigma_2 = \frac{N \times f_\sigma}{h}$$

As σ2 equal to zero and σ1 is equal to be)

$$\sigma m = \frac{1.37 \times 0.34}{3} = 0.16 \text{ N /mm}^2$$

Therefore, stresses developed in a model =0.168N /mm^2

9. Scalinig Model To Prototype Stresses

In the analysis of a photoelastic model fabricated from a polymeric material, the question of applicability of the result is often raised since prototype is usually fabricated from metal. Obviously, the elastic constant of the photoelastic model are greatly different from those of the metallic prototype. However, the stress distribution obtained for a plane-stress or plain-strain problem by a photoelastic analysis is usually independent of the elastic constant and the results for an elastic analysis are applicable to a prototype constructed from any material. Since photoelastic model may differ from the prototype in respect to scale, thickness and applied load as well as elastic constant, it is important to extend this treatment to include the scaling relationship. The literature abounds with scaling relationship employing dimensionless ratios and the Buckingham π theory. For instance, for a model with an applied load P, the dimensional less ratio for stress is

$$\sigma_p = \sigma_m \times \left(\frac{T_p}{T_m} \times \frac{h_m}{h_p} \times \frac{L_m}{L_p}\right)$$

Where,

h= thickness, L=typical lateral dimensions , T_p = Torque on a Prototype,

T_m = Torque on a model, σ_p = Stresses produced in prototype, σ_m = Stresses produced in a model, As model and prototype have same dimensions.

$h_m = h_p$ and $L_m = L_p$, Therefore

$$\sigma_p = \sigma_m \times \left(\frac{T_p}{T_m}\right)$$

By using Lewis equation,

Torque on prototype = 27656.72 N-mm and Torque on model = 91.22 N-mm

$\sigma_p = 0.16 \times \left(\frac{27656.72}{91.22}\right) =$ **47.31 N/mm^2**

Therefore stress developed in the prototype is = **47.31 N/mm^2**

Following table shows bending stress values of 5 slices of the gear.

Table 1. bending stress

Slice No.	Bending stress in N/mm^2
1	47.31
2	35.96
3	26.24
4	7.93
5	0.00

In helical gear the engagement between driver gear and driven gear teeth begins with point contact and gradually extends along the tooth surface. Due to initial point contact in helical gear the bending stresses produced at critical section (root of tooth)are maximum as compared to spur gear, which has kinematic line contact.

As stress distribution in helical gear teeth is complex the three dimensional photoelastic analysis technique has been carried out which not only measures the stress but also gives idea about stress distribution along the tooth width.

10. Solid Modeling And Modeling:

A solid modeling is done with Catia and then by using the hypermesh meshing is done. Analysis is done with Ansys Workbench 12.1

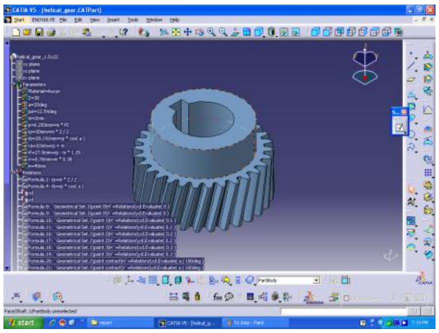

Figure5.Solid modeling with Catia

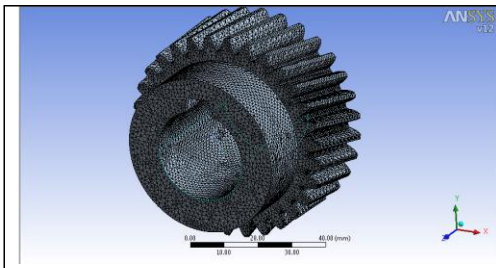	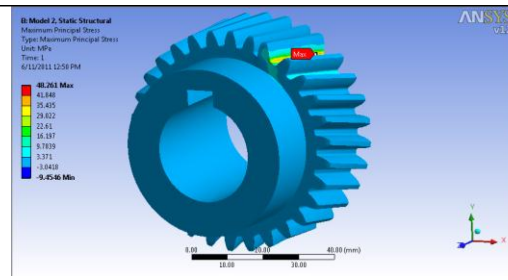
Figure 6. Meshing with Hypermesh	Figure 7 : Maximum Principal Stress plot

11. Result And Conclusion:

There is a good agreement between experimental and finite element results. The error in maximum bending stress is found to be 2.02 %.

In helical gear the engagement between driver gear and driven gear teeth begins with point contact and gradually extends along the tooth surface. Due to initial point contact in helical gear the bending stresses produced at critical section (root of tooth) are maximum as compared to spur gear, which has kinematic line contact.

The calculation of maximum stresses in a helical gear at tooth root is three dimensional problems. The accurate evaluation of stress state and distribution of stress is complex task. The stresses produced at any discontinuity are different in magnitude from those calculated by elementary formulae.

Experiment value N/mm^2	ANSYS value N/mm^2	%variation
47.31	48.26	2.02

REFERENCES

N.A. Rubayi and H.W. Tam, “Three-dimensional Photoelastic Study of Stresses in Rack Gears”, *Experimental Mechanics*, 1978, pp. 153-159.

Florin G. Tutulan, “Optimum design of the involute cycloid composite tooth profile helical gear”, *Bulletin of the Graduate scholl of engineering, Hiroshima University*, Vol. 53, No.1, 2004, pp 81-86.

James F. Doyle and James W. Phillips, “Manual on Experimental Stress Analysis”, *Society for Experimental Mechanics.*

Robert L. Johnson, “Model Making and Slicing for Three Dimensional Photoelasticity”, *Experimental Mechanics*, March 1969, pp 23-32.

Gary Alan Manney, A thesis on “ Investigations of Epoxy Resins for use in Photoelasticity”, *Texas Technology College*, May 1965.

Paul Black, “ An Investigation of Relative Stresses in Solid Spur Gears By Photoelastic method”, December 1936, Bulletin no. 288.

Ahmed Ghali1, Tony P. Pridmore, I. Arthur Jones, Peiji Wang and Adib A. Becker, “Boundary Extraction and Polarimetry in Translucent Specimens for Photoelastic Stress Analysis” , *Proceedings of SPIE-IS&T Electronic Imaging*, SPIE Vol. 5016 (2003), pp.115-122.

N.V. Scurria and J.F. Doyle,” Photoelastic Analysis of Contact Stresses in the Presence of Machining Irregularities”, September 1982, pp. 342-347.

Ping-Hsun Lin and Hsiang Hsi Lin, “Using Dynamic Analysis for Compact Gear design”, *NASA/TM*—1998-207419, 1998.

I.M. Allison and E.J. Hearn, “A New Look at the Bending Strength of Gear Teeth”, *Experimental Mechanics*, 1978, pp. 217-225.

Thomas L. Dolan, “A Photoelastic Study of Stresses in Gear Tooth Fillets*”, University of Illinois Enginering Experiment Station*, Bulletin No 335.

S. Timoshenko and J.N. Goodier, “Theory of Elasticity”, *McGrawhill Book Company*, pp 131-143.

James W. Dally, William F. Riley, “Experimental Stress Analysis”, *McGrawhill Book Company*, pp 374.

Dr. Sadhu Singh, “Experimental Stress Analysis”, *Khanna Publications*”, Fourth edition 2009, pp 281-392.