Experimental Analysis of the Stresses in a Spur Gear in Lathe machine operations by Photo Elasticity Technique.

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ABSTRACT

Gears have the numerous range of industrial applications. They are the most conventional means of transmitting power. Stresses with a higher values are developed at the mating positions of the gear teeth when they are transmitting the power. To transmit the power with high velocity ratio spur gears are used. The purpose of this paper is to identify the magnitude of the stresses for a spur gear used in lathe machine while transmitting power for operations such as drilling, tapping and turning. For this analysis we have performed various case studies. We went through analytical calculations before going for FEA and Experimental analysis. For simulation we used FEA tools such Hypermesh, Abacus. The stresses are observed by experimentally using the photo elasticity technique and then compared with the results of FEA.

Keywords: — Stresses, Photo elasticity, FEA, Gear.

Introduction

Photo elasticity is one of the most popular technique used for experimental stress analysis which is a non-destructive, graphic stress-analysis technique based on an opto-mechanical property which termed as birefringence, possessed by many transparent polymers. When Photoelastic specimen (or photoelastic coating applied to an ordinary specimen) is loaded and illuminated with an ordinary light source and seen with optical elements, this specimen shows fringe patterns that are concerned to the difference between the principal stresses in a plane normal to the light propagation direction. The technique is used basically for analyzing two dimensional plane problems. Provision of full field reliable values of difference between a principal normal stresses in the plane of the model is turned out to be the key

advantages of experimental stress analysis. It provides full-field values of the principal stress directions.

Testing Setup

Photo elasticity includes the use of the optical elements. The instrument used for the photo elasticity is called as Polariscope. A Polariscope is an optical setup that allows the fringe patterns in the loaded specimens to be analyzed. It consists of a light source, a polarizer, an optional quarter-wave plate, a specimen which is loaded on a loading frame, another optional quarter-wave plate, a second polarizer called analyzer, load cell and a load cell indicator.

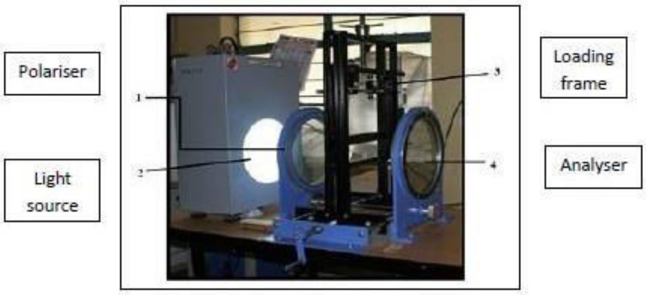


Figure 1 Polariscope Set Up

In the polariscope set up, two types of loading arrangement is available i.e. lateral as well as axial. A ‘S’ type load cell for compressive loads and ‘shear beam’ load cell for horizontal (lateral) loads is available is attached to loading lever. In case of vertical loading and lateral loading, load is applied by just tightening the nut. The load is sensed by load cell and its output is indicated in on the indicator. Loading indicators are different for the lateral as well as vertical loading. The frame on which the specimen is mounted can be adjusted in finite number of steps in both horizontal and vertical planes.

To apply load in lateral direction, we used shear type load cell which is used to apply load in lateral direction. It has maximum capacity of 25 kg. The whole attachment of lateral and axial loads is shown below.

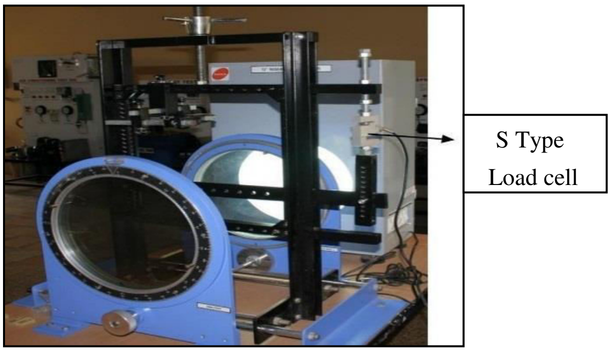
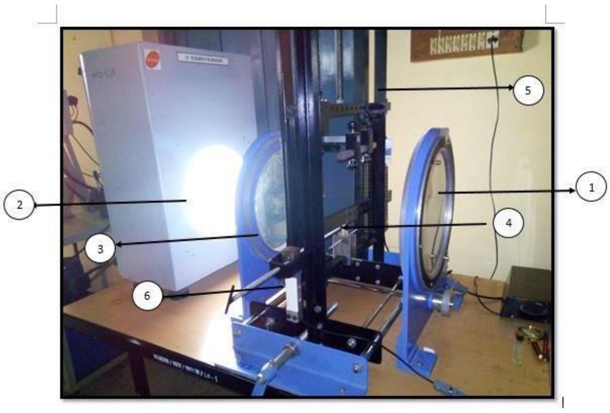


Figure 2 Axial Loading Arrangement



1. Analyzer 2.Light Source 3.Polarizer 4.Test Specimen 5.Frame 6.Lateral Load cell.

Figure 3 Lateral Loading Arrangement and loading

Experimentation on Photoelastic Model

The photoelastic material used for this study is Araldite cy230 along with the hardener HY951 with mixing proportion of 100:8 resp. This photoelastic model is manufactured with the casting process in controlled condition.
The procedure for casting the blocks is as follows.

1. Firstly by using acrylic sheet mould is to be prepared.
2. Calculate the amount of mixture necessary for preparing the photoelastic prototype.
3. The volume required 135 gram of araldite and 8% hardener of that volume and mixed with each other.
4. The mixture should be stirred in one direction continuously for 10 minutes till it is transparent and taking steady at list 5 minute.
5. The mixture is ready to pouring in the mould for preparation of the Model.
6. After pouring the mixture, allow the mixture to cure for 18 hours.
7. After 18 hours, remove the mould and take out the sheet and keep the sheet on plain glass for curing period of 7 days.

Precautions taken:

1. Air bubbles must be prevented while pouring epoxy resin hardener.
2. Proportion of epoxy resin & hardener must be accurate.

Figure 4 Photoelastic Prototype of tooth of spur gear

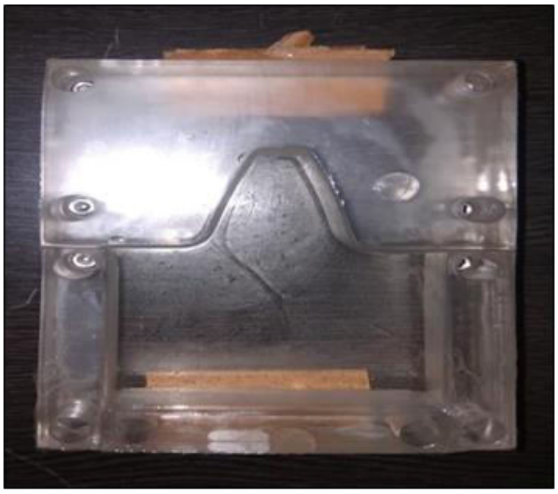


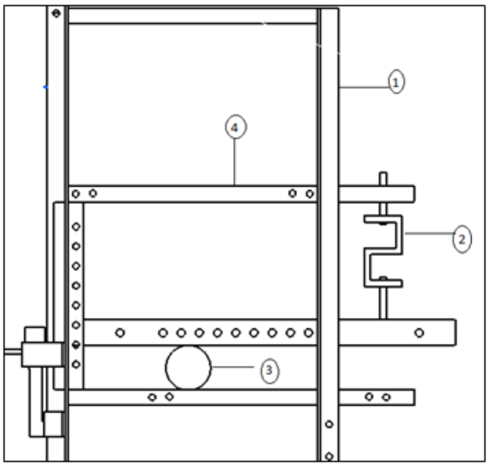
Figure 5 Mould of Photoelastic Prototype of tooth of spur gear

Material	Epoxy Resin
Trade name	Araldite CY – 230 With 10 % Hardener HY – 951
Poisson's Ratio (v)	0.38
Modulus of Elasticity E (MPa)	3300

Table 1 Mechanical Properties of Araldite

Calibration of Araldite CY230 Material

Although the material fringe constant is been given by the manufacturer, it is necessary to calibrate the material before the experimentation is carried out. Fringe constant should be calculated for every batch of the casting produced for ever time even if the material is same. Circular disc model is used for the calibration of the material. The reason is that, when the circular disc is loaded under diametric compression, the fringes are been seen accurately distributed. The leverage mechanism through which the load is been applied is been shown in the figure below.



1. Frame structure
2. Load cell
3. Calibration disk
4. Loading frame

Figure 6 Schematic of Loading Mechanism

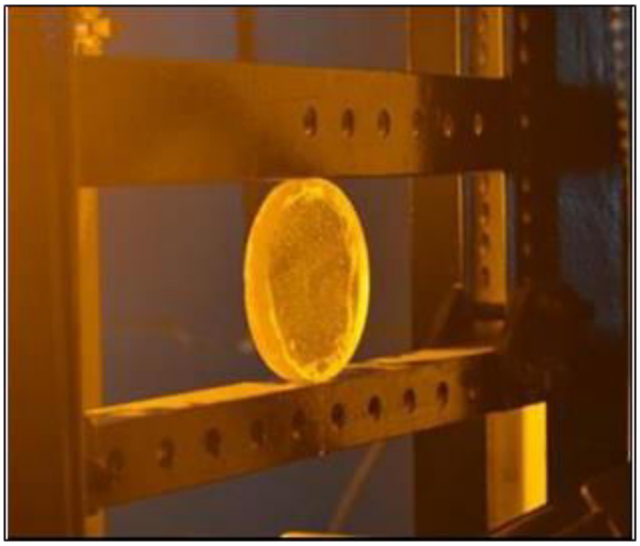


Figure 7 Disc under Diametral Compression

Procedure

1) The circular disc is been loaded in the universal loading frame under diametrical compression.
2) The distances X and Y are been measured initially.
3) Turn on the light source and apply light load 'P' on the model.
4) Observe the isoclinic fringe pattern and note down the isoclinic readings for the point of interested region.
5) Now further apply the known value of load step by step at the end of lever.

Use Tardy's method of compensation to determine average fringe order.

Figure 8 Fringes in Disc under Diametral Compression

Tardy's Method

This method is used for measuring the average fringe order by compensation at any desired point. Fractional fringe order may be found out by this method.

1. Confirm the pointer readings are zero
2. Confirm that the polariscope is in circular polariscope arrangement
3. Apply load on the model and read it on digital indicator.
4. Rotate polarizer plate such that minimum light passes through it
5. Now rotate the analyser such that the fringes observed either converge or diverge On clockwise or counter clockwise direction resp. and note down the readings N1 and N2 respectively.

Sample calculation

Observations

1. Disc Diameter: 70 mm
2. Thickness: 10 mm
3. Distance X = 505 mm
4. Distance Y = 190 mm

Consider the disc is applied with the load of 65 kg. P = 65 Kg. There are few fringes observed in the model. The fractional fringe order lies between fringe order 3 and fringe order 4. Now the analyzer is rotated by an angle of 48° in clockwise direction where the fringe order 3 passes through the centre forming a figure of 8. This is angle β. Now the analyzer is rotated by angle of 132° in anti-clockwise direction, the fringe order 4 passes through the centre forming shape of eight (8).

Calculate N1 and N2 by using the following relation

$N1 = n + (\beta /180)$

$N2 = n - (\beta /180)$

Where n are the lower and higher fringe orders respectively

$N1 = 3 + (48/180)$

$= 3.266$

$N2 = 4 - (48/180)$

$= 3.267$

The average is given by,

$N = (N1+N2)/2$

$= 3.266$

Now the material stress fringe constant is calculated by,

$F\sigma = [8P/\pi DN]$

$F\sigma = [8*65/\pi*70*3.266]$ $F\sigma$

$= 7.224$ Mpa

Sr. No.	Load Applied (load cell reading) W kg	Load On model 'P'= (W.X) /Y	Rotation of the Analyser		Fractional Fringe order at the centre of the disk under diametral compression			Material fringe Constant (fσ)	Average Material Fringe Constant (Fσ) Mpa
			β2 clock-wise	β2 anti-clock-wise	Lower Fringe Order (N1)	Higher Fringe Order (N2)	Avg Fringe Order (N)		
1	13.5	35	20	160	2.111	2.111	2.111	6.031	6.883
2	15	40	60	120	2.333	2.333	2.333	6.223	
3	16.76	45	65	115	2.361	2.362	2.361	6.918	
4	18.6	50	115	65	2.638	2.639	2.638	6.880	
5	20.49	55	150	30	2.833	2.833	2.833	7.047	
6	22.23	60	6	174	3.033	3.033	3.033	7.181	
7	24.21	65	48	132	3.266	3.267	3.266	7.224	
8	26.07	70	64	115	3.356	3.362	3.359	7.564	

Table 2 Average Material Fringe Constant

Photoelastic Stress Analysis

The photoelastic stress analysis method is very much advantageous because it gives direct visualization of stress distribution on the component. Just by looking at fringe patterns one can say the level of stresses induced in model. Calculated the principal Stress intensity by the formula

$I = N * F\sigma / h$

Where,
I- stress intensity
N- Average fringe order
Fσ- Material fringe constant h- Thickness of component

Loading Plan

Photoelastic model differs in mechanical properties from actual model. Hence the actual service load cannot be directly applied on photoelastic model for testing. By comparing of Young's modulus of the two materials we can determine of loads to be applied on model. The analytical expression is as follows.

For exact similarity strains should be same for model and prototype when loaded. Also the ratio of characteristic dimensions of model and prototype comes into picture while formulating similitude relationships.

$Fp = (Ep/ Em) * Fm$

Where,
Fp = Load of photoelastic model
Fm = Load of actual model
Ep = Young's modulus of photoelastic model
Em = Young's modulus of actual model

In case of photoelastic model being Araldite (Ep = 3300 MPa) and actual prototype materials are Grey cast iron (Em=110000Mpa), Steel (Em=210000Mpa), Al-Sic (Em=200000 Mpa). Now loads to be applied on model for testing are calculated below.

Sample Calculation:

For Grey Cast Iron drilling operation case (i) Fm = 1151.86N

$Fp = (Ep/Em) * Fm$

$= (3300/110000) * 1151.86$

$Fp = 34.56N$

Then all calculations are same shows in below table

Sr. No.	Operation	Case	Load of actual model (F_m) (N)	Load of photoelastic model (F_p) (N)		
				Grey cast iron	Steel	Al-Sic
1	Drilling	Case (i)	1151.86	34.56	18.10	22
		Case (ii)	1001.37	30.04	17.73	21.52
2	Tapping	Case (i)	747.15	19.41	13.74	14.32
		Case (ii)	669.33	18.08	12.51	15.04
3	Turning	Case	316.48	9.5	4.97	5.22

Table 3 Loading values of photoelastic model

Stresses Observed In Model

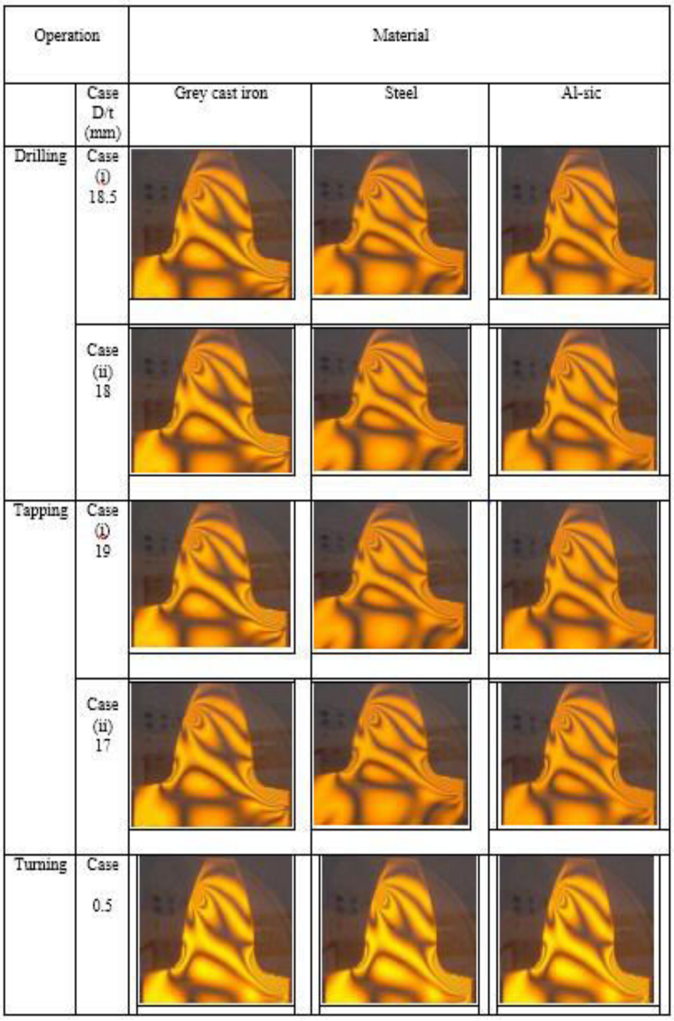


Figure 9 stresses observed in model

From the above table we have seen the fringes obtained on models. Table shows that various operations like drilling, tapping and turning are done on the lathe machine. In the first operation drilling, there are two cases was performed. In the case (i), calculating loads was applied on the model. Three calculating load was applied on the three different materials like grey cast iron, steel and al-sic. Fringes pattern shows on the model. By observing fringes on the model, we calculate stress intensity by the stress intensity formula. In drilling operation grey cast iron material shows less stress intensity than other two materials observed. The stress intensity of al-sic material is

8.00 Mpa which is approximately equal to grey cast iron material having stress intensity of 7.64 Mpa. In case (ii) observing fringes patterns on models by applying calculating loads, we saw that al-sic material shows low fringes than other two materials. By comparing all the stress intensity of materials, al-sic material shows less stress intensity for drilling second case. The average number of fringes order is as below. For grey cast iron - 25.72, for steel - 25.77 and for al-sic - 24.98. By observing fringes and calculating, we found that the stress intensity is 5.90 Mpa for grey cast iron, 5.91 Mpa for steel and 5.73 Mpa for al-sic material.

Now stress intensity calculated of the second operation is tapping. In tapping case (i) operation, by applying the calculating load on the model then we have seen that the number of fringes on model. Observing fringes patterns on models by applying calculating loads, we saw that al-sic material shows low fringes than other two materials. The average number of fringes order is follow. For grey cast iron 23.02, for steel 23.59 and for al-sic 22.62. While comparing the stress intensity of all materials, it has been seen that al- sic material shows less stress intensity for tapping first case. By observing fringes and calculating, we found that the stress intensity is 5.28 Mpa for grey cast iron, 5.41 Mpa for steel and 5.19 Mpa for al-sic material. Now in case (ii) by calculating the stress intensity for all materials, we found that al-sic material shows the less stress than the other two materials. For all materials the stress intensity is 4.51 Mpa for grey cast iron, 4.86 Mpa for steel and 4.35 Mpa for al-sic material. In tapping operation we observed from above discussion the al-sic material shows less stress intensity in the model than other two materials. Stress intensity of al-sic material and other two material have less difference. Comparing the above two operations, the high stress is observed in drilling operation than tapping operation.

In the turning operation, observing fringes patterns on models by applying calculating loads, we saw that al-sic material shows nearly equal fringes than other two materials. For all materials the stress intensity is 2.29 Mpa for grey cast iron, 2.09 Mpa for steel and 2.23 Mpa for al-sic material. From calculation we found that al-sic material shows the stress intensity is nearly equal to other two materials.

Experimental Result

Operation	D\t (mm)	Material	Experimental (Mpa)
Drilling	Case (i) 18.5	CI	7.64
		Steel	7.82
		Al-Sic	8.00
	Case (ii) 18	CI	5.90
		Steel	5.91
		Al-Sic	5.73
Tapping	Case (i) 19	CI	5.28
		Steel	5.41
		Al-Sic	5.19
	Case (ii) 17	CI	4.51
		Steel	4.86
		Al-Sic	4.35
Turning	Case 0.5	CI	2.29
		Steel	2.09
		Al-Sic	2.23

Table 4 Showing experimental results of different operations.

RESULT

The results from the FEA and Experimental process shows less difference. Stresses developed in case of drilling operations are much higher as compared with other two operations. Gears made up from steel material high stresses are induced and Al-Sic material stress induced are less. The comparison between the results shows that lesser than 5% error.

Operation	D\t (mm)	Material	Stress Intensity (FEA) (Mpa)	% Error	Experimental (Mpa)
Drilling	Case (i) 18.5	CI	8.00	4.5	7.64
		Steel	8.05	2.78	7.82
		Al-Sic	7.84	2.1	8.00
	Case (ii) 18	CI	6.14	3.9	5.90
		Steel	6.18	4.3	5.91
		Al-Sic	6.02	4.8	5.73
Tapping	Case (i) 19	CI	5.19	1.73	5.28
		Steel	5.22	3.8	5.41
		Al-Sic	5.09	2.14	5.19
	Case (ii) 17	CI	4.65	3.0	4.51
		Steel	4.67	4.2	4.86
		Al-Sic	4.55	4.39	4.35
Turning	Case 0.5	CI	2.18	4.8	2.29
		Steel	2.19	4.23	2.09
		Al-Sic	2.13	2.33	2.18

Table 5 showing comparisons of FEA and experimental results.

CONCLUSION

We know that the maximum force is required to drilling operation. Because of material is removed in maximum quantity. So Stresses developed in case of drilling operations are much higher as compared with other two operations. While in case of turning, stresses developed are less than the drilling and tapping operation.

The stresses in the Al-Sic material gear are nearly same as the other conventional materials of gear. From the FEA result, in drilling operation we get stress intensity value 6.14 for grey cast iron, 6.18 for steel and 6.02 for al-sic. And the experimental result for the same operation we get the stress intensity value 5.90 for grey cast iron, 5.91 for steel and 5.73 for al-sic. By comparing the above result we conclude that, the stresses in al- sic material gear are less or nearly same as the other conventional materials of gear such as steel, grey cast iron.

From the above discussion, stress intensity value of composite material gear like al-sic are superior to the other conventional material gears. So we can successfully replace the composite material gear to the other conventional materials gear.

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