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Study on Stress Analysis of Araldite HY-951 and CY-230 Bell Crank Lever using Photoelasticity and FEM

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Abstract
Bell crank lever is a bar capable of turning about a fixed point, used as a machine to lift the load by the application of small effort. Bell crank lever is used in railway signaling, governers of hartnell type, the drive for the air pump of condensers etc. The major stresses induced in the bell crank lever at the fulcrum are bending stress and fulcrum pin is shear stress. The maximum stresses are developed at the fulcrum. The Bell crank is a type of crank that changes motion through an angle. The angle can be any angle from 0 to 360 degrees, but 90 degrees and 180 degrees are most common. Hence, the work deals with the stress analysis of bell crank lever within the angle ranges 90^0 to 180^0 by finite element method using ANSYS WORKBENCH 14.5 software and Photoelasticity. Experimental and Analytical results are observed and compared, so that the obtained results are in close agreement with each other. For the photoelastic stress analysis which is the Experimental method, the bell crank lever models are prepared with photoelastic sheet of Araldite hardener HY-951 and curing agent CY-230 is used.
Keywords: Bell Crank Lever, Stress Analysis, MATLAB

1. Introduction

Stress analysis is an engineering discipline covering methods to determine the stresses in materials and structures subjected to forces or loads. Stress analysis is a primary task for civil, mechanical and aerospace engineers involved in the design of structures of all sizes, such as tunnels, bridges and dams, aircraft and rocket bodies, mechanical parts, and even plastic cutlery and staples. Stress analysis is also used in the maintenance of such structures, and to investigate the causes of structural failures. The present work deals with the stress analysis of bell crank lever within the angle ranges 90^0 to 180^0 by finite element method using ANSYS WORKBENCH 14.5 software and Photoelalstic Stress Analysis. Experimental and Analytical results are observed and compared, so that the obtained results are in close agreement with each other.

2. Experimental Stress Analysis

Bell crank lever is used to lift a load by the application of a small effort. For the analysis of bell crank lever the most critical area is considered and according to that the two dimensional model of bell crank lever is prepared. The different shapes of the bell crank lever are shown in the below figures. Three different loads, 100N, 150N, 200N were applied at one end and then the stresses calculated.

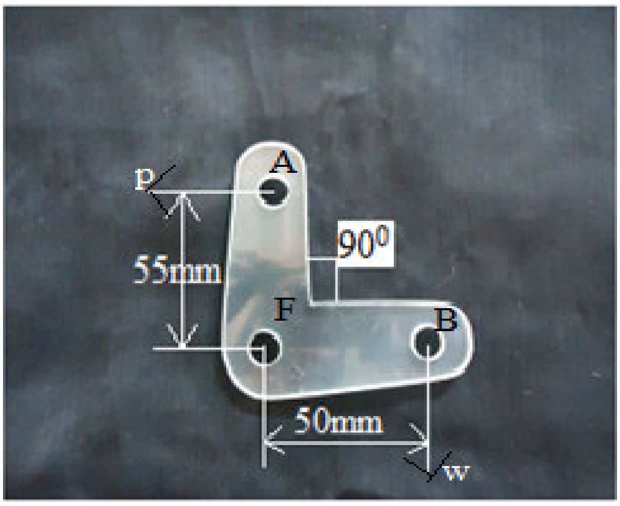

Figure 1 Bell Crank Lever with 90^0

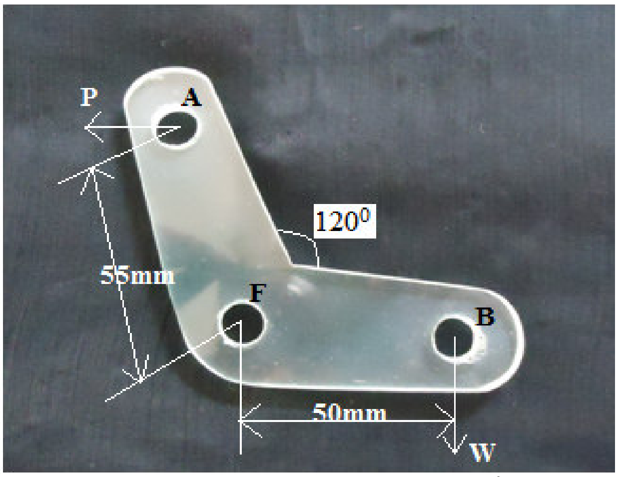

Figure 2 Bell Crank Lever with 120^0

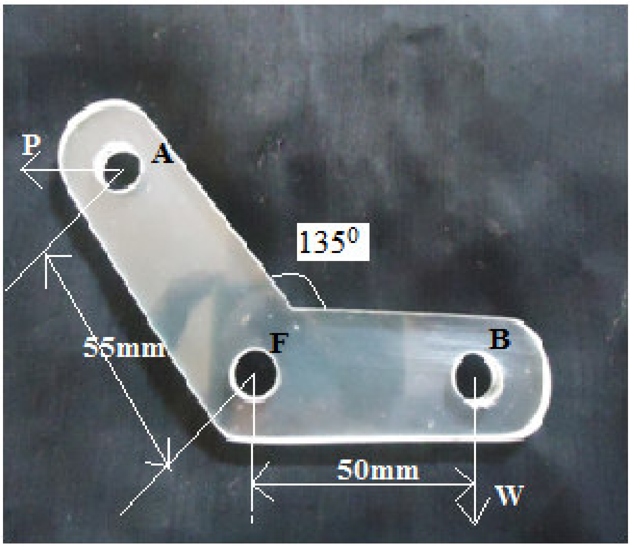

Figure 3 Bell Crank Lever with 135^0

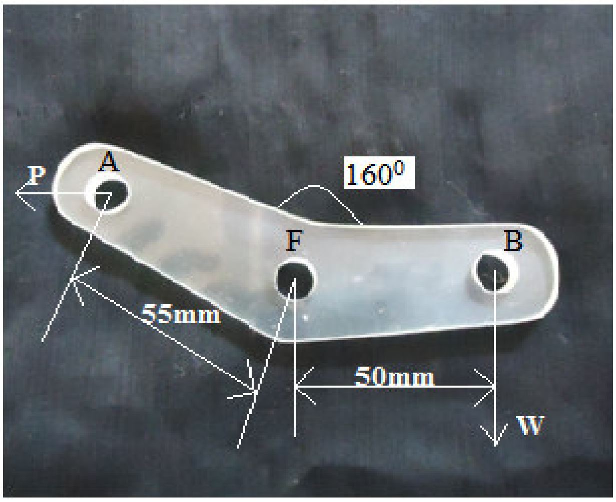

Figure 4 Bell Crank Lever with 160^0

Experimental stress analysis was done by photoelastic method. In photoelastic method, circular polariscope is used. For determining the fringe order, a circular disc of same material is used. Photoelastic model of bell crank lever is prepared from 5mm thick sheet casted from epoxy resin (mixture of Araldite CY 230 and hardener HY 951). Also circular shaped disc (calibration disc) of 65mm diameter is prepared from the same sheet.

This disc is taken and subjected to compressive load in the circular polariscope set up as shown in figure 5. Calibration was done on the disc to find material fringe value (F_σ).

Figure 5 Fringe pattern of Calibration disc in white light source

Values of fringe order are noted at different loads as shown in the table 4.5. Using the formula $F_\sigma = 8P/\pi DN$, material fringe values are determined and average is taken as 12.93 N/mm. where P = Load, N = Fringe order and D = diameter of the disc=65 mm. The material fringe value (F_σ) is the number of fringes produced per unit load. It is the property of the model material for a given wave length and thickness of the model.

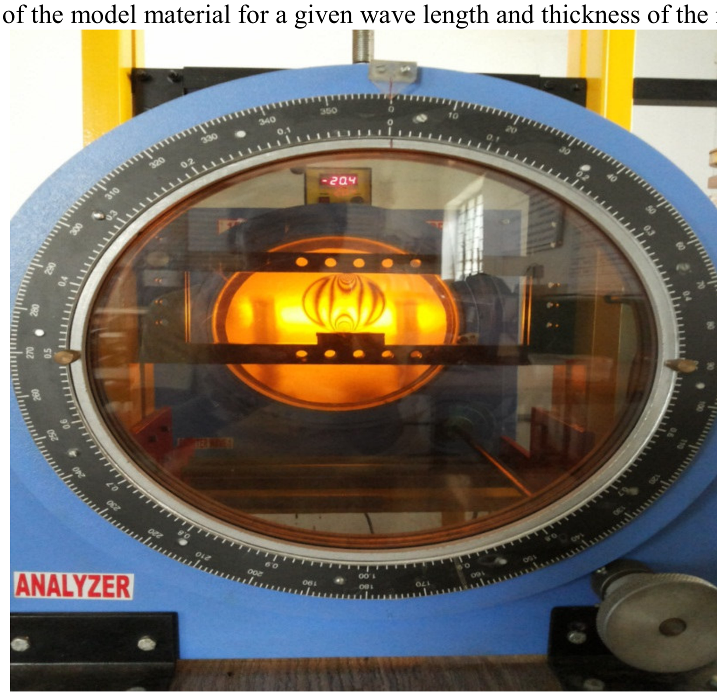

Figure 6 Fringe pattern of Calibration disc in monochromatic light source

Table 1 Determination of Material Fringe Value

S.No.	Load in (N)	Load in (kg)	Fringe Order (N)			Fringe Value (F_σ)	
			Lower (N_l)	Higher (N_h)	$(N_l + N_h)/2$	F_σ	Avg. (F_σ)
1	100	47.13	1.531	1.669	1.6	11.54	
2	150	82.33	2.353	2.461	2.407	13.43	12.93 N/mm
3	200	91.81	3.242	3.242	2.6	13.83	

2.1 Bell Crank Lever of 90^0:

The bell crank lever of 90^0 is kept in circular Polariscope arrangement for determining the stresses. At different loads the stresses are found which are listed below.

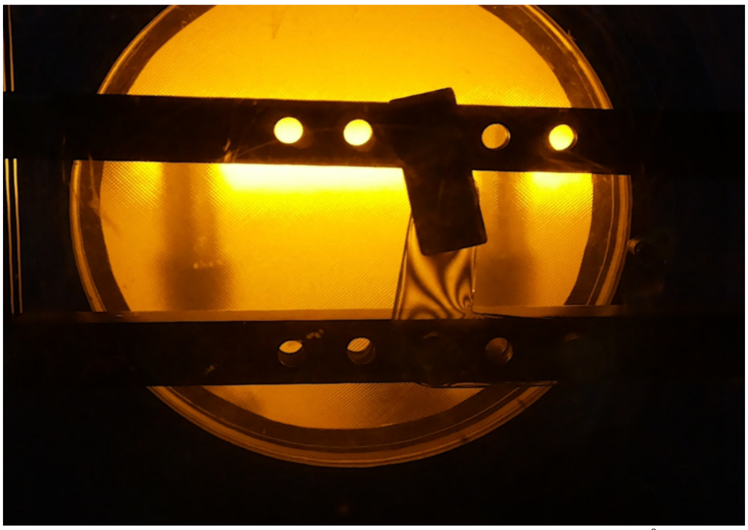

Figure 7 Fringes developed in Bell crank lever of 90^0

Table 2 Determination of Stresses using photoelasticity of Bell crank Lever at 90^0

S.No.	Load(kg)	Fringe Order, N	σ = NFσ/h (MPa)
1	10.2	3.09	8.01
2	15.3	4.65	12.03
3	20.4	6.38	16.52

From the above table 2, it is observed that, as the load increases, the principal stresses also increases.

2.2 Bell Crank Lever at 120^0:

The bell crank lever at 120^0 is kept in circular Polariscope arrangement for determining the stresses. At different loads the stresses are found which are noted below.

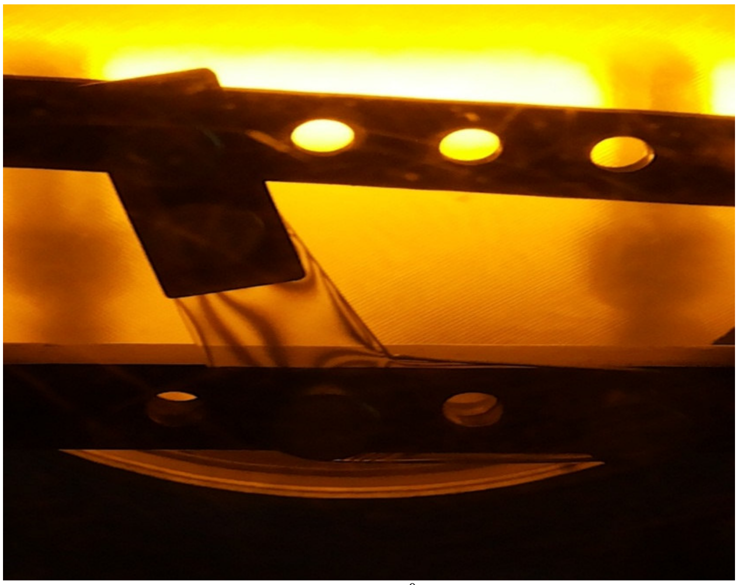

Figure 8 Bell crank lever at 120^0 in Circular Polariscope

Table 3 Determination of Stresses using photoelasticity of Bell crank Lever at 120^0

S.No.	Load(kg)	Fringe Order, N	σ = NFσ/h (MPa)
1	10.2	4.47	11.58
2	15.3	6.85	17.72
3	20.4	8.96	23.19

From the table 3, it is observed that, as the load increases, the principal stress also increases.

2.3 Bell Crank Lever at 135^0:
The bell crank lever at 135^0 is placed in circular Polariscope arrangement for determining the stresses. At different loads the stresses are found which are noted in below table.

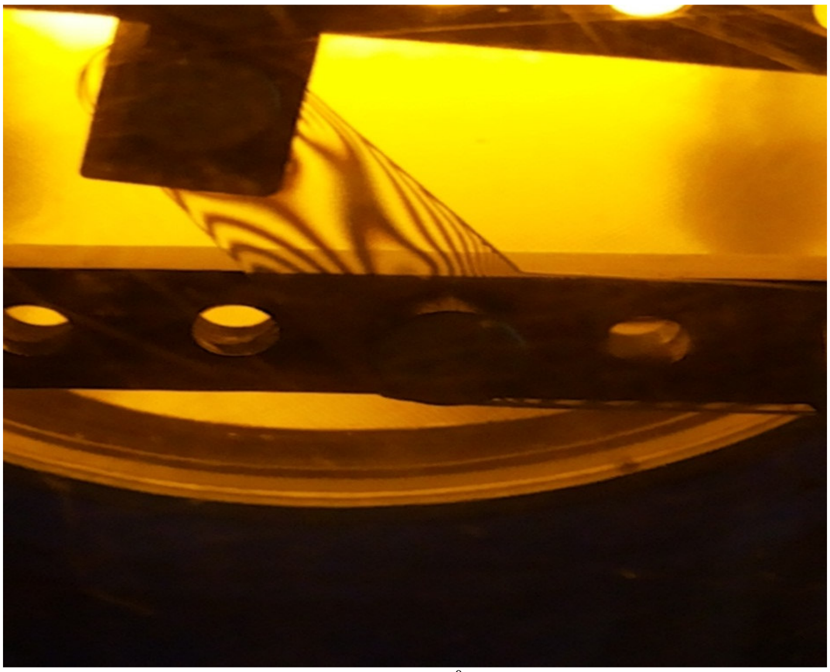

Figure 9 Bell crank lever at 135^0 in Circular Polariscope

Table 4 Determination of Stresses using photoelasticity of Bell Crank Lever at 135^0

S.NO	Load(kg)	Fringe Order, N	σ = NFσ/h (MPa)
1	10.2	4.67	12.09
2	15.3	7.15	18.51
3	20.4	9.4	24.45

From above table 4, it is observed that, as the load increases, the principal stress also increases.

2.4 Bell Crank Lever at 160^0:
The bell crank lever at 160^0 is kept in the circular Polariscope arrangement for determining the stresses. At different loads the stresses are found which are noted in below table.

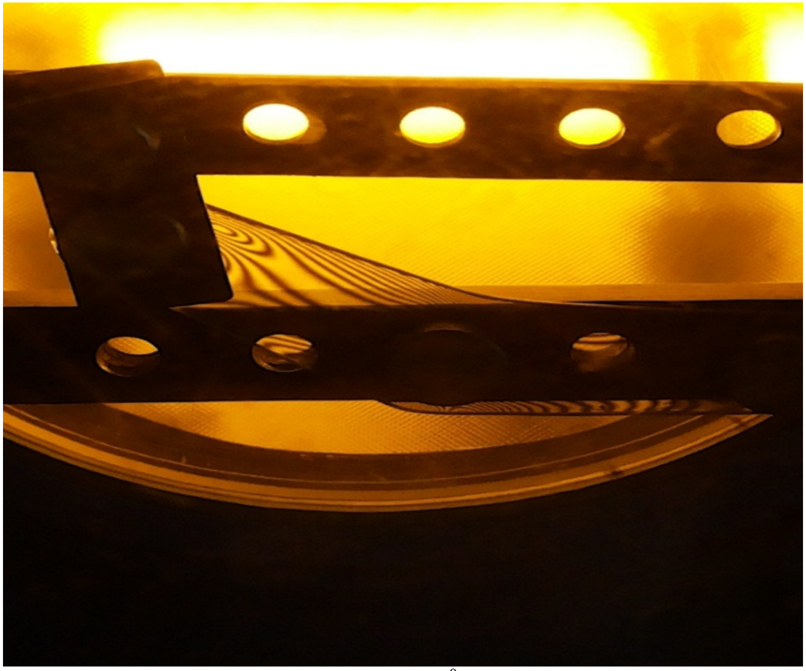

Figure 10 Bell crank lever at 160^0 in Circular Polariscope

Table 5 Determination of Stresses using photoelasticity of Bell Crank Lever at 160^0

S.NO	Load(kg)	Fringe Order, N	σ = NFσ/h (MPa)
1	10.2	4.64	12.01
2	15.3	6.92	17.9
3	20.4	9.28	24.02

From the above table 5, it is observed that, as the load increases, the principal stress also increases. The results obtained experimentally using photoelastic bench equipment by photoelastic stress analysis under whole field technique at different conditions is graphically shown in figure 11.

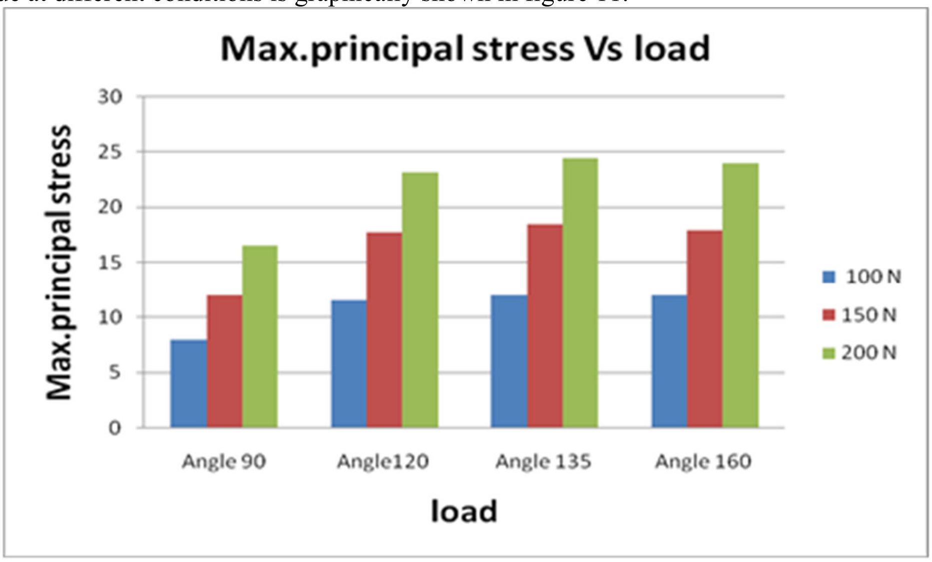

Figure 11 Effect of angle between two arms on max.principal stress (Experimental)

3. Analytical (Finite Element Analysis):

By using ANSYS WORKBENCH, the stress analysis was done at four different angles of bell crank lever between load arm and effort arm at three different loads which are 100N, 150N, and 200N. In this the maximum principal stress and maximum shear stress are found by varying the load. In the bell crank lever, the load is applied at the lever section in the downward direction, the effort is applied at arm section in the horizontal direction and it is fixed at the fulcrum of the bell crank lever with fulcrum pin.

3.1 Bell Crank Lever at 90^0:

a) Maximum Principal Stress when Bell Crank Lever of 90^0 subjected to 100N Load

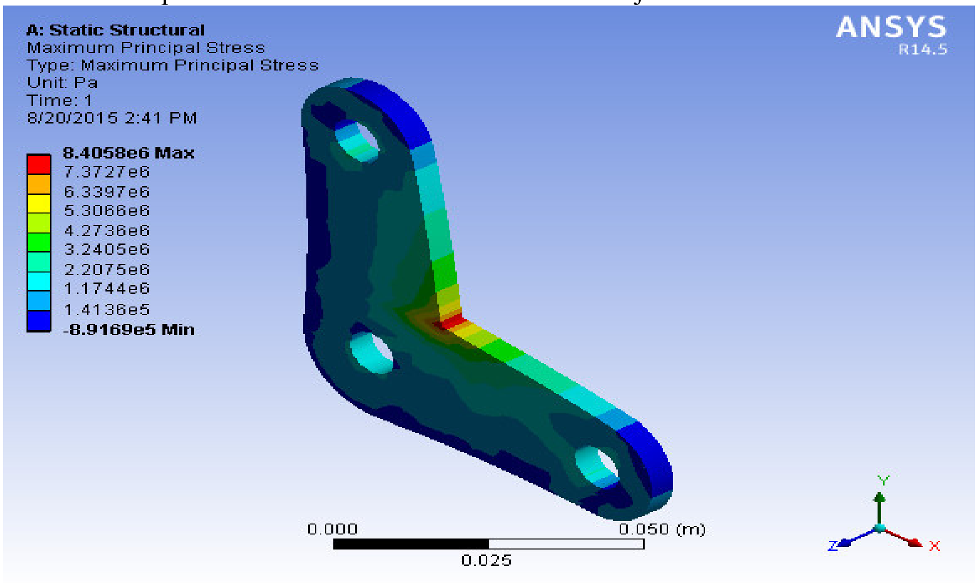

Figure 12 Bell crank lever with 90^0 at 100N load

The maximum principal stress is 8.40Mpa and maximum shear stress is 4.09Mpa.

b) Maximum Principal Stress when Bell Crank Lever of 90^0 subjected to 150N Load

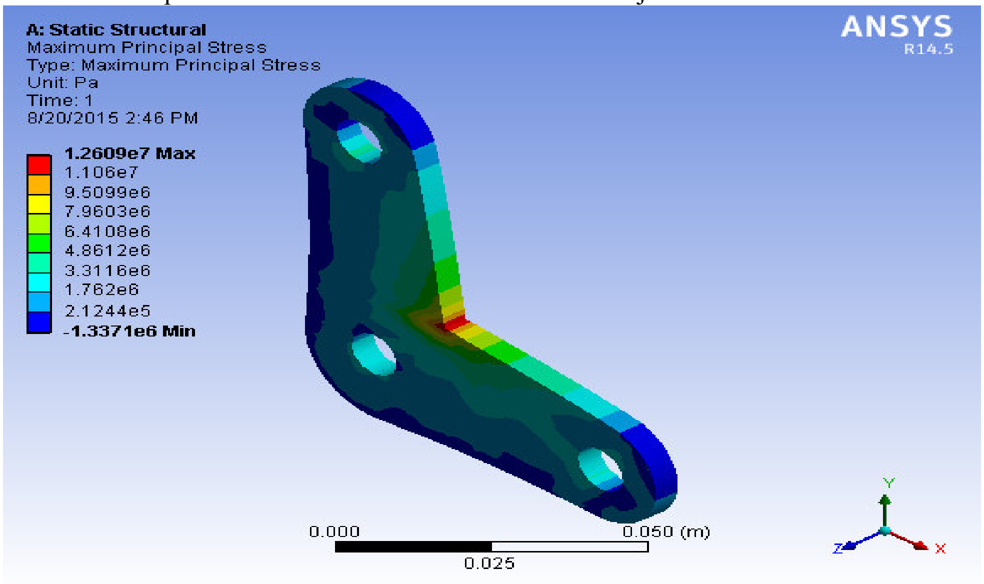

Figure 13 Bell crank lever with 90^0 at 150N load

The maximum principal stress was 12.60Mpa and maximum shear stress was 6.14Mpa.

c) Maximum Principal Stress when Bell Crank Lever of 90^0 subjected to 200N Load

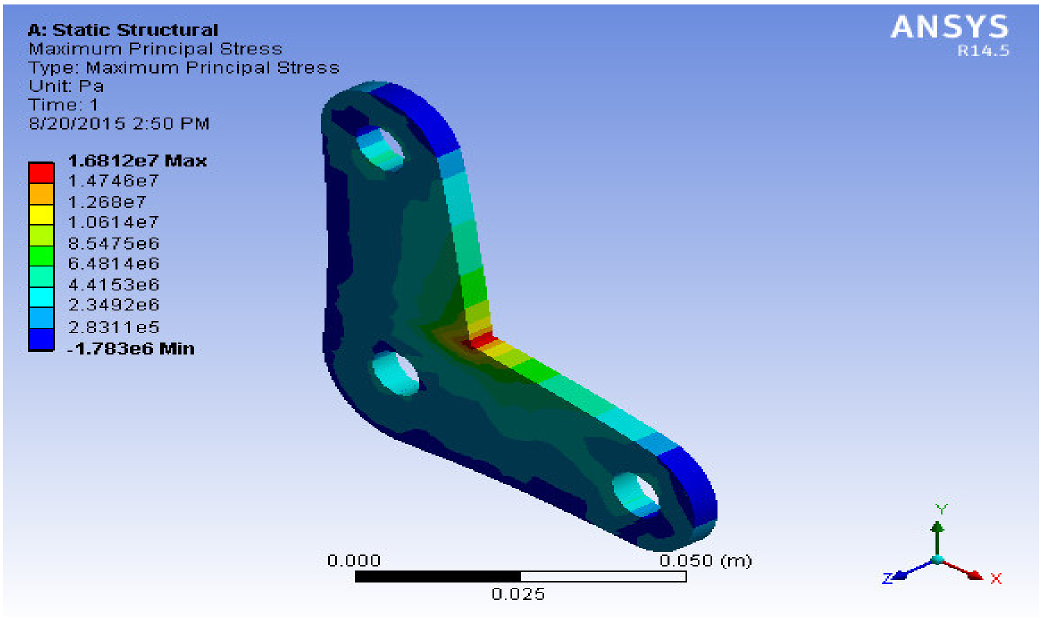

Figure 14 Bell crank lever with 90^0 at 200N load

The maximum principal stress was 16.81Mpa and maximum shear stress was 8.19Mpa.

3.2 Bell Crank Lever at 120^0:

a) Maximum Principal Stress when Bell Crank Lever of 120^0 subjected to 100N Load:

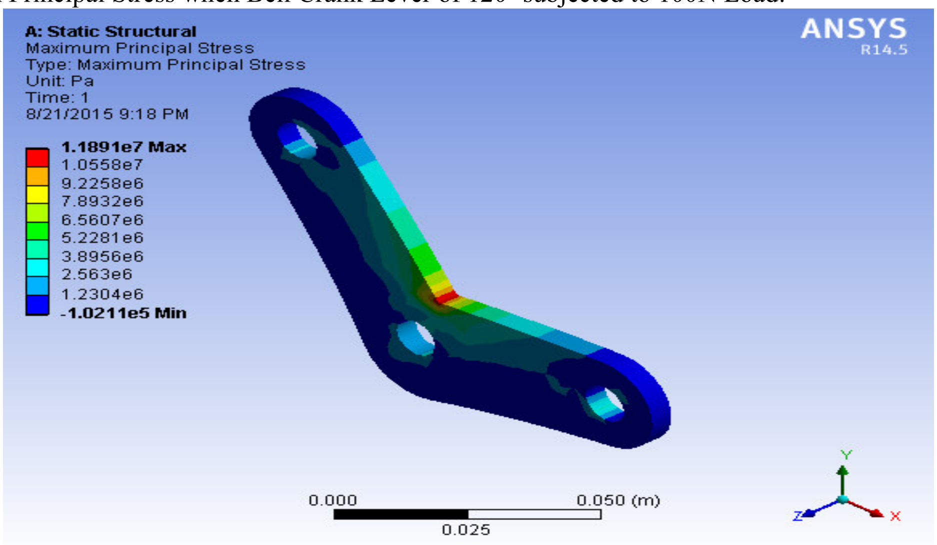

Figure 15 Bell crank lever with 120^0 at 100N load

The maximum principal stress was 11.89Mpa and maximum shear stress was 5.79Mpa.

b) Maximum Principal Stress when Bell Crank Lever of 120^0 subjected to 150N Load

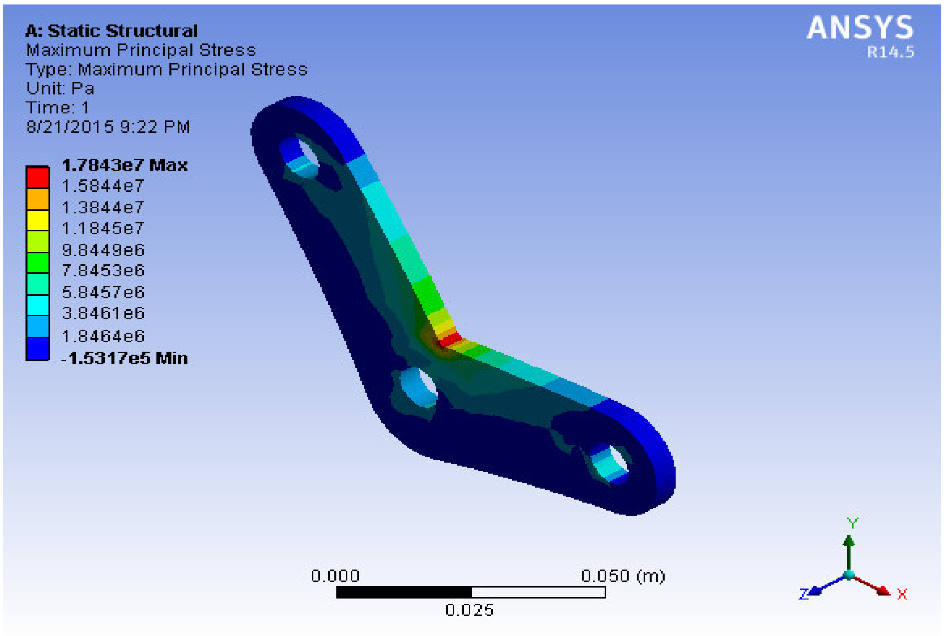

Figure 16 Bell crank lever with 120^0 at 150N load

The maximum principal stress was 17.84Mpa and maximum shear stress was 8.69Mpa.

c) Maximum Principal Stress when Bell Crank Lever of 120^0 subjected to 200N Load

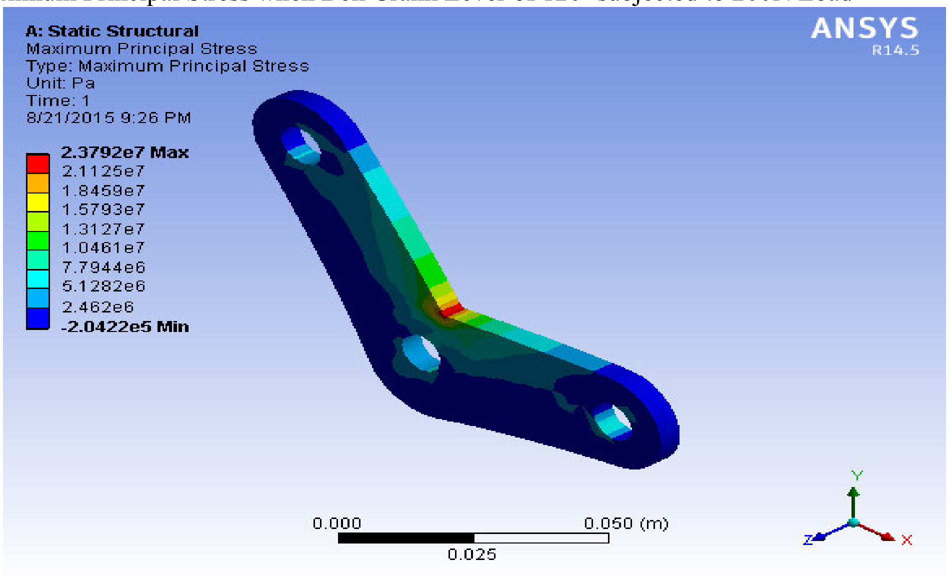

Figure 17 Bell crank lever with 120^0 at 200N load

The maximum principal stress was 23.79Mpa and maximum shear stress was 11.6Mpa.

3.3 Bell Crank Lever at 135^0:

a) Maximum Principal Stress when Bell Crank Lever of 135^0 subjected to 100N Load:

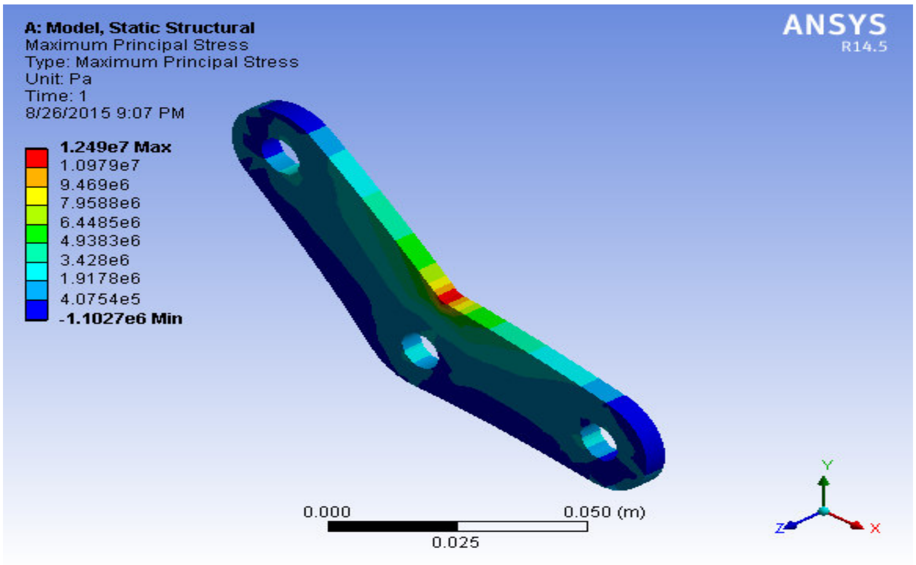

Figure 18 Bell crank lever with 135^0 at 100N load

The maximum principal stress was 12.49Mpa and maximum shear stress was 6.2Mpa.

b) Maximum Principal Stress when Bell Crank Lever of 135^0 subjected to 150N Load

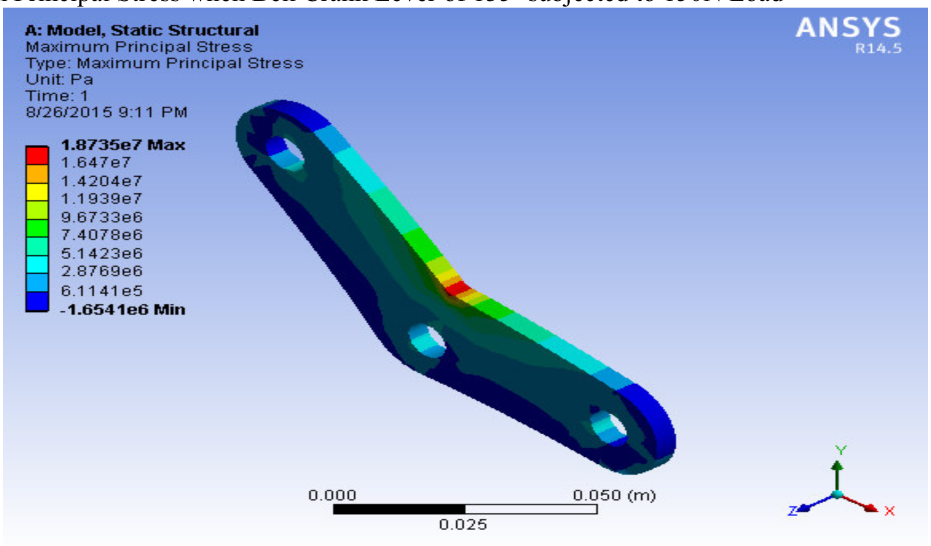

Figure 19 Bell crank lever with 135^0 at 150N load

The maximum principal stress was 18.73Mpa and maximum shear stress was 9.15Mpa.

c) Maximum Principal Stress when Bell Crank Lever of 135^0 subjected to 200N Load:

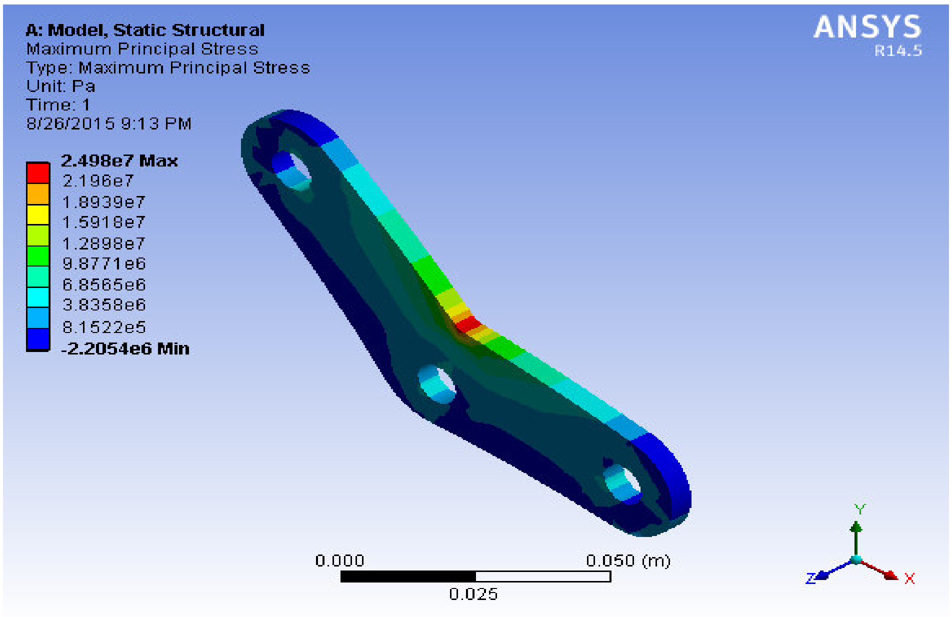

Figure 20 Bell crank lever with 135^0 at 200N load

The maximum principal stress was 24.98Mpa and maximum shear stress was 12.21Mpa.

3.4 Bell Crank Lever at 160^0:

a) Maximum Principal Stress when Bell Crank Lever of 160^0 subjected to 100N Load:

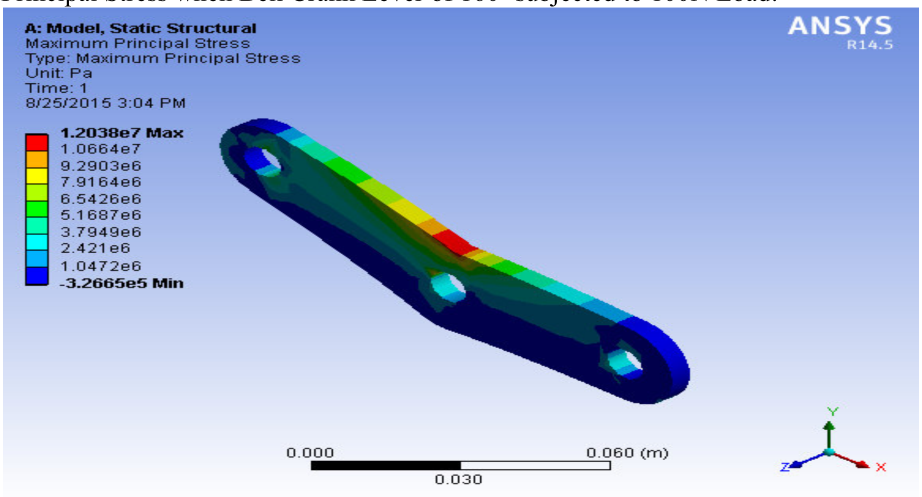

Figure 21 Bell crank lever with 160^0 at 100N load

The maximum principal stress was 12.03Mpa and maximum shear stress was 5.98Mpa.

b) Maximum Principal Stress when Bell Crank Lever of 160^0 subjected to 150N Load

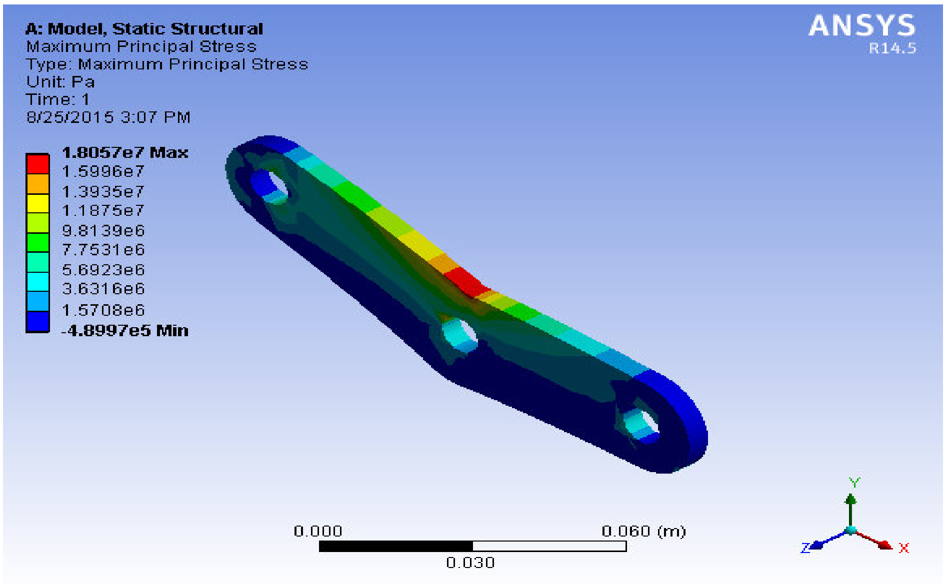

Figure 22 Bell crank lever with 160^0 at 150N load

The maximum principal stress was 18.05Mpa and maximum shear stress was 8.97Mpa.

c) Maximum Principal Stress when Bell Crank Lever of 160^0 subjected to 200N Load

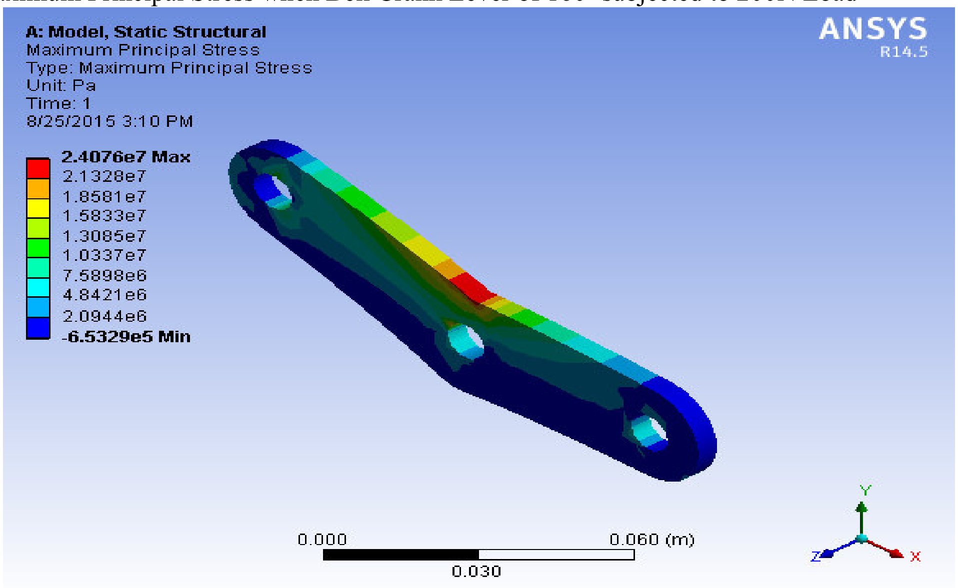

Figure 23 Bell crank lever with 160^0 at 200N load

The maximum principal stress was 24.07Mpa and maximum shear stress was 11.97Mpa.

Table 6 Analysing stresses induced in lever by using ANSYS WORKBENCH

Angle (N)	Load (N)	ANSYS WORKBENCH (MPa)	
		σ_{max}	τ_{max}
90^0	100	8.40	4.09
	150	12.60	6.14
	200	16.81	8.19
120^0	100	11.89	5.79
	150	17.84	8.69
	200	23.79	11.6
135^0	100	12.49	6.2
	150	18.73	9.15
	200	24.98	12.21
160^0	100	12.03	5.98
	150	18.05	8.97
	200	24.07	11.97

From the table 6, it is observed that, as the load increases, then effort increases and then the maximum principal stress and shear stress also increases. The results are graphically shown in fig. 24.

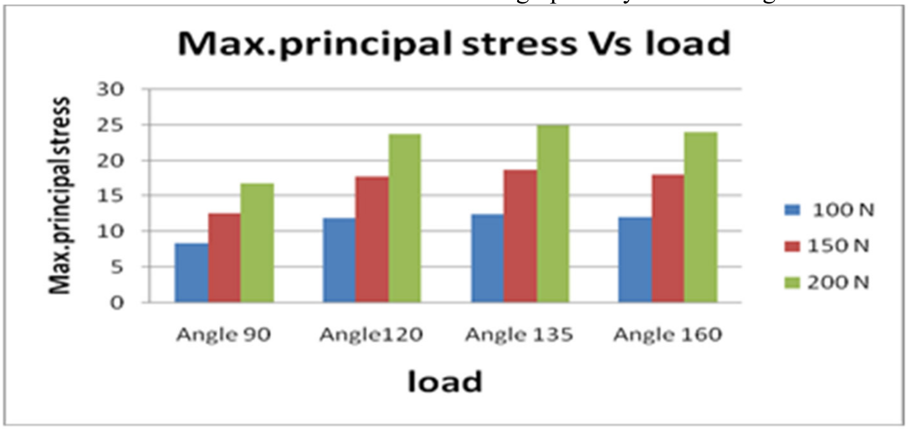

Figure 24 Effect of angle between two arms on max.principal stress (ANSYS)

4. Comparison of Results

The Bell Crank Lever was analyzed by the methods which are Experimental method (Photoelasticity) and Numerical method (Finite Element Analysis).

Table 7 Comparison of results

Angle	Load (N)	Photoelasticity (Mpa)		ANSYS WORKBENCH at Lever section (Mpa)	
		σ_{max}	τ_{max}	σ_{max}	τ_{max}
90^0	100	8.01	4.03	8.40	4.09
	150	12.03	6.01	12.60	6.14
	200	16.52	8.27	16.81	8.19
120^0	100	11.58	5.64	11.89	5.79
	150	17.72	8.67	17.84	8.69
	200	23.19	12.57	23.79	11.6
135^0	100	12.09	6.04	12.49	6.2
	150	18.51	9.14	18.73	9.15
	200	24.45	12.25	24.98	12.21
160^0	100	12.01	6.02	12.03	5.98
	150	17.9	8.73	18.05	8.97
	200	24.02	12.15	24.07	11.97

From the above table 7, as the load increases, the effort increases and maximum principal stress and maximum shear stress also increases. The optimum angle is 90^0.

5. Conclusion

The Bell Crank Lever was analyzed by the methods which are Experimental (Photoelasticity) and Numerical (Finite Element Analysis) methods, and from the obtained results it is concluded that, At the lever section, as the load and angle between the arms increases, the maximum principal and shear stresses also increases. And the optimum angle is observed at 90^0. By comparing the results experimental and analytical reveals that they are in close agreement with each other with minimum percentage of error.

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