Effect of Elastic Constants on Stress Concentration Factor and its Mitigation in Rectangular Plate With Central Circular Hole Under in Plane Loading

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***Abstract*— The effect of different material properties on SCF has been studied. Five models of plate have been considered for analysis. Poisson's ratio and elastic constants E_X, E_Y and G_{XY} have been varied from its original values. All the five models for four materials considered have been analyzed for D/A=0.1 and 0.5, by considering all the variations in material properties. Model 1, is the plate with central circular hole for isotropic and orthotropic materials. All other models are modified design of Model1 for mitigation of SCF.**

Keywords— ***Stress concentration factor, mitigation of stress concentration factor, elastic constants***.

NOMENCLATURE

A	Width of rectangular plate
D	Diameter of main hole
D’	Diameter of Auxiliary hole
E	Modulus of elasticity
E_i	Modulus of elasticity in i direction
G_{xy}	Modulus of rigidity for XY plane
SCF	Stress concentration factor = $\sigma_{max}/\sigma_{nom}$
L	Length of rectangular plate
$(SCF)_{M1}$	SCF in Model 1
$(SCF)_{VM1}$	Percentage Variation in SCF in Model 1
$(SCF)_{RM2}$	Percentage reduction in SCF in Model 2
$(SCF)_{RM3}$	Percentage reduction in SCF in Model 3
$(SCF)_{RM4}$	Percentage reduction in SCF in Model 4
$(SCF)_{RM5}$	Percentage reduction in SCF in Model 5
$(\nu)_V$	Percentage Variation in Poission’s ratio
$(E_X)_v$	Percentage Variation in E_X
$(E_X / Ey)_V$	Percentage Variation in E_X / Ey
$(E_X / G_Xy)_V$	Percentage Variation in E_X / G_Xy
$(E_Y / G_Xy)_V$	Percentage Variation in E_Y / G_Xy
X	Length of cavity
σ	Uniformly distributed load (N)
σ_{max}	Maximum stress at discontinuity, N/mm^2
ν	Poisson’s Ratio
Φ	Width of Cavit

I. INTRODUCTION

Failure in real engineering components almost invariably begins at the root of a geometrical discontinuity. The classic example of discontinuity is rectangular plate with central circular hole. Analysis of stress concentration around discontinuities in plates under various loading conditions has been worked out by various researchers.

The work carried out by various researchers for analysis of SCF is compiled and presented by Peterson [1]. Shastry and Raj [2] have analyzed the effect of fibre orientation for a unidirectional composite laminate with finite element method by assuming a plane stress problem under in plane static loading.

Hanus [3] formed parameterized geometry models of orthotropic material subjected to uni-axial tension and studied the interaction between elliptical holes and free edges.

Rajaiah et. al. [4] proposed hole shape optimization in a finite plate by photo elasticity method. They introduced auxiliary holes around main hole for mitigation of SCF and also optimized the shape of circular holes. The effort is made by experimental determination of reduction in SCF by a) introduction of circular holes b) optimization of shape of main hole c) optimizing the shape of main hole as well as auxiliary holes.

Stress concentration factors, Kt, for a flat bar with circular-arc or V-shaped notches are considered by Noda and Takase [5] based on the exact solutions for special cases and accurate numerical results. A set of Kt formulas useful for any notch shape is proposed. For the limiting cases of deep (d) and shallow (s) notches, the body force method is used to calculate the Kt values and is formulated as Ktd and Kts. The notch shape is classified into several groups according to the notch radius and notch depth. The least squares method is applied for calculation of Kt/Ktd and Kt/Kts. Convenient formulas are proposed that are useful for any notch shape in a flat test specimen.

Zirka et. al. [6] have analyzed stress concentration around circular hole in a rectangular plate for orthotropic and isotropic plates under dynamic and static loading. They have used photo elastic method for analysis.

Sanyal and Yadav [7] have proposed the optimum distance and size of auxiliary holes for mitigation of SCF in plate with circular hole. Introducing the optimum auxiliary holes in the line of original hole, about 17% mitigation in SCF is achieved by them. They have proposed an optimum distance between the original hole and relief hole and also an optimum size of relief hole by assuming elliptical stress flow lines.

Kubair [8] numerically investigated the effect of the material property in-homogeneity on the SCF due to a circular hole in functionally graded panels. Functionally graded materials are composites in which the material properties vary continuously as a known function of the spatial position. A parametric study was performed by varying the functional form and the direction of the material property gradation. The results from parametric study showed that the SCF is reduced away from Young's modules .In exponential functionally graded materials the variation in the in-homogeneity length scale influences the SCF the most.

Mittal and Jain [9] analyzed the effect of fibre orientation on stress concentration factor in fibrous plate with central circular hole under transverse static loading by using two dimension finite element methods.

Rao et. al.[10] evaluated the stress around square and rectangular cutouts in symmetric laminates. It has been analyzed that the maximum stress and its location is mainly influenced by the type of loading.

Extensive literature has been published on analysis of stress concentration and mitigation of stress concentration. However research work reported in the area of effect of material properties on SCF is limited.

II. PROBLEM DESCRIPTION

The five models of plate have been considered for analysis of effect of elastic constants of different composite materials on Stress Concentration Factor.

Model1 is the Plate with central circular hole for orthotropic materials, Model2 is Plate with central circular hole and one set of auxiliary holes for orthotropic materials and Model3 is Plate with central circular hole and two set of auxiliary holes for orthotropic materials. Model4 is plate with central cavity of size 0.8*D by 8*D. Model5 is plate with central cavity of size 0.9*D by 8*D. All the models are shown in Fig.1 to Fig.5.

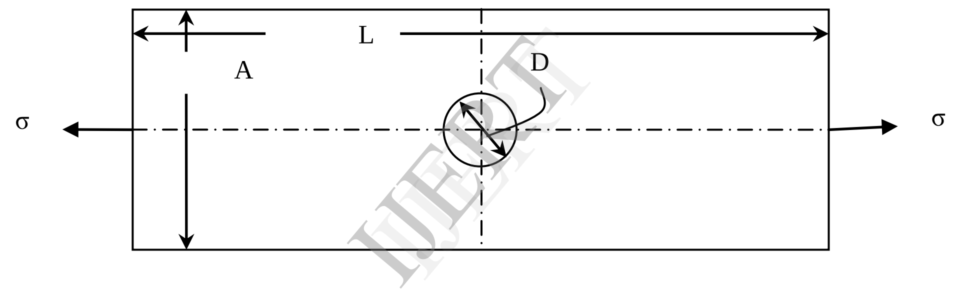

Fig.1 Model1

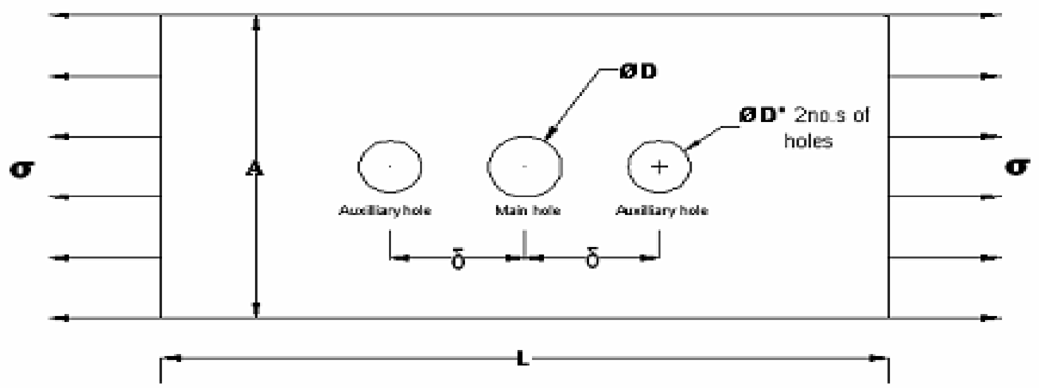

Fig.2 Model2

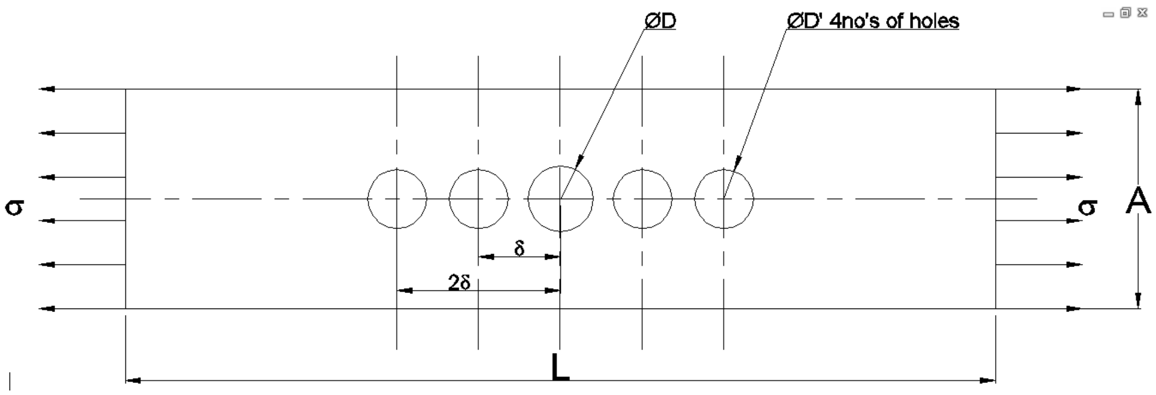

Fig.3. Model3

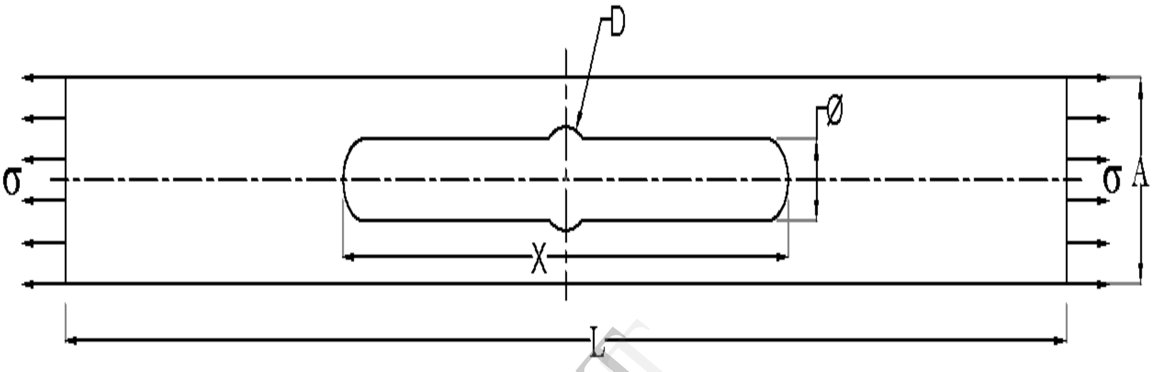

Fig.4. Model4

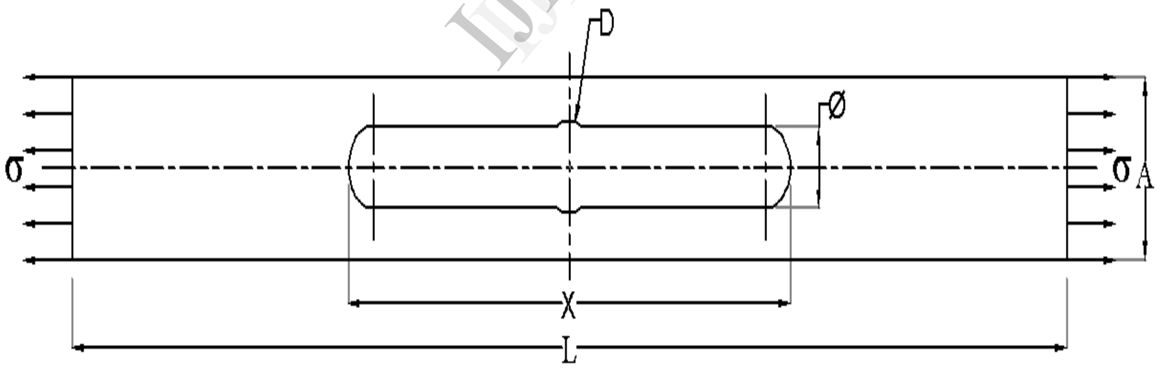

Fig.5. Model5

The model1 is the basic model of plate and has been optimized for mitigation of SCF by providing auxiliary holes and optimizing the shape of the main hole. The models considered are for optimum size of auxiliary holes and optimum shape of the main hole.

III. FINITE ELEMENT ANALYSIS

Rectangular plate of 400*100 has been considered for model1, model2 and model3. Rectangular plate of 600*100 has been considered for model4 and model5. Element 8node 82solid has been taken and size of element has been taken as 1mm.

As the modulus of elasticity in x-direction is varied E_X/E_Y and E_X/E_{XY} changes keeping Poisson's ratio and E_Y constant.

Similarly, when modulus of elasticity in y-direction is varied E_X/E_Y and E_Y/E_{XY} changes keeping Poisson's ratio and E_X constant.

The properties of materials has been varied from -50% to 50%, at an interval of 10 from the original values. The magnitude of properties has been considered and all the five models have been analyzed for D/A=0.1 and 0.5.

IV. RESULT AND DISCUSSION

All the models have been analyzed for all the considered variables. The SCF for all the cases has been reported in tabular form and compared. The SCF in model1 for all the materials has been taken as reference for studying the variation in SCF with change in material properties and reduction in SCF. The variation in SCF has been observed in model1 by changing the material properties of model1. As the Poisson's ratio increases the SCF increases, this variation is very less.

The percentage reduction in SCF for all other models as compared to SCF of model1 has been determined and tabulated. The variation in percentage reduction in SCF by varying different material properties for same model is less. The maximum reduction in SCF has been reported for model4 for all the cases considered.

The material properties and variation in these properties has been shown in Table 1 to Table 7.

Table1. Properties of orthotropic materials

Material	E_X (Gpa)	E_Y	G_{XY}	ν	E_X/E_Y	E_X/G_{XY}	E_Y/G_{XY}
Eglass Epoxy	39	8.6	3.8	0.28	4.53	10.26	2.26
Boron Epoxy	201	21.7	5.4	0.17	9.26	37.22	4.02
Boron Aluminium	235	137	47	0.3	1.72	5.00	2.91
Graphite Epoxy	294	6.4	4.9	0.23	45.94	60.00	1.31

Table 2. Percentage variation in Poisson's Ratio

Material	ν	10	30	50	0	-10	-30	-50
Eglass Epoxy	0.28	0.308	0.364	0.42	0.28	0.252	0.196	0.14
Boron Epoxy	0.17	0.187	0.221	0.255	0.17	0.153	0.119	0.085
Boron Aluminium	0.3	0.33	0.39	0.45	0.3	0.27	0.21	0.15
Graphite Epoxy	0.23	0.253	0.299	0.345	0.23	0.207	0.161	0.115

Table 3. Percentage variation in E_X/E_Y by varying E_Y

Material	E_X/E_Y	10	30	50	0	-10	-30	-50
Eglass Epoxy	4.53	4.99	5.90	6.80	4.53	4.08	3.17	2.27
Boron Epoxy	9.26	10.19	12.04	13.89	9.26	8.34	6.48	4.63
Boron Aluminium	1.72	1.89	2.23	2.57	1.72	1.54	1.20	0.86
Graphite Epoxy	45.94	50.53	59.72	68.91	45.94	41.34	32.16	22.97

Table 4. Percentage variation in E_X/G_{XY}

Material	E_X/G_{XY}	10	30	50	0	-10	-30	-50
Eglass Epoxy	2.26	2.49	2.94	3.39	2.26	2.04	1.58	1.13
Boron Epoxy	4.02	4.42	5.22	6.03	4.02	3.62	2.81	2.01
Boron Aluminium	2.91	3.21	3.79	4.37	2.91	2.62	2.04	1.46
Graphite Epoxy	1.31	1.44	1.70	1.96	1.31	1.18	0.91	0.65

Table 5. Percentage variation in E_X

Material	E_X	10	30	50	0	-10	-30	-50
Eglass Epoxy	39	42.9	50.7	58.5	39	35.1	27.3	19.5
Boron Epoxy	201	221.1	261.3	301.5	201	180.9	140.7	100.5
Boron Aluminium	235	258.5	305.5	352.5	235	211.5	164.5	117.5
Graphite Epoxy	294	323.4	382.2	441	294	264.6	205.8	147

Table 6. Percentage variation in E_Y

Material	E_Y	10	30	50	0	-10	-30	-50
Eglass Epoxy	8.6	7.82	6.62	5.73	8.60	9.56	12.29	17.20
Boron Epoxy	21.7	19.73	16.69	14.47	21.70	24.11	31.00	43.40
Boron Aluminium	137	124.55	105.38	91.33	137.00	152.22	195.71	274.00
Graphite Epoxy	6.4	5.82	4.92	4.27	6.40	7.11	9.14	12.80

Table 7 Percentage variation in G_{XY}

Material	G_{XY}	10	30	50	0	-10	-30	-50
Eglass Epoxy	3.8	3.45	2.92	2.53	3.80	4.22	5.43	7.60
Boron Epoxy	5.4	4.91	4.15	3.60	5.40	6.00	7.71	10.80
Boron Aluminium	47	42.73	36.15	31.33	47.00	52.22	67.14	94.00
Graphite Epoxy	4.9	4.45	3.77	3.27	4.90	5.44	7.00	9.80

The variation in Poission's ratio has very less effect on SCF.

The ratio E_y/G_{xy} is varying from 1.3 to 4.02 for all the materials considered. E_y/G_{xy} varying from 1.72 to 45.94. The variation in E_y/G_{xy} values is maximum from 5 to 60.

As the magnitude of E_y varies by keeping all other properties constant, the value of E_x/E_y changes. The magnitude of E_y/G_{xy} is very less as compared to E_x/E_y and consequently its effect is less on SCF. The magnitude of E_x varies for, -50% to 50% which changes the magnitude of both E_x/E_y and E_y/G_{xy}.

Table 8. Variation in SCF due to different Poisson's ratio in E-glass Epoxy models for D/A=0.1

S.No.	(v)V	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	3.81	-0.45	25.14	25.14	44.12	32.20
2	-30	3.81	-0.33	25.17	25.17	44.15	32.17
3	-10	3.80	-0.09	25.11	25.11	44.07	32.10
4	0	3.80	0.00	25.11	25.11	44.06	32.16
5	10	3.79	0.14	25.10	25.10	44.05	32.27
6	30	3.78	0.38	25.04	25.04	43.97	32.11
7	50	3.78	0.45	25.11	25.11	43.97	32.13

Table 9. Variation in SCF due to different E_X / Ey in E-glass Epoxy models for D/A=0.1

S.No.	$(E_X / Ey)_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	3.67	3.39	24.59	27.96	43.57	33.19
2	-30	3.70	2.46	25.56	27.06	44.45	32.70
3	-10	3.71	2.25	24.24	26.25	43.16	31.30
4	0	3.80	0.00	25.11	25.94	44.06	32.16
5	10	3.83	-1.04	25.56	25.42	44.45	32.18
6	30	3.88	-2.21	25.96	24.97	44.41	32.48
7	50	3.89	-2.47	25.46	24.50	44.39	32.28

Table 10. Variation in SCF due to different E_X / G_Xy in Eglass Epoxy models for D/A=0.1

S.No.	$(E_X / G_Xy)_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	3.24	14.51	20.33	18.97	35.92	27.21
2	-30	3.52	7.23	25.28	25.84	40.44	30.57
3	-10	3.75	1.19	25.10	25.46	43.72	32.23
4	0	3.80	0.00	25.11	25.94	44.06	32.16
5	10	3.85	-1.40	25.02	24.93	43.38	32.41
6	30	3.89	-2.47	23.95	24.88	43.05	32.65
7	50	3.95	-4.17	23.22	25.90	43.50	30.84

Table 11. Variation in SCF due to different E_X in E-glass Epoxy models for D/A=0.1

S.No.	(EX)V	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	3.24	14.37	23.50	8.40	28.96	14.23
2	-30	3.33	12.11	23.78	13.24	33.23	26.70
3	-10	3.56	6.04	24.12	19.78	38.54	28.43
4	0	3.79	0.00	24.99	25.82	43.97	32.04
5	10	3.84	-1.35	25.09	23.32	46.60	35.40
6	30	4.06	-7.15	25.21	21.30	49.12	38.76
7	50	4.13	-8.95	25.38	17.29	51.56	42.82

For E-glass epoxy the percentage variation in SCF in Model1 for D/A=0.1 when changing the magnitude of Poission;s ratio from -50% to 50% is very less . The variation in SCF is very less in model1 when varying poisson’s ratio in all cases. It is reported as -.0.45% to 0.45% .As the value of Poission;s ratio decreases so does the value of SCF. The effect of reducing SCF is insignificant as it comes to just about 2%. The maximum reduction on SCF has been reported for Model 4.

As E_x/E_y changes the percentage variation in SCF is -2.4% to 3.4% As the ratio E_x/E_y increases the SCF decreases . The percent reduction in SCF from model 2 to model 5 increases for both the cases of E_x/E_y that is increasing or decreasing the E_x/E_y causes very less percentage change as compared to the actual values of properties of materials .It is 3% to 4 % .

By changing the ratio E_y /G_{xy} the percentage variation in SCF for Model1 varies from 14.5 % to -4.1%.

The percentage variation in E_x reported in SCF in Model 1 is from -9% to 14.3% .As the E_x decreases the SCF also decreases and as the magnitude of E_x increases the SCF decreases .The reduction in SCF varies from 2% to -2% in Model 2,-17% to 8% in Model 3 , -16% to 9% in Model 4 , -18% to 10% in Model 5 . This shows that as the E_x decreases the SCF increases and the percentage reduction in SCF reported is less as compared to the SCF for original material. This percentage deviation in SCF is maximum as compared to the variation due to other material properties.

Table 12. Variation in SCF due to different Poisson's ratio For Boron Epoxy

S.No.	$(\nu)_V$	$(SCF)_{M1}$	$(SCF)_{VM1}$	$(SCF)_{RM2}$	$(SCF)_{RM3}$	$(SCF)_{RM4}$	$(SCF)_{RM5}$
1	-50%	4.82	-0.09	24.19	32.45	46.01	32.32
2	-30%	4.82	-0.07	24.19	32.47	46.12	32.41
3	-10%	4.82	-0.07	24.19	32.49	46.21	32.50
4	0%	4.81	0.00	24.20	32.54	46.28	32.54
5	10%	4.81	0.02	24.20	32.61	46.30	32.66
6	30%	4.81	0.04	24.21	32.65	46.36	32.80
7	50%	4.81	0.07	24.21	32.71	46.39	32.82

Table 13. Variation in SCF due to different E_X / Ey For Boron Epoxy

S.No.	$(EX/EY)_V$	$(SCF)_{M1}$	$(SCF)_{VM1}$	$(SCF)_{RM2}$	$(SCF)_{RM3}$	$(SCF)_{RM4}$	$(SCF)_{RM5}$
1	-50	4.74	1.59	22.82	34.83	46.19	32.60
2	-30	4.76	1.07	23.27	34.12	46.20	32.59
3	-10	4.79	0.50	4.98	33.52	46.25	32.56
4	0	4.81	1.16	24.20	32.54	46.28	32.54
5	10	4.84	-0.58	24.43	30.13	46.30	32.50
6	30	4.86	-0.99	24.40	29.19	46.34	32.49
7	50	4.87	-1.18	24.36	28.66	46.35	32.47

Table 14. Variation in SCF due to different E_X / G_Xy for Boron Epoxy

S.No.	$(EX/GXY)_V$	$(SCF)_{M1}$	$(SCF)_{VM1}$	$(SCF)_{RM2}$	$(SCF)_{RM3}$	$(SCF)_{RM4}$	$(SCF)_{RM5}$
1	-50	5.01	-3.67	23.91	44.28	53.06	38.67
2	-30	4.99	-3.67	23.82	40.23	50.65	35.65
3	-10	4.95	-2.84	23.61	36.34	48.77	34.54
4	0	4.81	0.00	24.20	32.54	46.28	32.54
5	10	5.23	-8.66	21.43	34.54	47.67	33.54
6	30	5.43	-12.81	18.34	36.12	48.76	35.67
7	50	5.54	-15.03	16.73	37.26	50.13	37.00

Table 15. Variation in SCF due to different E_X for Boron Epoxy

S.No	(EX)v	$(SCF)_{M1}$	$(SCF)_{VM1}$	$(SCF)_{RM2}$	$(SCF)_{RM3}$	$(SCF)_{RM4}$	$(SCF)_{RM5}$
1	-50	4.19	12.86	23.21	28.69	42.26	30.62
2	-30	4.34	8.22	23.15	29.24	43.98	30.95
3	-10	4.62	4.60	23.09	31.25	45.65	31.66
4	0	4.81	0.00	24.20	32.54	46.27	32.54
5	10	4.89	-4.25	24.66	32.03	46.98	33.61
6	30	4.92	6.25	24.99	32.57	47.12	34.01
7	50	5.20	-8.04	25.00	32.74	48.24	34.98

Poission's ratio variation in Boron Epoxy Models for D/A=0.1 has negligible effect on SCF. The percentage reduction in SCF is maximum in Model 4.As compared to the other materials it has 46% reduction in SCF.

The effect of percentage reduction in SCF is very less when changes are made in Ex/E_y. The percentage reduction in SCF varies from 4% to 8% when changing Ex/G_{xy} from -50% to 50%.

Variation in SCF of Model 1 is 12.8% to -801% .The percentage reduction in SCF varies from 1% to 4 %, The SCF reduces as E_x decreases and SCF increases as E_x reduces.

Table 16. Variation in SCF due to different Poisson's ratio for Boron Aluminium

S.No.	$(v)_V$	$(SCF)_{M1}$	$(SCF)_{VM1}$	$(SCF)_{RM2}$	$(SCF)_{RM3}$	$(SCF)_{RM4}$	$(SCF)_{RM5}$
1	-50	3.20	-1.08	23.24	22.34	37.92	30.47
2	-30	3.19	-0.81	23.13	22.23	37.87	30.41
3	-10	3.17	-0.18	23.05	22.12	37.83	30.28
4	0	3.16	0.00	22.95	22.07	37.83	30.26
5	10	3.15	0.46	22.84	22.05	37.80	30.16
6	30	3.14	0.77	22.73	22.05	37.78	30.25
7	50	3.13	1.14	22.67	22.04	37.74	30.09

Table 17. Variation in SCF due to different E_X / Ey for Boron Aluminium

S.No.	$(EX / Ey)_V$	$(SCF)_{M1}$	$(SCF)_{VM1}$	$(SCF)_{RM2}$	$(SCF)_{RM3}$	$(SCF)_{RM4}$	$(SCF)_{RM5}$
1	-50	3.04	4.01	22.16	21.19	37.24	25.57
2	-30	3.01	4.01	22.57	21.52	37.56	27.66
3	-10	3.15	3.00	22.80	21.98	37.74	29.13
4	0	3.16	0.00	22.95	22.07	37.83	30.26
5	10	3.19	-1.35	23.18	22.14	38.03	28.16
6	30	3.22	-2.36	23.25	22.30	38.15	28.01
7	50	3.26	-2.90	23.52	22.47	38.23	27.06

Table 18. Variation in SCF due to different E_X / G_Xy for Boron Aluminium

S No.	$(E_X / G_Xy)_V$	$(SCF)_{M1}$	$(SCF)_{VM1}$	$(SCF)_{RM2}$	$(SCF)_{RM3}$	$(SCF)_{RM4}$	$(SCF)_{RM5}$
1	-50	2.98	5.72	24.62	24.22	34.66	32.19
2	-30	2.99	5.51	23.95	23.08	35.22	31.54
3	-10	3.06	3.30	23.21	23.78	36.95	31.02
4	0	3.16	0.00	22.95	22.07	37.83	30.26
5	10	3.21	-1.44	23.02	23.65	39.54	30.56
6	30	3.33	-5.23	23.84	24.38	40.58	31.04
7	50	3.41	-7.76	24.04	25.97	41.49	31.14

Table 19. Variation in SCF due to different E_X for Boron Aluminium

S.No.	$(E_X)_V$	$(SCF)_{M1}$	$(SCF)_{VM1}$	$(SCF)_{RM2}$	$(SCF)_{RM3}$	$(SCF)_{RM4}$	$(SCF)_{RM5}$
1	-50	2.65	16.27	19.09	18.72	30.98	17.70
2	-30	2.94	7.09	20.13	19.45	32.23	21.88
3	-10	3.06	3.30	21.56	21.56	34.35	26.54
4	0	3.16	0.00	22.95	22.07	37.83	30.26
5	10	3.24	-2.39	23.34	22.87	39.12	30.45
6	30	3.33	-5.23	24.23	23.45	41.34	30.98
7	50	3.49	-10.21	24.52	24.15	42.58	31.48

In Boron Aluminium Model 1 the percentage variation in SCF is very less as the Poission's ratio varies , the reduction in SCF reported for Model 2,3,4,and Model 5 also varies very less with changing Poission;s ratio.

The maximum percent reduction in SCF has been reported for Model 4. E_x/E_y ratio has been varied from -50% to 50% by changing E_y and keeping other properties constant. The variation in SCF for Model 1 has been reported as 4% to -3%. the SCF decreases as E_x/E_y effect is maximum in case of Model 5 .The percentage reduction in SCF reported is 2.5% to 30% .The change in E_x/G_{xy} is 5.7% to -7.7% on SCF in Model 1.The variation in E_x effects the most on SCF.

Table.20. Variation in SCF due to different Poisson's ratio for Graphite Epoxy

S.No.	(v)V	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	5.54	-1.79	24.54	33.89	47.30	32.46
2	-30	5.53	-1.66	24.12	33.65	47.02	32.32
3	-10	5.41	-1.01	23.99	33.01	46.26	31.84
4	0	5.44	0.00	23.34	32.94	46.56	31.55
5	10	5.44	-1.89	23.34	33.02	46.56	31.54
6	30	5.44	-1.00	23.34	33.13	46.56	31.54
7	50	5.43	0.07	23.34	33.22	46.56	31.53

Table 21.Variation in SCF due to different E_X / Ey for Graphite epoxy

S.No.	$(EX/EY)_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	5.33	2.05	23.62	31.68	46.54	30.60
2	-30	5.40	1.99	23.60	31.99	46.54	30.58
3	-10	5.42	1.20	23.45	32.55	46.55	31.01
4	0	5.44	0.00	23.34	32.94	46.56	31.55
5	10	5.48	-2.10	23.37	32.95	46.55	31.11
6	30	5.50	-1.85	23.40	32.98	46.56	31.25
7	50	5.52	-1.47	23.44	32.98	46.57	31.33

Table22. Variation in SCF due to different E_X / G_Xy for Graphite epoxy

S.No.	(EX/GXY)v	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	4.98	8.49	25.41	35.49	46.52	32.30
2	-30	5.01	7.54	24.99	34.22	46.52	32.00
3	-10	5.26	6.24	23.15	33.75	46.54	31.99
4	0	5.44	0.00	23.34	32.94	46.56	31.55
5	10	5.59	-8.56	22.99	32.58	46.52	31.13
6	30	5.62	-7.78	21.15	31.99	46.49	31.00
7	50	5.79	-6.45	21.86	31.47	46.44	30.80

Table 23. Variation in SCF due to different E_X for Graphite epoxy

S.No.	EX	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	4.81	11.59	25.10	32.01	46.33	32.52
2	-30	5.06	6.95	24.80	32.41	46.38	32.52
3	-10	5.22	4.01	24.21	32.76	46.43	32.51
4	0	5.44	0.00	23.34	32.94	46.56	31.55
5	10	5.67	-4.27	23.30	32.87	46.49	31.55
6	30	5.75	-5.74	23.23	32.72	46.43	31.56
7	50	5.85	-7.61	23.19	32.68	46.42	31.57

The reduction in SCF is 46% in Model 4 .The effective change in Poission's ratio is negligible on SCF.

Effect of variation in E_x is 11% to -7.6%. The reduction in SCF is very less. The reduction in SCF is maximum in Model 4.

All the Models have been analyzed by considering all the variation in material properties for D/A=0.5.The variation in SCF has been reported in tabular form.

Table 24.Variation in SCF due to different Poisson's ratio for E-Glass for D/A=0.5

S.No.	(v)V	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	3.06	-0.99	24.68	16.33	23.83	5.85
2	-30	3.05	-0.85	24.41	16.56	23.83	5.83
3	-10	3.04	-0.37	24.27	17.25	23.63	5.72
4	0	3.03	0.00	24.16	17.85	23.27	5.72
5	10	3.03	0.85	24.15	17.85	23.27	5.74
6	30	3.02	0.48	24.15	17.85	23.25	5.78
7	50	3.01	0.59	24.14	17.85	23.25	5.76

Table 25. Variation in SCF due to different E_X / Ey for E-Glass Epoxy for D/A=0.5

S.No	$(E_X / Ey)_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	2.99	1.25	25.96	20.19	23.72	6.08
2	-30	3.01	1.13	25.78	19.95	23.67	5.98
3	-10	3.03	2.25	24.99	18.54	23.54	5.71
4	0	3.03	0.00	24.16	17.85	23.27	5.72
5	10	3.10	-1.33	24.20	20.57	22.02	5.62
6	30	3.10	-1.51	24.22	22.98	22.64	5.59
7	50	3.10	-2.28	24.22	25.50	22.82	5.40

Table 26. Variation in SCF due to different E_X / G_{XY} for E-Glass Epoxy D/A=0.5

S.No.	$(E_X / G_{XY})_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	2.67	12.06	23.91	22.19	22.79	6.58
2	-30	2.85	10.21	24.02	20.99	23.00	6.63
3	-10	2.95	9.21	24.17	18.46	23.15	5.87
4	0	3.03	0.00	24.16	17.85	23.27	5.72
5	10	3.10	-11.99	24.23	18.01	23.28	5.52
6	30	3.33	10.56	24.30	18.41	23.45	5.30
7	50	3.33	-9.85	24.41	18.45	23.54	5.21

Table 27. Variation in SCF due to different E_X for E-Glass Epoxy for D/A=0.5

S.No.	$(EX)_v$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	3.33	9.06	22.87	19.33	2.42	3.25
2	-30	3.25	7.56	23.11	19.95	2.37	3.98
3	-10	3.13	5.21	24.11	20.15	2.26	4.54
4	0	3.03	0.00	24.16	21.72	2.14	5.72
5	10	2.99	8.01	24.13	22.02	2.11	5.12
6	30	2.65	11.32	24.11	22.95	1.99	4.79
7	50	2.55	16.02	24.10	23.50	1.47	4.34

Table 28. Variation in SCF due to different Poisson's ratio for Boron Epoxy for D/A=0.5

S.No.	(v)V	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	4.32	-0.13	25.37	18.68	22.41	2.56
2	-30	4.32	-0.09	25.36	18.68	22.40	2.67
3	-10	4.32	-0.07	25.36	18.67	22.37	2.71
4	0	4.32	0.00	25.36	18.67	22.36	2.75
5	10	4.32	0.02	25.35	18.67	22.33	2.80
6	30	4.31	0.14	25.35	18.66	22.31	2.86
7	50	4.31	0.13	25.35	18.66	22.29	2.91

Table 29. Variation in SCF due to different E_X / E_Y for Boron Epoxy for D/A=0.5

S.No.	$(E_X / E_Y)_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	4.24	1.74	25.32	19.96	21.56	3.77
2	-30	4.24	1.65	25.32	19.25	21.67	3.66
3	-10	4.35	1.12	25.34	18.95	22.35	2.96
4	0	4.32	0.00	25.36	18.67	22.36	2.75
5	10	4.32	-1.01	25.50	18.67	22.01	2.69
6	30	4.37	-1.60	25.51	18.25	21.99	2.05
7	50	4.39	-1.81	25.54	17.74	21.77	2.05

Table 30. Variation in SCF due to different $E_X / G_X y$ for Boron Epoxy for D/A=0.5

S.No.	$(E_x / G_{xy})_v$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	4.55	-5.31	26.81	34.07	38.46	-10.39
2	-30	4.43	-4.26	24.94	32.26	33.30	-8.76
3	-10	4.35	-1.27	23.61	23.55	28.15	-5.24
4	0	4.32	0.00	25.36	18.67	22.36	2.75
5	10	4.76	-8.56	28.26	22.26	24.75	-5.13
6	30	5.12	-20.55	31.62	24.85	26.08	-6.45
7	50	5.55	-28.46	35.77	29.48	31.36	-9.86

Table 31. Variation in SCF due to different E_X for Boron Epoxy for D/A=0.5

S.No.	(EX)v	$(SCF)_{M1}$	$(SCF)_{VM1}$	$(SCF)_{RM2}$	$(SCF)_{RM3}$	$(SCF)_{RM4}$	$(SCF)_{RM5}$
1	-50	3.50	18.92	24.57	18.67	21.13	11.56
2	-30	3.70	16.24	24.86	18.69	21.37	11.92
3	-10	4.01	13.86	25.01	18.71	21.98	12.11
4	0	4.32	0.00	25.36	18.74	22.36	12.55
5	10	4.56	-18.00	25.59	18.80	22.85	12.97
6	30	4.79	-15.96	26.00	18.85	23.01	13.12
7	50	4.91	-13.81	26.24	18.89	23.47	13.56

Table 32. Variation in SCF due to different Poisson's ratio for Boron Aluminium for D/A=0.5

S.No.	(v)V	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	2.43	2.77	21.01	15.58	20.02	2.49
2	-30	2.46	2.02	22.57	16.63	21.02	4.08
3	-10	2.49	1.92	23.60	17.72	22.15	5.50
4	0	2.49	0.00	24.03	18.08	22.51	5.95
5	10	2.50	-2.85	23.16	18.33	22.84	6.81
6	30	2.52	-2.52	22.56	19.09	23.93	11.85
7	50	2.55	-2.18	22.54	20.69	24.68	9.06

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Table 33. Variation in SCF due to different E_X / Ey for Boron Aluminium for D/A=0.5

S.No.	$(E_X / Ey)_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	2.43	2.77	23.27	14.45	22.08	5.38
2	-30	2.45	1.78	23.10	16.67	22.10	5.34
3	-10	2.47	0.98	23.87	17.56	22.34	5.67
4	0	2.49	0.00	24.03	18.08	22.51	5.95
5	10	2.51	-0.62	24.09	18.40	22.56	5.91
6	30	2.52	-1.02	24.10	18.70	22.61	5.89
7	50	2.55	-2.18	24.11	18.91	22.64	5.87

Table 34. Variation in SCF due to different E_X / G_{XY} for Boron Aluminium for D/A=0.5

S.No.	$(E_X / G_{XY})_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	2.23	10.54	22.56	12.35	6.70	6.07
2	-30	2.30	7.80	23.87	14.43	11.54	6.04
3	-10	2.34	6.19	23.30	16.70	15.43	6.01
4	0	2.49	0.00	24.03	18.08	22.51	5.95
5	10	2.54	-1.82	24.08	18.30	26.78	5.91
6	30	2.61	-4.63	24.10	18.51	30.87	5.87
7	50	2.71	-8.70	24.10	18.61	34.17	5.85

Table 35. Variation in SCF due to different E_X for Boron Aluminium for D/A=0.5

S.No.	$(E_X)_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	2.43	2.77	30.67	27.56	30.12	10.93
2	-30	2.46	2.25	28.65	24.37	27.25	8.27
3	-10	2.47	1.25	26.25	20.09	25.64	6.01
4	0	2.49	0.00	24.03	18.08	22.51	5.95
5	10	2.51	-1.26	22.85	16.25	20.14	3.25
6	30	2.54	-1.99	20.46	13.25	18.24	0.22
7	50	2.55	-2.18	18.03	11.63	16.91	-1.71

Table.36. Variation in SCF due to different Poisson's ratio for Graphite Epoxy for D/A=0.5

S.No.	(ν)V	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	5.31	-0.10	26.83	15.43	15.23	-4.47
2	-30	5.31	-0.10	26.80	15.33	15.22	-4.42
3	-10	5.30	-0.10	26.77	15.29	15.24	-4.39
4	0	5.30	0.00	26.73	15.27	15.26	-4.38
5	10	5.30	0.10	26.72	15.24	15.26	-4.39
6	30	5.30	0.10	26.72	15.22	15.26	-4.39
7	50	5.30	0.10	26.72	15.22	15.26	-4.39

Table 37. Variation in SCF due to different E_X / E_y for Graphite Epoxy for D/A=0.5

S.No.	$(E_X / E_y)_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	5.11	3.61	26.03	14.24	14.22	-0.47
2	-30	5.22	3.00	26.25	14.73	14.66	-1.99
3	-10	5.25	1.25	26.65	15.02	14.95	-3.25
4	0	5.30	0.00	26.73	15.27	15.26	-4.39
5	10	5.39	1.37	26.35	13.25	14.01	-5.26
6	30	5.44	2.56	26.25	11.92	12.25	-6.23
7	50	5.47	-3.10	27.12	11.45	11.96	-7.35

Table 38. Variation in SCF due to different E_X / G_{XY} for Graphite Epoxy for D/A=0.5

S.No.	$(E_X / G_{XY})_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	4.48	15.51	24.59	11.03	2.28	-4.47
2	-30	4.65	13.22	25.12	12.56	7.55	-4.41
3	-10	4.99	12.33	26.01	14.01	11.25	-4.40
4	0	5.30	0.00	26.73	15.27	15.26	-4.39
5	10	5.65	-15.98	27.13	15.65	18.25	-4.26
6	30	5.86	-13.55	27.65	16.35	21.55	-4.20
7	50	5.94	-12.06	27.98	16.87	24.83	-4.10

Table.39. Variation in SCF due to different E_X for Graphite Epoxy for D/A=0.5

S.No.	$(E_X)_V$	(SCF)M1	(SCF) VM1	(SCF) RM2	(SCF) RM3	(SCF) RM4	(SCF) RM5
1	-50	4.25	19.92	24.60	15.04	19.01	-0.04
2	-30	4.28	16.54	25.17	15.10	18.79	-1.02
3	-10	5.01	13.02	26.20	15.20	16.99	-3.22
4	0	5.30	0.00	26.73	15.27	15.26	-4.39
5	10	5.56	19.81	27.05	15.40	14.01	-6.25
6	30	5.85	15.99	27.99	15.42	12.99	-8.26
7	50	5.94	-12.05	28.06	15.59	11.10	-9.08

Variation in SCF is small for D/A=0.5 as compared to D/A=0.1 in all the cases. The reduction in SCF is very less in Model5. In some cases the SCF increases as can be served when comparing the results of Model1 and Model5 and this is due to changing material properties.

V .CONCLUSIONS

The variation of Poisson's ratio effects very less on SCF of model1. The reduction in SCF in different models is almost same when varying Poisson's ratio.

The variation in elastic constants effects the SCF, the variation in E_X effects the most on SCF . We can conclude that the modulus of elasticity of the material in the direction of loading effects the most on SCF. The reduction in SCF is maximum in Model4 in all the cases and minimum in Model5.

The effect of variation in material properties is most in Model4. We can conclude that the proposed Model4 is best for highest mitigation in SCF.

As the size of hole increases the mitigation in SCF is less by the proposed methods. In Model5 the SCF increases as compared to Model1 by varying material properties.

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REFERENCES

[1] Peterson R.E., "Stress concentration design factors", John Wiley and sons, New York, 1966.

[2] Shastry B.P, Raj G.V. Effect of fibre orientation on stress concentration in a unidirectional tensile

[3] laminate of finite width with a central circular hole. Fiber Science Technology; 10: 151-154. 1977.

[4] Hanus J.B, Burger C.P, "Stress Concentration factors for elliptical holes near an edge",Experimental Mechanics, Vol. 21, 1981

[5] Rajaiah K. & Naik N.K., "Hole Shape optimization in a finite plate in the presence of auxiliary holes", Experimental Mechanics pp157-161, June 1984.

[6] Noda N. Takes A., Y., "Stress Concentration Factor Formulas Useful for All Notch Shapes in a Flat Test Specimen under Tension and Bending", Journal of Testing and Evaluation (JTE) 30,369-381.2002.

[7] Zirka A. I. , Malezhik M. P. and Chernyshenko I. S. , "Stress Distribution in an Orthotropic Plate with Circular Holes under Impulsive Loading", International Applied Mechanics, Vol. 40, No. 2, 2004.

[8] Sanyal S., Yadav P. "Relief holes for stress mitigation in infinite thin plate with single circular hole loaded axially " , ASME International Mechanical Engineering Congress & Exposition , 2005.

[9] Kubair D.V, Bhanu B. - Chandar, "Stress concentration factor due to a circular hole in functionally graded panels under uni- axial tension ", International Journal of Mechanical Sciences , 50,Pg732-742, 2007.

[10] Jain N.K., Mittal N.D., "Effect of fiber orientation on stress concentration factor in a laminate with central circular hole under transverse static loading. Indian Journal of Engineering & Material Sciences; 15: 452-458. 2008.

[11] Rao D.K.N., Babu M.R., Reddy K.R..N.. and Sunil D., "Stress around square and rectangular cutouts in symmetric laminates" Composite Structures,Vol92, pp 2845–2859, 2010.