DESIGN OPTIMIZATION OF HYBRID COMPOSITE LAMINATE USING SCF

Jin Woo Lee, Niket Shah, Jay Patel, Maj Mirmirani, Sathya N. Gangadharan
Embry-Riddle Aeronautical University, Daytona Beach, Florida, 32114

and

Nagendra Somanath
Pratt and Whitney Jet Engines, United Technologies Corp., E.Hartford, Connecticut, 06108

Introduction

Stress concentration factor (SCF) is one of the major safety issues in designing a notched structure. Unlike isotropic material, different composite material and layups of laminate causes different stress concentration factors. A lot of layup and hybrid material combination can be made for hybrid composite laminate. Thus, hybrid composite materials need a consistent procedure for evaluating SCF in plates with holes. In this research, an effective method and procedure are developed to find SCF of hybrid composite laminate.

Method of Approach

A consistent process for hybrid composite plate with a hole is proposed. Finite element model (FE Model) is developed and mesh is calibrated using optimizer. SCF of different layup of hybrid composite laminates are calculated and the data is analyzed.

Materials

Type	Isotropic	Orthotropic	
Material	Al2024-T6	Graphite/Epoxy Thornel 300	Glass/Epoxy Schotchply 1002
E_1 (ksi)	10500	21400	5600
E_2 (ksi)	10500	1600	1200
G_{12} (ksi)	3920	770	600
ν_{12}	0.33	0.29	0.26

Table 1. Material properties

Model

A model of 20 in × 5 in full plate with 1 in diameter hole is used for this work. A 2-inch inner square and two rings with 0.53 in and 0.6 in radius are defined for mesh control. Dimensions and region definitions are defined in Figure 1.

Boundary Condition

Uniaxial tension loads of 100 lb/in are applied at left and right edges of model in X-direction. Also simply supported boundary conditions are applied along the loading edge to translation y and z, and rotation x and y direction. Free boundary condition is used for other locations.

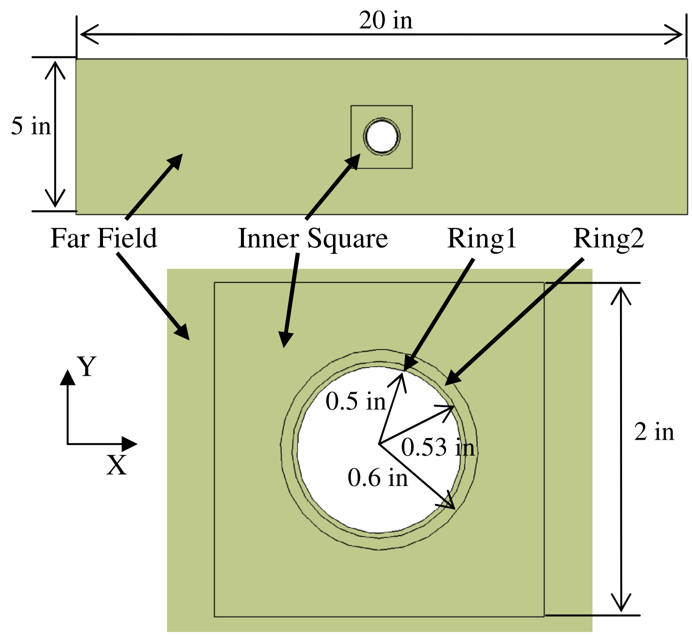

Figure 1. Dimensions and regions definition of model

Stress and Strain Concentration Factors

Stress concentration factor, K_t, and strain concentration factor, K_s, can be obtained using equation (1) and (2).

$$K_t = \frac{\sigma}{\sigma_0} \tag{1}$$

$$K_s = \frac{\epsilon}{\epsilon_0} \tag{2}$$

Maximum major principal stress and strain at ring2 region are used for near hole stress, σ, and strain, ϵ. Average value of stress and strain are obtained at the location of 1.5 in distance from loaded edge of plate for far field stress, σ_0, and strain, ϵ_0. Stress and strain values in ring1 and loading edge region are ignored because of free edge effect [1] in order to ensure stable loading end zone, a la St. Venant.

FE Model Calibration

FE model is calibrated by optimizer changing mesh control size on each region to get optimum mesh. SHERPA method, which adaptively combines strategies from several different search methods and uses them simultaneously, is used for optimization. Al2024-T6 isotropic material (Table 1) is used for mesh optimization. K_t = 3 should be satisfied for isotropic material. The objective of optimization is set to meet K_t value of 3. Maximum number of iteration is set as 200. NX NASTRAN 6 is used FEA for tool. Quad shaped elements are used for far field region, and triangular elements are used for other regions. Composite layup property is defined by PCOMP element property. To obtain laminate level stress and strain value, "PARAM,NOCOMPS,0" card is used in NASTRAN input file. Design variables (DV) are set as Table 2, and the responses are defined as Table 3. Same value of discrete variables are used for mesh size control on far field and inner square region to get perfect quad shape element without triangular elements in far field region. Constraints are used to avoid abrupt change of mesh size between mesh size M1 to M2 and M2 to M3.

Discrete DV	1	2	3
M3 = Far Field & Inner Square	0.5 in	0.25 in	0.125 in
Continuous DV	Minimum	Baseline	Maximum
M2 = Ring2	0.005 in	0.1 in	0.5 in
M1 = Ring1	0.005 in	0.1 in	0.5 in

Table 2. Definition of design variables

Response	Formula	Type	Option	Target
K_t	= MaxStress / 1000 psi	Objective	Meet	3
K_s	= MaxStrain / 9.525E-5	Prerequisite	-	-
Meshchk12	= M1/M2	Constraint	≤	10
Meshchk21	= M2/M1	Constraint	≤	10
Meshchk23	= M2/M3	Constraint	≤	10
Meshchk32	= M3/M2	Constraint	≤	10

Table 3. Definition of response variable

Layups

Layup	Ply Thickness	Laminate Thickness
$[0/\pm45/90]_s$ (Quasi-isotropic)	0.0125 in	0.1 in
$[0_2/\pm30/\pm45/\pm60/90_2]_s$	0.005 in	0.1 in

Table 4. Layup cases

Result and Discussion

Mesh optimization

Best mesh design is occurred at 136th iteration out of 200 iterations. Table 5 shows the result of the optimum mesh design.

SCF of Different Layup Cases

The angle is measured from +X-axis, and the origin is located at center of the hole. (r, θ) is coordinate of maximum stress or strain location written in polar coordinate system. Also, same location is expressed using Cartesian coordinate system (x, y). Position 2 is symmetric position of position 1.

	No. of Elements	Element Type	Min	Optimum Design	Max
Far Field	6144	Quad	0.125 in	0.125 in	0.5 in
Inner Square	376	Tri			
Ring2	46	Tri	0.005 in	0.42575 in	0.5 in
Ring1	74	Tri	0.005 in	0.08915 in	0.5 in
K_t	-	-	-	3.0034	-
K_s	-	-	-	2.9804	-

Table 5. Result of mesh optimization

Material	Graphite/Epoxy		Glass/Epoxy	
Position	1	2	1	2
Max Stress	3001.79 psi	2747.37 psi	2998.7 psi	2744.99 psi
(r in, θ deg)	(0.5524,267.63)	(0.5513,86.62)	(0.5524,267.63)	(0.5513,86.62)
(x in, y in)	(-0.0228,-0.5519)	(0.0325,0.5503)	(-0.0228,-0.5519)	(0.0325,0.5503)
Far Field Stress	1000.157 psi		1000.118 psi	
K_t	3.0013	2.7469	2.9983	2.7447
Max Strain	3.5892E-4	3.3146E-4	1.084E-3	9.9985E-4
Far Field Strain	1.1981E-4		3.6171E-4	
K_s	2.9957	2.7665	2.9969	2.7642
(r in, θ deg)	(0.5524,267.63)	(0.5513,86.62)	(0.5524,267.63)	(0.5513,86.62)
(x in, y in)	(-0.0228,-0.5519)	(0.0325,0.5503)	(-0.0228,-0.5519)	(0.0325,0.5503)

Table 6. Result of quasi-isotropic layup

Material	Graphite/Epoxy		Glass/Epoxy	
Position	1	2	1	2
Max Stress	3001.79 psi	2747.36 psi	2998.4 psi	2743.45 psi
(r in, θ deg)	(0.5524,267.63)	(0.5513,86.62)	(0.5524,267.63)	(0.5513,86.62)
(x in, y in)	(-0.0228,-0.5519)	(0.0325,0.5503)	(-0.0228,-0.5519)	(0.0325,0.5503)
Far Field Stress	1000.157 psi		1000.114 psi	
K_t	3.0013	2.7469	2.9981	2.7431
Max Strain	3.5892E-4	3.3146E-4	1.084E-3	9.9928E-4
(r in, θ deg)	(0.5524,267.63)	(0.5513,86.62)	(0.5524,267.63)	(0.5513,86.62)
(x in, y in)	(-0.0228,-0.5519)	(0.0325,0.5503)	(-0.0228,-0.5519)	(0.0325,0.5503)
Far Field Strain	1.1981E-4		3.6171E-4	
K_s	2.9957	2.7665	2.9969	2.7627

Table 7. Result of $[0_2/\pm30/\pm45/\pm60/90_2]_s$ layup

Conclusion

The optimized mesh is developed, and the results of SCF of given layup case brought reasonable results. Mesh calibration using optimizer is reliable procedure than the trial and error method.

Future Work

A number of hybrid composite layup cases will be researched. A response surface can be developed based on the results.

References

[1] J. N. Reddy and D. H. Robbins, *Modeling of Thick Composite Using A Layer-wise Laminate Theory*, International Journal for Numerical Methods in Engineering, 1993