



Stress concentration and its effect on composite Bolted joints

B.Srinivasa Rao, G.S. Shiva Shankar, V.Krishnaraj, G.Krishna

Mechanical Engineering Department, PSG College of Technology, Coimbatore, India

ABSTRACT

The failure strength of bolted connections of glass fiber woven mat/epoxy composite laminates with different staking sequence containing a circular hole was investigated numerically. B, D and E types of bolted joints were considered. Analysis has been done for different values of edge - to- hole diameter ratio (E/D ratio). Stress concentration is estimated in drilled laminates using Hart-Smith criteria of stress concentration. The influence of stress concentration on the efficiency of the joint was estimated numerically. Progressive damage model will be used in the analysis of damage progression and ultimate joint strength of laminates. Strength enhancement will be compared between the laminates with drilled holes with different geometric values.

Keywords: Composite laminates, Staking sequence, Stress concentration.

1.INTRODUCTION

The origin of this study lies within the framework of an industrial agreement to study the behavior of composite materials (carbon/epoxy, glass/epoxy) used in structural work in the field of aeronautics. In order to anticipate possible problems of mechanical resistance and life span on these materials, a series of tensile tests and finite element study have been planned. The objective here is to calculate stress concentration around a circular hole in the composite plate under longitudinal tensile load. The increasing use of composite materials in the design of structural parts with high mechanical performance requires a better understanding and modeling the behavior of these structures. Holes in composites will create stress or strain concentrations and hence will reduce the mechanical properties. The aim of this project is to investigate the stress concentration in woven fabric composites with circular hole. Assuming that woven fabric composites are orthotropic composites, stresses around holes can be calculated from the given equations. Problems related to the determination of stresses in a plate weakened by an opening and deformed by forces applied to the middle plane are very important in the design of engineering structures. It is known that the effect of an opening in an isotropic plate, which is not filled or reinforced, causes an increase of stress in certain places near the opening as compared with a plate without any opening. This effect is called the stress concentration. Problems of stress concentration in isotropic plates have been studied sufficiently, including different cases of openings and loads. In the case of an anisotropic material, the stress distribution has been studied sufficiently only for plates with elliptic and circular openings.

Research studies on stress concentration factor of a hole in the viscoelastic plate have dealt mostly with plates of circular or square holes. In certain investigations the stress concentration around a circular hole or circular inclusion in a fiber reinforced viscoelastic plate under uniform shear. The plate is assumed to be made of a viscoelastic material and reinforced unidirectionally by elastic fibers. A large part of the research that has been done on the mechanically fastened joints has been concerned with the experimental determination of the influence of geometric factors on the joint

strength. The usual procedure is testing specimens until final failure, varying the factors under study and keeping the other factors constant. Several investigators have highlighted the importance of width, end distance, hole diameter and laminates thickness on the joint strength.

The design procedure given in [1, 2] is the different way of approach for calculating the value stress concentration factor. In this paper the method of reducing the stress concentration was given. He proposed that by increasing the thickness around the hole one can reduce the stress concentration. An observed result of this paper also gives the idea of increasing strength of the joint around the hole. J.M. Whitnfy and R, J.Nuismer [3] two related criteria based on stress distribution were presented for predicting the uniaxial tensile strength of laminated composites containing through the thickness discontinuities of a general shape. Hart-Smith. L.J [4, 5] considered that net tension failure occurs when the bolt diameter is a large fraction of the strip width. This fraction depends on the type of material and lay-up used. Bearing failure occurs predominantly when the bolt diameter is a small fraction of the plate width. This mode of failure leads to an elongation of the hole. Shear-out failure can be regarded as a special case of bearing failure. This mode of failure can occur at very large end distances for highly orthotropic laminates. Cleavage failures are associated with both an inadequate end distance and too few transverse plies. A different approach was used to study the behavior of bolted joints. A simple theory to calculate the elastic stress concentration factors at loaded holes was used. Combining this analysis with tests on composite materials to account for the stress concentration relief that occurs in laminates prior to failure, a considerable generalization to geometries for which data was not available, was achieved here. Matthews F.L [6] investigated the mode of joint failure using E glass fiber-reinforced plastic (GFRP) and Carbon fiber-reinforced plastic (CFRP). He concluded that as the width of the specimen decreases, there is a point where the mode of failure changes from one of bearing to one of tension. Collings [7] T.A tested CFRP for a range of laminates configuration, hole sizes, w/d , e/d and t/d . the general trends obtained were in agreement with Matthews F.L work

2. PROBLEM FORMULATION:

Advanced composite materials offer the construction industry an outstanding combination of properties that are not available from other conventional materials currently in use. These are fibers such as glass, aramid and carbon that can be utilized in certain orientation, volume fraction, and type of matrix, such as epoxy resin, to obtain maximum efficiency of composite joint.

Whenever discontinuities are there in geometry of the component and it is subjected to the external load, stress lines will be concentrated at that portion and due to this stress concentration, strength of the joint will reduce and it will reduce the efficiency of the joint also.

In this present investigation the effect of various geometric parameters of the three different types of joints (B, D, E- Joints) on stress concentration and efficiency of the bolted joints was studied. For easy reference the names are given to different joints based on holes pattern over plate.

This nomenclature is as shown in Fig 1:

2.1 DESIGN PROCEDURE OF THE BOLTED JOINTS:

The design procedure could be summarized as follows:

1. Determine the material properties experimentally and determine the ultimate tensile strength of the material F_{tu} .
2. Compute the values of the elastic isotropic stress concentration factor $K_{i,e}$ according to the connection configuration.

3. Determine the composite stress concentration factor $K_{i,c}$ experimentally for a limited no of specimens.
4. Determine correlation coefficient C using the values of $K_{i,e}$ and $K_{i,c}$.
5. Develop the failure envelope defining the efficiency of the connection to predict the ultimate load capacity of any connection configuration with any fiber direction.

3.0 CALCULATION OF STRESS CONCENTRATION FACTOR (K):

3.1 FOR ISOTROPIC MATERIALS: $K_{I,E}$

Connection with one column of bolts (as per Hart-smith (1980)) as shown in Fig 2

$$K_{I,e} = 2 + \left(\frac{w}{d} - 1 \right) - 1.5 \frac{\left(\frac{w}{d} - 1 \right)}{\left(\frac{w}{d} + 1 \right)} \theta$$

Where

$$\theta = 1.5 - \frac{0.5}{\left(\frac{e}{w} \right)}; \frac{e}{w} \leq 1; \quad \theta = 1; \frac{e}{w} \geq 1$$

3.2 FOR COMPOSITES:

In case of GFRP members (as per Rosner (1992))

$$\theta = 1.5 - \frac{0.5}{\left(\frac{e}{w} \right)}; \frac{e}{w} \leq \infty$$

When connections with multicolumn of bolts:

i.e.) for B, D, and E-Types of joints:-

$$K_{I,e} = 1 + \left[1 - \left(\frac{d}{p} \right)^2 \right]^{2.41} + \left(\frac{p}{d} - 1 \right) - 1.5 \frac{\left(\frac{p}{d} - 1 \right)}{\left(\frac{p}{d} + 1 \right)} \theta$$

And $p = w/n$

n = no of holes.

Where θ is defined as

$$\theta = 1.5 - \frac{0.5}{\left(\frac{n \cdot e}{w} \right)}$$

$$K_{I,e} = 1 + \left[1 - \left(\frac{nd}{w} \right)^2 \right]^{2.41} + \left(\frac{w}{nd} - 1 \right) - 1.5 \frac{\left(\frac{w}{nd} - 1 \right)}{\left(\frac{w}{nd} + 1 \right)} \theta$$

For composite materials some stress concentration is relieved by the progressive cracking of matrix, fiber-matrix debonding, and fiber break or fiber pullout. Therefore the behavior of FRP composites is in between fully elastic and plastic materials.

As per Hart-Smith (1980) the stress concentration of the elastic and FRP materials are related with the linear relationship as below.

$$(K_{i,e} - 1) = C (K_{i,c} - 1)$$

Where C is correction factor.

Based on the least-squares regression analysis, the correlation coefficients C for the five different configurations with zero degree orientation with respect to the applied load ,as per Hassan 1995 are as below

For connection type A, C=0.22

For connection type B, C=0.40

For connection type C, C=0.16

For connection type D, C=0.50

For connection type E, C=0.30

Here in this analysis B, D, E Types of joints are analyzed for K values.

4.0 EFFICIENCY OF THE JOINT:

“It defined as the ultimate strength at notched portion of the connection to the notched tensile strength of the material”

$$\text{efficiency} = \frac{P_{uh}}{F_{tu} \cdot t \cdot w}$$

$$P_{uh} = \frac{F_{tu} A_{net}}{K_{tr}}$$

$$P_{uh} = \frac{F_{tu}}{K_{tr}} t(w - nd)$$

4.1 EFFICIENCY IN TERMS OF STRESS CONCENTRATION:

For isotropic materials:

$$\text{efficiency} = \frac{1}{K_{tr}} \left(1 - \frac{nd}{w} \right)$$

For composite materials:

$$\text{efficiency} = \frac{1}{C(K_{tr} - 1) + 1} \left(1 - \frac{nd}{w} \right)$$

Here by using above formulae efficiency of the joints was predicted. Variation of the efficiency with respect to the d/w and the ratio of e/d was plotted on the graphs.(Fig.3,4 &5)

From these graphs we can predict the optimal values of the geometric parameters (like hole dia, width and edge distance) can be determined.

5.0 RESULTS AND DISCUSSION:**5.1 RESULT TABLES:****Joint-B:**

Sl.No	e/d	d/w	n	nd/w	w/nd	teta	k	C	efficiency
1	2	0.03	2	0.06	16.66667	-2.66667	21.20518	0.4	0.103501
2	2	0.06	2	0.12	8.333333	-0.58333	9.986481	0.4	0.19153
3	2	0.09	2	0.18	5.555556	0.111111	6.363428	0.4	0.260701
4	2	0.12	2	0.24	4.166667	0.458333	4.612072	0.4	0.31086
5	2	0.15	2	0.3	3.333333	0.666667	3.591563	0.4	0.343706
6	2	0.18	2	0.36	2.777778	0.805556	2.924836	0.4	0.361595
7	2	0.21	2	0.42	2.380952	0.904762	2.453062	0.4	0.366804
8	2	0.24	2	0.48	2.083333	0.979167	2.09927	0.4	0.361184

Sl.No	e/d	d/w	n	nd/w	w/nd	teta	k	C	efficiency
1	3	0.03	2	0.06	16.66667	-1.27778	19.3577	0.4	0.112668
2	3	0.06	2	0.12	8.333333	0.111111	9.168029	0.4	0.206224
3	3	0.09	2	0.18	5.555556	0.574074	5.880848	0.4	0.277746
4	3	0.12	2	0.24	4.166667	0.805556	4.292852	0.4	0.32799
5	3	0.15	2	0.3	3.333333	0.944444	3.367204	0.4	0.359549
6	3	0.18	2	0.36	2.777778	1.037037	2.761438	0.4	0.37546
7	3	0.21	2	0.42	2.380952	1.103175	2.331499	0.4	0.378442
8	3	0.24	2	0.48	2.083333	1.152778	2.007773	0.4	0.370606

Sl.No	e/d	d/w	n	nd/w	w/nd	teta	k	C	efficiency
1	5	0.03	2	0.06	16.66667	-0.16667	17.87971	0.4	0.121261
2	5	0.06	2	0.12	8.333333	0.666667	8.513267	0.4	0.219709
3	5	0.09	2	0.18	5.555556	0.944444	5.494784	0.4	0.293076
4	5	0.12	2	0.24	4.166667	1.083333	4.037475	0.4	0.343117
5	5	0.15	2	0.3	3.333333	1.166667	3.187716	0.4	0.373316
6	5	0.18	2	0.36	2.777778	1.222222	2.630719	0.4	0.387342
7	5	0.21	2	0.42	2.380952	1.261905	2.234249	0.4	0.388298
8	5	0.24	2	0.48	2.083333	1.291667	1.934574	0.4	0.378504

JOINT-D:

Sl.No	e/d	d/w	n	nd/w	w/nd	teta	k	C	efficiency
1	5	0.03	3	0.09	11.11111	0.388889	11.6047	0.5	0.144391
2	5	0.06	3	0.18	5.555556	0.944444	5.494784	0.5	0.25251
3	5	0.09	3	0.27	3.703704	1.12963	3.562981	0.5	0.319966
4	5	0.12	3	0.36	2.777778	1.222222	2.630719	0.5	0.352547
5	5	0.15	3	0.45	2.222222	1.277778	2.074868	0.5	0.357739
6	5	0.18	3	0.54	1.851852	1.314815	1.69843	0.5	0.340939
7	5	0.21	3	0.63	1.587302	1.34127	1.426235	0.5	0.304999
8	5	0.24	3	0.72	1.388889	1.361111	1.228424	0.5	0.251299

Sl.No	e/d	d/w	n	nd/w	w/nd	teta	k	C	efficiency
1	2	0.03	3	0.09	11.11111	-1.27778	13.69185	0.5	0.123878
2	2	0.06	3	0.18	5.555556	0.111111	6.363428	0.5	0.222722
3	2	0.09	3	0.27	3.703704	0.574074	4.041984	0.5	0.289569
4	2	0.12	3	0.36	2.777778	0.805556	2.924836	0.5	0.326128
5	2	0.15	3	0.45	2.222222	0.944444	2.264523	0.5	0.336956
6	2	0.18	3	0.54	1.851852	1.037037	1.822889	0.5	0.325907
7	2	0.21	3	0.63	1.587302	1.103175	1.507304	0.5	0.295138
8	2	0.24	3	0.72	1.388889	1.152778	1.279296	0.5	0.24569

Sl.No	e/d	d/w	n	nd/w	w/nd	teta	k	C	efficiency
1	3	0.03	3	0.09	11.11111	-0.35185	12.53232	0.5	0.134493
2	3	0.06	3	0.18	5.555556	0.574074	5.880848	0.5	0.238343
3	3	0.09	3	0.27	3.703704	0.882716	3.775871	0.5	0.305703
4	3	0.12	3	0.36	2.777778	1.037037	2.761438	0.5	0.340295
5	3	0.15	3	0.45	2.222222	1.12963	2.159159	0.5	0.348194
6	3	0.18	3	0.54	1.851852	1.191358	1.753745	0.5	0.33409
7	3	0.21	3	0.63	1.587302	1.23545	1.462265	0.5	0.300536
8	3	0.24	3	0.72	1.388889	1.268519	1.251034	0.5	0.248775

JOINT-E:

Sl.No	e/d	d/w	n	nd/w	w/nd	teta	k	C	efficiency
1	3	0.03	4	0.12	8.333333	0.111111	9.168029	0.3	0.255042
2	3	0.06	4	0.24	4.166667	0.805556	4.292852	0.3	0.382322
3	3	0.09	4	0.36	2.777778	1.037037	2.761438	0.3	0.41873
4	3	0.12	4	0.48	2.083333	1.152778	2.007773	0.3	0.399284
5	3	0.15	4	0.6	1.666667	1.222222	1.549443	0.3	0.343397
6	3	0.18	4	0.72	1.388889	1.268519	1.251034	0.3	0.26039
7	3	0.21	4	0.84	1.190476	1.301587	1.073202	0.3	0.156562
8	3	0.24	4	0.96	1.041667	1.326389	1.003227	0.3	0.039961

Sl.No	e/d	d/w	n	nd/w	w/nd	teta	k	C	efficiency
1	2	0.03	4	0.12	8.333333	-0.58333	9.986481	0.3	0.238099
2	2	0.06	4	0.24	4.166667	0.458333	4.612072	0.3	0.36475
3	2	0.09	4	0.36	2.777778	0.805556	2.924836	0.3	0.405718
4	2	0.12	4	0.48	2.083333	0.979167	2.09927	0.3	0.391042
5	2	0.15	4	0.6	1.666667	1.083333	1.601526	0.3	0.338852
6	2	0.18	4	0.72	1.388889	1.152778	1.279296	0.3	0.258353
7	2	0.21	4	0.84	1.190476	1.202381	1.086142	0.3	0.155969
8	2	0.24	4	0.96	1.041667	1.239583	1.005884	0.3	0.03993

Sl.No	e/d	d/w	n	nd/w	w/nd	teta	k	C	efficiency
1	5	0.03	4	0.12	8.333333	0.666667	8.513267	0.3	0.270438
2	5	0.06	4	0.24	4.166667	1.083333	4.037475	0.3	0.397647
3	5	0.09	4	0.36	2.777778	1.222222	2.630719	0.3	0.429756
4	5	0.12	4	0.48	2.083333	1.291667	1.934574	0.3	0.406132
5	5	0.15	4	0.6	1.666667	1.333333	1.507776	0.3	0.347122
6	5	0.18	4	0.72	1.388889	1.361111	1.228424	0.3	0.262043

7	5	0.21	4	0.84	1.190476	1.380952	1.06285	0.3	0.157039
8	5	0.24	4	0.96	1.041667	1.395833	1.001101	0.3	0.039987

6. CONCLUSION:

The purpose of this study is to find the ultimate strength of the notched composite member. Changing the fiber orientation from 0° to 90° leads to the change in the correlation factor. In this case it will be reduces, because in 90° fiber orientation with respect to the applied load specimen, the load is restricted by the randomly distributed fiber plies, thus shows the more isotropic behavior. We can find the correlation coefficient by using FEA.in future work these predicted values will be compared with the experimental results and optimal values of the geometric parameters will be predicted.

From these graphs we can predict the optimal values of the geometric parameters (like hole dia, width and edge distance) can be determined.

We can do this analysis for different fiber orientations and stacking sequences for getting the maximum efficiency of the connection.

Once if we know the efficiency of the joint, one can find the ultimate load of multibolted connection of the composite plate

REFERENCES:

1. Lotfi Toubal, Moussa Karama , Bernard Lorrain “Stress concentration in a circular hole in composite plate .composite structures” 60(2004)p:66-72.
2. Rosen T.Tenchev, Magne K.Nygard, Andreas Echtermeyer. “Design procedure for reducing the stress concentration around the holes in laminated composites”. Composites 26 (1995) p: 815-828.
3. J.M.Whitnfy, R.J.Nuismer. “Stress fracture criteria for laminated composite containing stress concentration”. Nonmetallic materials division air force materials laboratory, Wright Patterson AFB-ohlo45433 (1974).
4. Hart-SmithL.J “Mechanically-fastened joints for advanced composites-phenomelological considerations and simple analysis”. Douglas Paper 6748(1978) p 1-32.
5. Hart-Smith L.J. “Design and analysis of bolted and riveted joints in fibrous composite structures”. Douglas Paper 7739(1986) p: 1-15.
6. P.P.Camanho, F.L.Matthews. “Stress analysis and strength prediction of mechanically fastened joints in FRP”. Composites part a 28a (1997) p: 529-547.
7. Callings T.A.The strength of bolted joints in multi-directional CFRP laminates. Composites; 8 :(1977) 43-54.

FIGURES

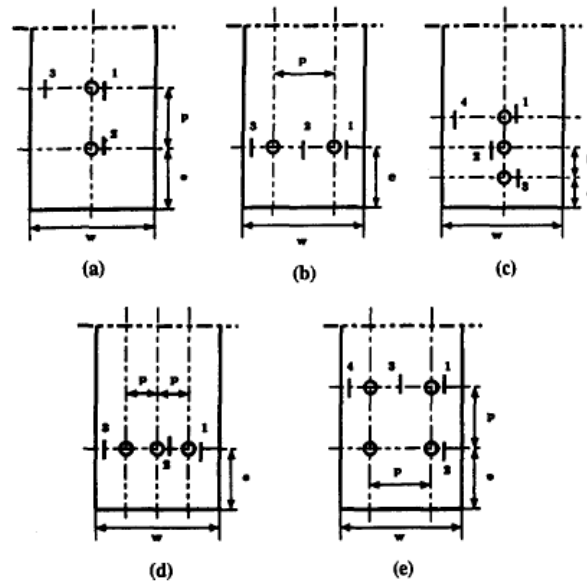


FIG. 1. Connection Configuration: (a) Joint A; (b) Joint B; (c) Joint C; (d) Joint D; (e) Joint E

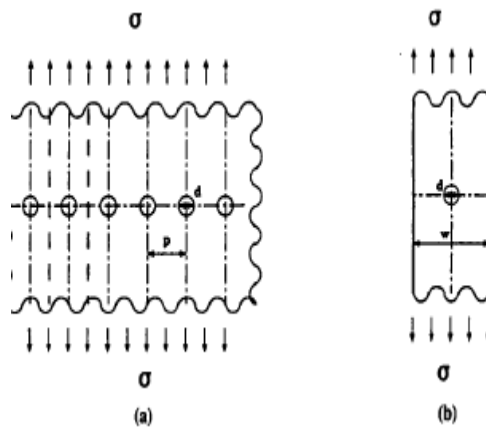
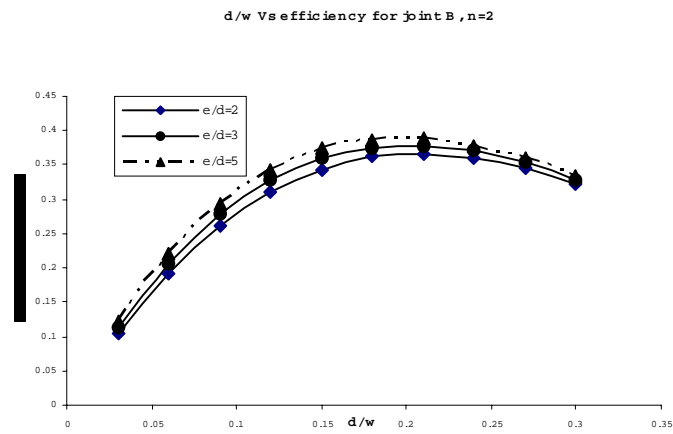
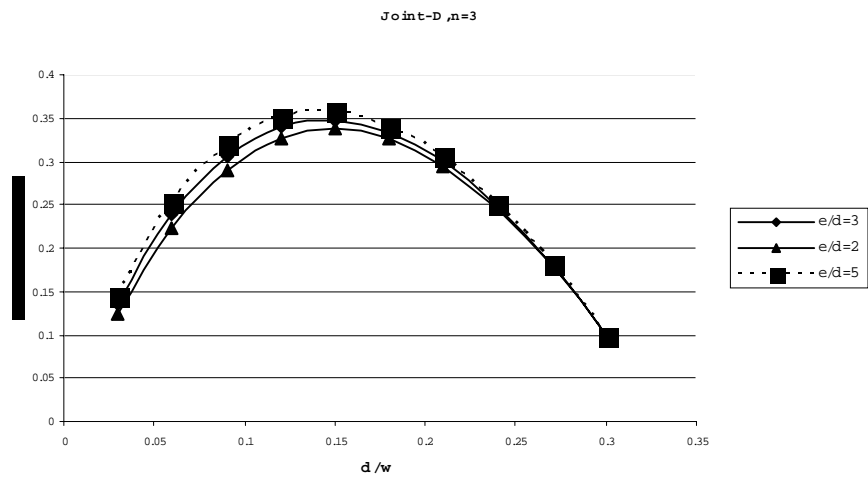


Fig.2 Hart-Smith Connection

Fig.3: d/w v/s efficiency for joint BFig.4: d/w v/s efficiency for joint D

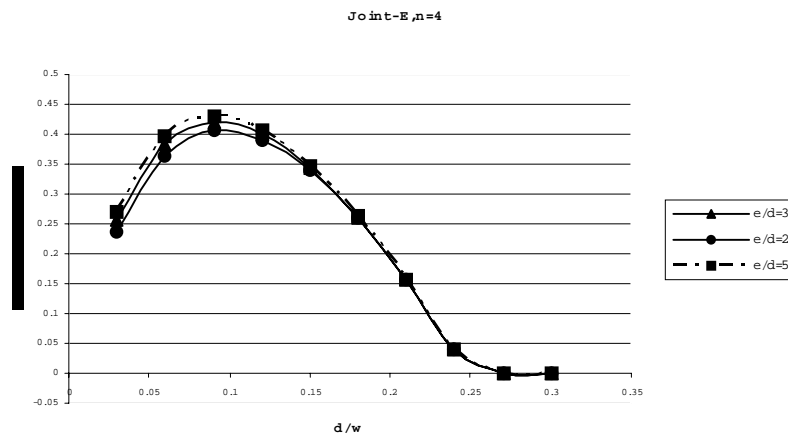


Fig.5: d/w v/s efficiency for joint E