Numerical and experimental analysis on load sharing & optimization of the joint parameters of polymer composite multi bolted joints

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Abstract. In the present work, the bearing failure of composite bolted connections of composite laminates was analysed both experimentally and numerically. The glass fiber woven mat 600GSM/ epoxy composite laminates were prepared using wet-layup technique. The process parameters were taken care during preparation of laminates. Examination is done for various estimations of edge-to-hole diameter and width-to-hole diameter proportion. Stress is evaluated in laminates by utilizing Hart-Smith criteria. Ideal estimation of e/d proportion, d/w proportion is recommended for most extreme effectiveness. A numerical technique is utilized for the rough determination of a load shared by bolts in a numerous “bolted” joints loaded in tension were investigated experimentally and numerically. The effect of un-evenness in load shearing is suggested.

Key words: Composite laminates; e/d ratio; d/w ratio; Stress concentration; Numerically; Hart-Smith.

Nomenclature:
P – Load Applied
w – width of plate
d – diameter of the bolt
e – edge distance
t – thickness
p – pitch

1. Introduction
Mechanical joints need that rivet or bolt holes are penetrated into composite that diminished the c/s area of structure and local stress will be introduced. This Stress concentration can bring about ply de-lamination since they will incorporate through thickness pliable and shear stresses. Mechanical joints can be promptly examined before gathering keeping in mind in administration. Samples of two regular blasted joints are the single lap joint and twofold strap joints. These joints and the pertinent measurements are appeared in ‘Figure1’. The single lap joint is the least complex and most weight effective however the heap results in a minute because of balance stress. The twofold lap Joint takes out the minute however includes extra weight from the straps and extra fastener. A laminate has been made by piling up on top of the each different layers of fortification situated in various headings. Composites, if legitimately utilized, offer numerous points of interest over metals. Cases of such points of interest are: high strength and high stiffness to-weight proportion, great fatigue strength and corrosion resistance and low thermal expansion. It is more efficient for developing complex shapes by joining non-complex geometrical shape. In spite of the fact that composites can be about as successful
as some conventional materials, going along with them is the place issues have a tendency to emerge, which is one principle issue concerning composite materials that infections makers. Along these lines, joining and connection have been perceived as empowering advances for effective use of composite parts in different aviation and ground based applications.

The distinctive method for computing the estimation of stress concentration is explained and decreasing the stress concentration is described by increase in strength of joint around the hole. J.M.Whitnfy and R. J.Nuismer [1,2] excessively related criteria in view of Stress dispersion were displayed. Hart-Smith.L.J [1] considered that net strain distribution happens when the bolt diameter across is a huge fraction of the strip width. This relies upon the sort of material and lay-up utilized. This failure mode can happen at expansive end separations for exceedingly orthotropic overlays. An easy hypothesis to figure out the flexible Stress concentration components at stacked holes was utilized [6]. Consolidating this investigation on composites to represent the Stress concentration alleviation that happens in overlays preceding failure, an extensive speculation to geometries for which information was not accessible, was accomplished here. Likewise, in the present work, the diverse phases of an examination from plain opening to multi-row pin joint are worked out.

1.1 Modes of Failure in Mechanical-Joints.
The designer of composite must consider 4 important stresses in mechanical joints, The Bearing Stress, The Shear-out Stress, The Net area Stress and The Transverse split stress. At the point any of these 4 stresses reach a critical value the joint will fail as appeared in ‘Figure 2’. The Gross Stress obtained is utilized to rate the viability of the joint. For metals single clasp joints can have efficiencies as high as 80%. Polymer network fiber composite laminates have efficiencies for the most part under half because of their quality anisotropy and powerlessness to redistribute stress.

Bearing failures are connected with hole damage, for example, near de-laminating and lattice breaking. To advance bearing failures, a lower stiffness material is set in the bearing region. Nearby de-laminate can be affected close to the opening region by utilizing the interference fit fasteners. ‘Figure 3’ demonstrates the design of various joints.
2. Methodology and Fabrications
Composites made up of Epoxy/Glass with HY-971 hardener by piling-up order of $0^\circ/90^\circ$ were created with 16 symmetrical layers by utilizing hand lay-up procedure [7]. The trials were completed utilizing Zwick UTM. The trial set up is appeared in ‘Figure 4’. The instrumented (with centrally drilled hole) composite bolted joints used for this analysis.

3. Load sharing analysis
Here, analysis for determining the distribution of load between the individual bolts in a line of bolts in a symmetrical lap joint is outlined.

3.1 Model Equations.
The relative displacement of plate and straps between the $i$th and $(i+1)$th bolts yields for $i=1, 2, \ldots, (n-1)$ is given below (SIMS.G.D - 1999):
\[ R_{i+1} = \frac{C_i}{C_{i+1}} R_i + \frac{(2K_p + K_s)}{C_{i+1}} R_i - \frac{2K_p}{C_{i+1}} P + \frac{(2K_p + K_s)}{C_{i+1}} \sum_{r=1}^{i-1} R_r -- -(1) \]

Where,
- \( R_i \rightarrow \) \( i \)th bolt load
- \( P \rightarrow \) external applied load
- \( C_i \rightarrow \) a constant for the \( i \)th bolt dependent upon material properties, plate and strap dimensions and includes effects of bending, shear and bearing. \( K_p \) and \( K_s \) are given by:
  \[ K_p = \frac{p}{wt_p E_p}, \quad K_s = \frac{p}{wt_s E_s} \]

Where,
- \( p \rightarrow \) hole spacing or pitch and
- \( E_p \) and \( E_s \rightarrow \) Young's modulus for the plate and strap respectively.

The overall equilibrium condition gives:
\[ C_i = C_{bs} + C_{bb} + C_{bbr} + C_{pbr} -- -(2) \]

Each bolt constant \( C_i \) has contributions from the various beam mechanisms in operation as in (2) where
\[ C_{bs} = \frac{2i_s + t_p}{3G_p A_b} \quad \text{(shear effect)} \]
\[ C_{bb} = \frac{8t_r^3 + 16t_r^2 t_p + 8t_r t_p^2 + t_p^3}{192 E_{bb} I_b} \quad \text{(bending effect)} \]
\[ C_{bbr} = \frac{2i_s + t_p}{t_s t_p E_{bbr}} \quad \text{(bearing effect)} \]
\[ C_{pbr} = \frac{1}{t_s E_{pbr}} + \frac{2}{t_p E_{pbr}} \quad \text{(plate bearing effect)} \]

In the above mathematical statements, \( E_{bb}, E_{bbr}, E_{pbr}, E_s, E_p, E_b \) are young's moduli for the joints. In this work Gauss-Seidel cycle technique is utilized. 'Figure 5' demonstrates the load carried among the bolts. The Table 1 indicates examination of load shared by multi bolted joints experimentally and numerically.

\[ R_{i+1} + \mu \frac{P - \lambda \sum_{r=1}^{i-1} R_r}{1 + \lambda} \quad -- -(3) \]

Where,
\[ \mu = \frac{2K_p}{C} \quad \text{(3a) -and-} \quad \lambda = \frac{2K_p + K_s}{C} \quad ---(3b) \]
Table 1. Comparisons of Experimental and Numerical results for load sharing analysis

| Bolt number | Load applied: 10 KN |
|-------------|---------------------|
|             | Numerical Load      | Experimental Load |
| 1           | 5548.3              | 5492              |
| 2           | 1023.5              | 987               |
| 3           | 630.7               | 625               |
| 4           | 2798.7              | 2732              |

3.2 Output of Gauss-Seidel Algorithm.
Value of $\lambda=4.037$ & Value of $\mu=2.692$ to be entered
Value of applied load in KN: 10

2500.00000  0.000000
2500.00000  0.000000
2500.00000  0.000000
2500.00000  0.000000
5841.460449 1159.710327 230.238235 2769.868408
5575.380371 922.356323 686.941833 2816.615479
5528.259766 1050.793335 631.300293 2790.943359
5553.757812 1019.309875 629.743347 2798.483887
5547.507324 1024.010376 630.985657 2798.791504
5548.440430 1023.509155 630.639465 2798.705811
5548.340820 1023.520264 630.710388 2798.723389
5548.343262 1023.532349 630.698792 2798.720459
5548.345703 1023.528076 630.700256 2798.720947
5548.344727 1023.529175 630.700134 2798.720947
4. Optimization of efficiency

Hart-Smith (1980) suggested that the elastic stress concentration factor $K_{ic}$ is given by

$$K_{ic} = 1 + \left[ 1 - \left( \frac{nd}{w} \right)^2 \right]^{\gamma_{241}} + \left( \frac{w}{nd} - 1 \right) - 1.5 \left( \frac{w}{nd} - 1 \right) \theta$$

Where $\theta$ is defined as

$$\theta = 1.5 - \frac{0.5}{n,e}$$

The equation for Structural efficiency of composite materials is given by,

$$\text{Efficiency} = \frac{1}{C[K_{ic} - 1] + 1} \left( 1 - \frac{nd}{w} \right)$$

Where, $C$ is correction coefficient and for joint-B configuration $C=0.40$ obtained from least-squares regression analysis.

‘Figure 6’ shows the Variation of the efficiency for different ratios of $e/d$ and $d/w$. Relation between ultimate load and $d/w$ ratio has been plotted in ‘Figure 7’.

![Relation between efficiency and d/w ratio (Joint B)](image)

Figure 6. Relation between efficiency and d/w ratio
Conclusions

Based on the work done the following conclusions have been drawn:

1. Load shared by each bolt in multi-bolted connection obtained from the numerical analysis and experimentation has good agreement. Unevenness in load sharing among bolts is more in bolted joints, if the number of bolts in a column exceeds 4 joints.
2. Maximum efficiency for orthotropic bolted joints is achieved by preventing net tension failure when e/d = 3 and d/w = 0.18.
3. When the hole diameter to laminate width ratio increases, the ultimate load bearing capacity decreases.

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