Effect of various parameters on double lap bolted GFRP-to-steel joint by experimentally and numerically

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Abstract- In structural applications such as in aircraft, space craft and in civil engineering structures the components are often fasten to the structural members by threaded fasteners to maintain integrity in fastened structure due to their high reliability, strong load bearing capacity, easier to assemble and disassemble, more tolerant to environmental damages and helpful in preventing interlamination. The bolted joints are carefully designed due to the stress concentration at the surrounding of the hole. It is well known that stress concentrations near the fastener holes could initiate delamination, which severely reduces the strength of the structure. The bolted joint strength is also affect by parameters such as joint configuration, joint geometry, loading conditions, etc. The present work is focused on analyzing effect of various parameters such as washer outer diameter sizes, preload, and edge to hole diameter ratio on the strength of double lap bolted joint structure subjected to tensile loading by using experimental and numerically. The numerical results were found in good agreement with the experimental results.

Keywords*:* **bolted joint, double lap, GFRP, strength**

Nomenclature:

L	Length of plate
W	Width of Plates
D	Minimum hole diameter
t_G	Plate thickness of GFRP plate
t_S	Plate thickness of steel plate
E	Edge distance
p	centre to centre distance between two bolts
T	Tightening torque
D_w	Washer outer diameter size
F_P	Preload
FEA	Finite Element Analysis
FEM	Finite Element Method

1. INTRODUCTION

In general, built-up structures are the combinations of different types of joining. The method of assembly is important consideration in design of built-up structures. In structural applications such as in aircraft, space craft and in civil engineering structures the components are often fasten to the structural members by threaded fasteners to maintain integrity in fastened structure. In general, increase in bolt-fastening forces lead increase in joint strength compared to the other joints because it is relatively more reliable to transfer higher loads, easier to assemble and disassemble, more tolerant to environmental damages and helpful in preventing interlamination. The bolted joints are carefully designed due to the stress concentration at the surrounding of the hole. It is well known that stress concentrations near the fastener holes could initiate delamination, which severely reduces the strength of the structure. The bolted joint strength is also affect by parameters such as joint configuration, joint geometry, loading conditions, fastening parameters, and material parameters. The main objective of this paper is to study the effects of washer outer diameter size, preload, and edge to hole diameter ratio on strength of double lap single bolted joint using experimentally and finite element analysis.

2. LITERATURE REVIEW

Tajeuna et. al.[1] studied the effect of geometrical parameters of Al-to-steel bolted connections to predict the optimal geometric configuration foe single-lap and double-lap bolted connections by experimentally and numerically. P.A. Sharos et. al. [2] was predicts the strength of multi-bolted composite joint at various loading rates by analytically using damage approximation function. V.P. Lawlor et. al. [3] was studied the effect of variable clearance in multi-bolt, double lap, composite joint on load distribution, quasi-static strength, fatigue life and failure modes by experimentally. U.A. Khashaba et. al. [4] was studied the effect washer size and tightening torque on the performance of bolted joints in [0/±45/90] glass fiber reinforced epoxy (GFRE) composites and determined the mechanical properties (tensile, compressive, and in-plan shear) of GFRE laminates by experimentally and theoretically. M.P.Cavatorta et. al. [5] described a finite element simulation and experimental validation of a composite bolted joint loaded in bending and torsion. Ali Najafi et. al. [6] studied the failure behavior of bolted joints including failure mode, failure load and joint stiffness through finite element simulation embedded in progressive failure analysis (PFA). T.N.Chakherlou et. al. [7] studied the effect of the clamping force variation in interference fitted double shear lap bolted joints of aluminum 2024-T3 under static and cyclic loads by experimentally and also FE analysis was performed to compare with experiments of the static loading. Kunliang Liu et. al. [8] studied the effects of pre-tightening force and connection mode on the strength and progressive damage of composite laminates with bolted joints by FE analysis and compares their results with analytical results. Jong-Hwa Yun et. al. [9] was evaluated the new method for improving the strength of multi-bolted joints by considering the effect of hole clearance by experimentally and FEA. Faruk Sen et. al. [10] performed an experimental failure analysis to determine the failure behavior of bolted composite joint under various preload moments, two different geometrical parameters (edge- to-hole dia. ratio (E/D) and plate width-to-hole dia. Ratio (W/D)) and ply orientations. Fengrui Liu et. al. [11] was developed an analytical tri-linear joint stiffness model for load transfer analysis in highly torque multi-bolt composite joints with clearance.

3. EXPERIMENTAL ANALYSES

The experimental analysis is carried out to measure strength of double lap single bolted joint structures by using computerised universal testing machine. The schematic representation of experimental setup is shown in fig.1.Experimental testing specimen containing two steel plates and one GFRP plate is shown in fig. 2. The size of plates, steel plate is 192mm X 40mm X 5mm and GFRP plate is 192mm X 40mm X 2mm. To measure displacement occurred in the joint during the experiment the gauge length is marked on the GFRP plate.

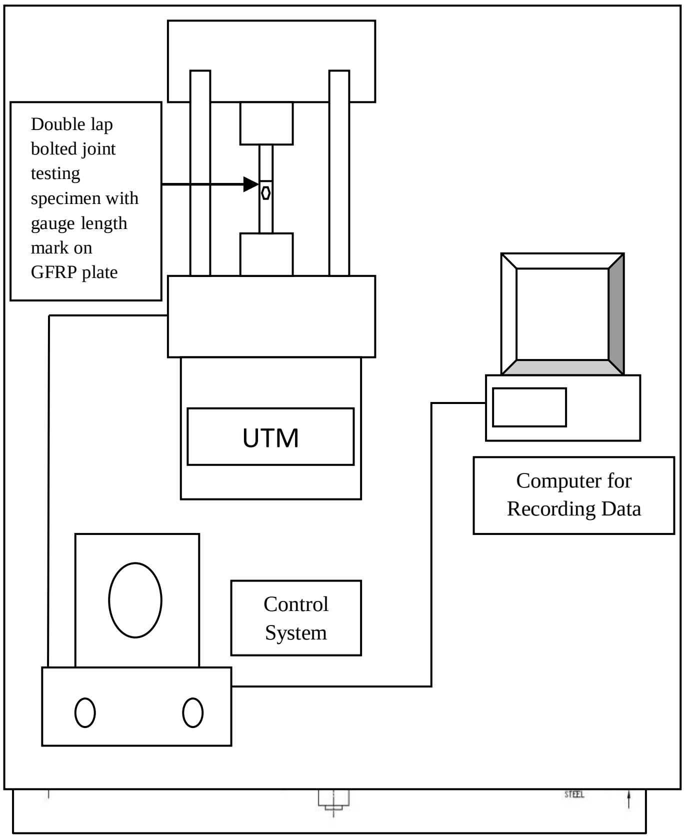


Fig. 2 Double lap Single bolted joint

A. Steps in Experimental Analysis

1. Take composite plate specimen and the gauge length is marked on that to measure the total deflection occurred after experiment.
2. Then the composite plate fastened with steel plates with help of bolt to form double lap bolted joint.
3. The tightening torque is applied on bolt with help of torque wrench to get required preload.
4. The bolted joint was clamped between the two jaws of universal testing machine.
5. Suitable connections were made to get required readings through computer.
6. The control panel of universal testing machine has two operating valves at both ends to maintain required oil pressure.
7. The tensile load was applied on the joint and maximum load, total deflection and Ultimate strength was measured.
8. Experiment setup was taken to the initial condition (i.e. zero load condition).
9. The above procedure was repeated to calculate the strength of the double lap single bolted structure by varying following parameters such as,
   a) Washer outer dia. size [20mm, 23mm and 30mm]
   b) Preload [25KN, 30KN and 35 KN]
   c) Edge to hole diameter ratio (E/D) [3, 4 and 5]

4. FINITE ELEMENT ANYLSIS

A. Configuration of test specimen

Similar to the experimental specimen, the FE model has six basic components: two steel plates, GFRP plate, Washer, Bolt and Nut as shown in fig.3. The solid model of specimen is prepared by using Creo Parametric 2.0 software and the model is saved in IGS file format. The solid model is imported into ANSYS Workbench 16.0 for FEA.

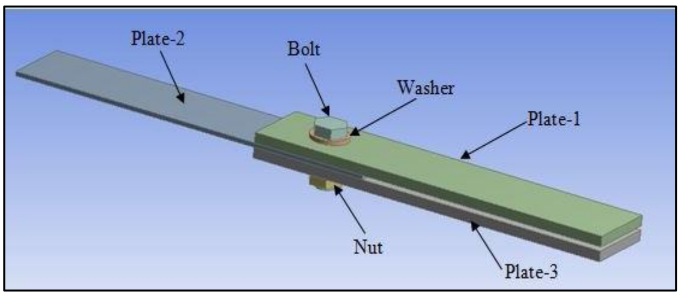


Fig. 3 Double Lap Single Bolted Joint

B. Material Property

The1045 Steel for plate 1 and plate 3 and GFRP (Woven E-Glass epoxy) for plate 2 and; Medium carbon alloy steel for Nut and Bolt and alloy steel for Washer is used. The material property of fastened plates is shown in Table 1and Table 2.

Density	7810 Kg/m^3
Modulus Of Elasticity	201GPa
Poisson's Ratio	0.3
Yield Strength	507MPa
Tangent Modulus	3350MPa
Tensile Ultimate Strength	250MPa
Tensile Ultimate Strength	460MPa

Table 1 Material Property of 1045 steel

Elastic properties		
Young's modulus GPa	**Poisson's ratio (μ)**	**Shear modulus (G) GPa**
E_{11}= 25GPa	μ_{12}= 0.2	4 GPa
E_{22}= 25GPa	μ_{21}=0.2	
E_{33}= 0.6E_{11}GPa	μ_{13}=0.2	

Table 2 Material property of GFRP

C. Contact Conditions

There are seven contact interactions are established for all contact surfaces in the finite element model are shown in table 3.

Sr. No	Contact	Target	Type of Interaction
1	Plate-2	Plate-1	Frictional
2	Plate-2	Plate-3	Frictional
3	Bolt	Nut	Bonded
4	Washer	Plate-3	Frictional
5	All plate holes	Bolt shank	Frictional
6	Bolt	Washer	Frictional
7	Nut	Plate-1	Frictional

Table 3 Contact conditions

D. Meshing

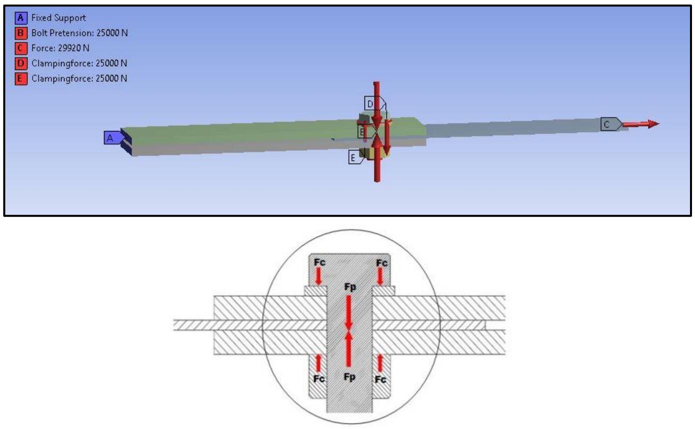
All components of bolted structure are meshed by using Hex Dominant method with Quad/ tri mesh type having mesh size 2mm with fine relevance and span angle centre. There are total 83771 nodes and 15515 elements are formed on meshing.

E. Boundary condition

All degrees of freedom of all nodes and elements of outer left side surface of plate-1 and plate-3 is fixed support as shown in Fig. 4.

F. Loading Conditions

From experimental test the value of peak load is get and that amount of load is applied to one side of GFRP plate which is shown in fig. 4. When bolt is tightening by tightening torque, all the washer face of bolt head and nut i.e. contact face transmit clamping force (Fc) to face of washer and fastened plate i.e. target face respectively which help to clamp fastened plates together as shown in Fig. 4. The contact faces apply uniform distributed load on the target faces. The applied clamping forces are equal in magnitude but opposite in direction along axial direction of bolt shank. Also the preload force (Fp) is applied on the cylindrical surface of the bolt shank along the axial direction which is equal in magnitude but opposite in direction of each other as shown in Fig.4.



Clamping Force (F_C)
Bolt- Pretension = Preload (F_P)

Fig. 4 Fixed support and forces acting on bolted joint in FEA

5. RESULTS AND DISCUSSION

The results obtained from the experiment and finite element analysis of double lap single bolted joint for different parameters are discussed below,

A. Effect of Washer outer diameter size on bolted joint strength

To see the effect of washer outer diameter size, the size is varied as 20 mm, 23 mm and 30 mm and other parameter of joint such as edge to hole dia. ratio, width to hole dia. ratio, preload ,plate thickness, etc. are kept constant. The maximum strength (max. stress) value obtained for single bolted structures from experiment was validated using ANSYS and the values are shown in the table 4.

Washer size D_w (mm)	Peak load P (KN)	Displacement (mm)	Max. strength (MPa) by using	
			Experimental	FEM
20	26.76	0.6	655.31	784.1
23	26.16	0.85	639.15	755.7
30	25.56	1.1	625.92	751.82

Table 4 Comparison between experimental and FEM results for diff. washer sizes

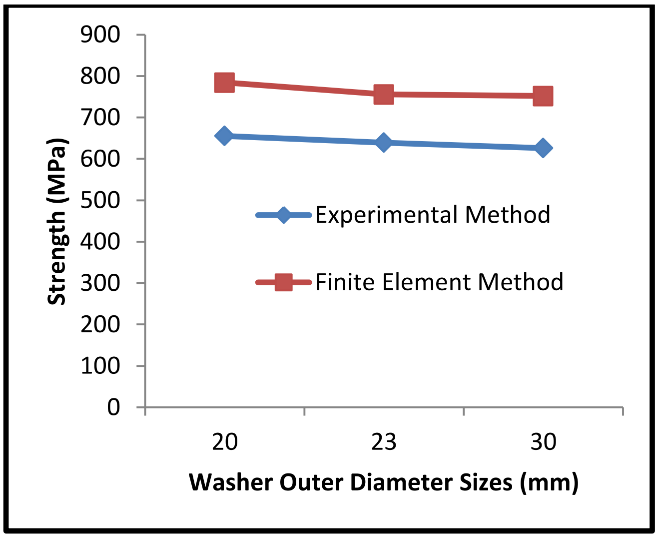


Fig. 5 Comparative graph of strength analysis of different washer outer diameter sizes

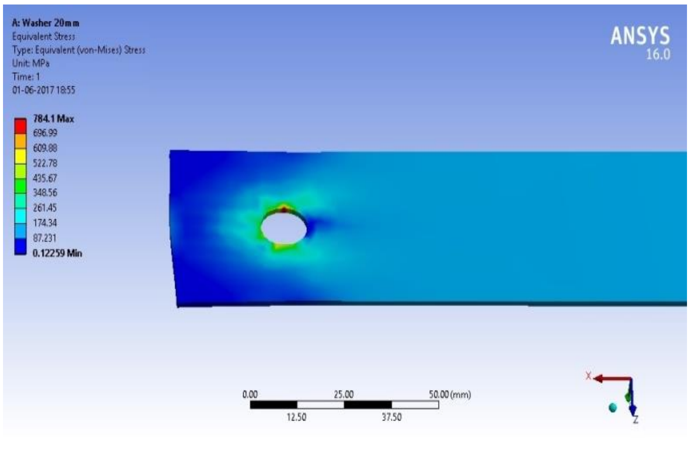


Fig. 6 Simulation of FEA result for single bolted double lap joint with 20 mm washer size

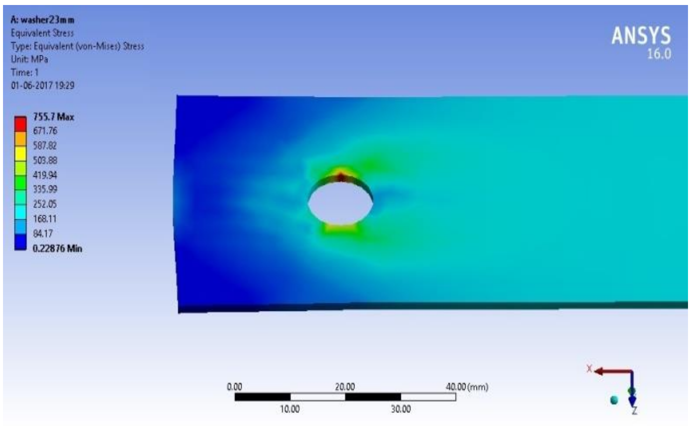


Fig. 7 Simulation of FEA result for single bolted double lap joint with 23 mm washer size

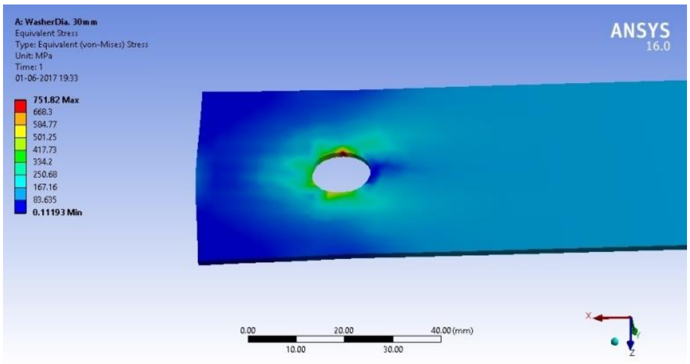


Fig. 8 Simulation of FEA result for single bolted double lap joint with 30 mm washer size

B. *Effect of preload on bolted joint strength*

The preload which is applied on structure is from the tightening torque applied on the bolt and the expression is shown as,

$$F_P = \frac{M}{kD_b}$$

Where, F_P = Preload

M = Tightening torque
k = constant $k \approx 0.2$, for most small to medium size bolts
D_b = Nominal diameter of bolt
The bolt is tightened by means of mechanical torque wrench which is shown in fig.10. The torque applied in this analysis are 50 Nm, 60 Nm and 70 Nm so the preload on the bolt shank caused by these pre-torques are 25 KN, 30 KN and 35 KN respectively to obtain their effects on strength of bolted structure at other parameters are kept constant such as, plate thickness, washer size, W/D ratio and E/D ratio. The maximum strength (max. stress) value obtained for single bolted structures from experiment was validated using ANSYS and the values are shown in the table 5.

Tightening Torque T (Nm)	Preload F_P (KN)	Peak load P (KN)	Disp. (mm)	Max. strength (MPa) by using	
				Exp.	FEM
50	25	26.76	0.6	655.31	784.1
60	30	28.12	0.65	688.61	803.25
70	35	29.95	0.5	733.43	849.16

Table 4 Comparison between experimental and FEM results for diff. Preload

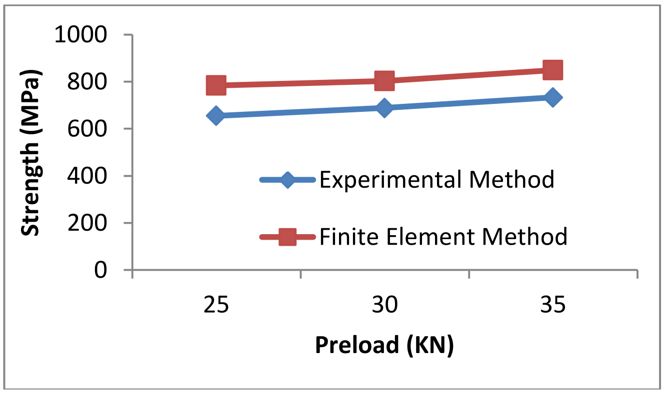


Fig. 9 Comparative graph of strength analysis of different preload

Fig. 10 Torque wrench

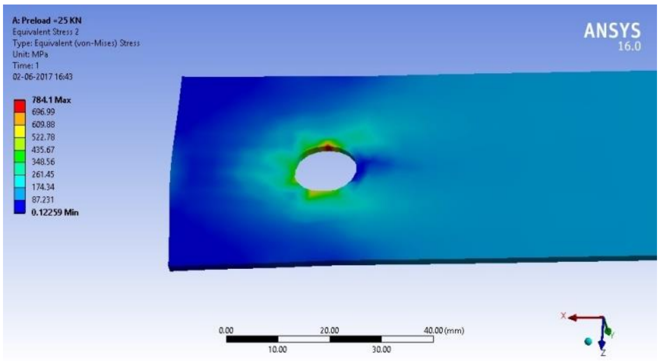


Fig. 11 Simulation of FEA result for single bolted double lap joint with preload 25 KN

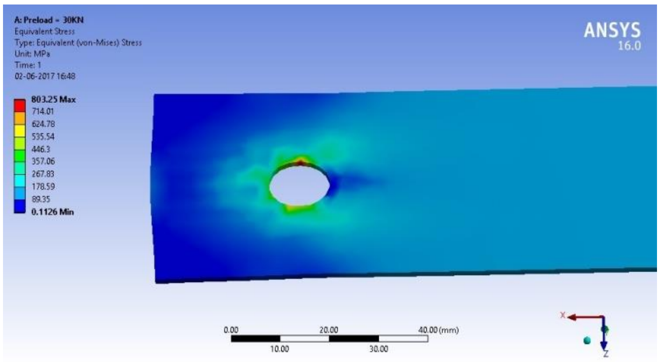


Fig. 12 Simulation of FEA result for single bolted double lap joint with preload 30 KN

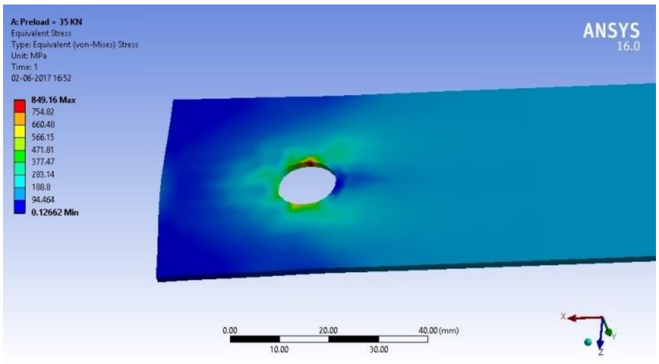


Fig. 13 Simulation of FEA result for single bolted double lap joint with preload 35 KN

C. Effect of edge to hole diameter (E/D) ratio on bolted joint strength

The three different levels of E/D ratio were chosen as shown in table 5 to find their effect on the strength of joint.

E/D	Peak load P (KN)	Displacement (mm)	Max. strength (MPa) by using	
			Experimental	FEM
3	26.76	0.6	655.31	784.1
4	28.00	1	685.67	813.75
5	28.78	1.5	704.29	828.89

Table 5 Comparison between experimental and FEM results for diff. E/D ratio

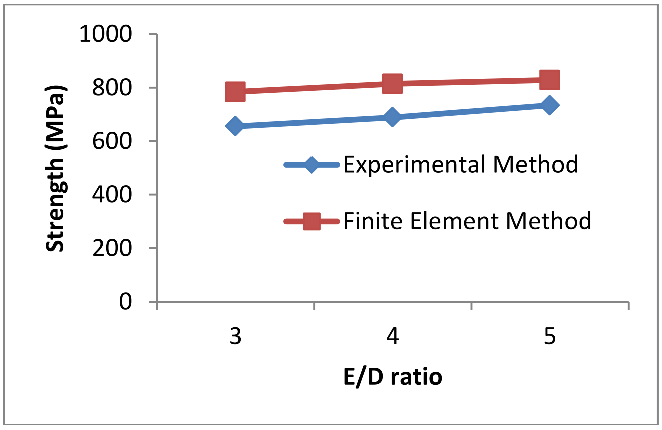


Fig. 14 Comparative graph of strength analysis of different E/D ratio

The results show that the increasing E/D ratio affects the strength bolted joint. The strength increases with the increase in E/D ratio as shown in fig.14.

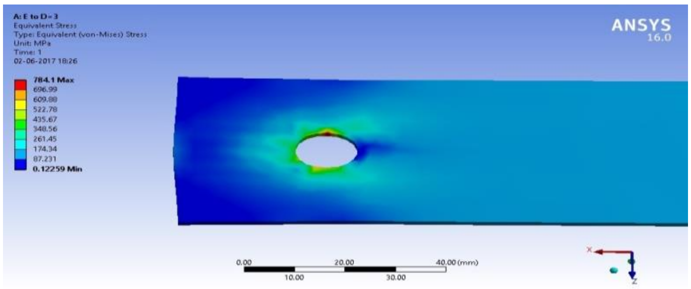


Fig. 15 Simulation of FEA result for single bolted double lap joint with E/D ratio is 3

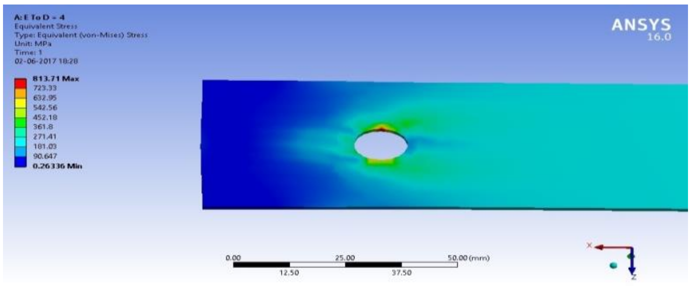


Fig. 16 Simulation of FEA result for single bolted double lap joint with E/D ratio is 4

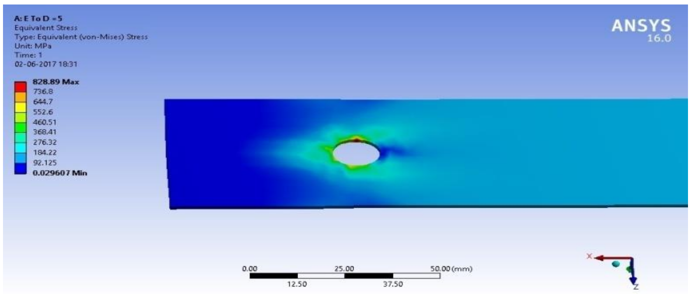


Fig. 17 Simulation of FEA result for single bolted double lap joint with E/D ratio is 5

6. CONCLUSIONS

Due to the changes in the bolting parameters (joint configuration, fastening parameters and geometrical parameters) there is a significant change in strength of bolted structure.

The effect of washer outer diameter sizes on the strength of double lap bolted structure shows that when washer size increases the strength of bolted joint decreases.

The effect of preloads on the strength of double lap bolted structure shows that when preload increases the strength of bolted joint increases.

The effect of edge to hole diameter ratios (E/D ratios) on the strength of double lap bolted structure shows that when E/D ratio increases the strength of bolted joint increases.

The effect of width to hole diameter ratios (W/D ratios) on the strength of double lap bolted structure shows that when W/D ratio increases the strength of bolted joint increases.

7. REFERENCES

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