International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Experimental and Numerical Analysis of Effect of Washer Size and Preload on Strength of Double Lap Double Bolted GFRP-To-Steel Joint

Amol N. Kadam[1], S. M. Ingale[2]

[1]Research Scholar, Dept. of Mechanical Engg., SGI Atrigre, 416118,India

[2]Associate Professor, Dept. of Mechanical Engg., SGI Atrigre, 416118,India

Abstract: ***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. Most of the components are often fasten to the structural members by threaded fasteners to maintain integrity in fastened structure. When two fastened members are connected together by means of mechanical attachments, the resulting joint strength depends largely on the mechanical properties and failure characteristics of the joined materials. In service and under cyclic loading, the relative displacement at the interface is inevitable for bolted assemblies, in addition the effect of clamping force on the stress concentration close to the hole. However, the presence of holes for the bolt induces high stress concentration which is recognized to be a source of damage developed during fatigue loading. The Failure of bolted connection depends upon different parameter, these parameters include: joint geometry (specimen width, end distance, and hole diameter); joint configuration (single lap, double lap, single bolt, single bolt row, or multi-bolt row);loading condition (tension, compression or combined static and/or fatigue loading); fastening parameters (bolt/hole clearance, bolt/washer clearance, tightening torque or clamping force, washer size, and presence of countersink); and material parameters (stacking sequence, fiber shape, matrix type, fiber volume fraction). The present work is focused on analyzing effect of various parameters such as washer outer diameter sizes and preload on the strength of double lap double 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: strength, double bolt, bolted joint, double lap, GFRP, washer, preload

Nomenclature:

L	Length of plate
W	Width of Plates
D	Minimum hole diameter
E	Edge distance
p	centre to centre distance between two bolts
T	Tightening torque
D_w	Washer outer diameter size
F_P	Preload

1. Introduction

Mechanical fastened joints are the most common method of connecting structural application such as in aircraft, space craft and civil engineering structures. The bolt fasteners can clamp joint parts together well and shows the good load carrying capacity. Drilling fastener holes in members inherently introduce a stress concentration near the hole and this stress concentration reduces the strength of the joint. It is well known that stress concentrations near the fastener holes could initiate delamination or other types of damage modes, which severely reduce the strength of the structure and lead to final failure [1]. Fibre-reinforced composites have a rather good rating as regards to life time in fatigue. However, the same does not apply to the number of cycles to initiate damage or to the evolution of damage. It is well acknowledged that in a fibre-reinforced composite, damage starts very early and that the extent of the damage areas grows steadily, while the damage mechanism in these areas may change. Such gradual deterioration of the material is accompanied by a loss of stiffness in the damage areas, which leads to a continuous redistribution of stress and a reduction of stress concentrations inside a structural component.The bolted joint strength is also affect by parameters such as joint configuration, joint geometry, loading conditions, fastening parameters, and material parameters. In this present work, the effect of washer outer diameter size and preload on the strength of bolted joint are investigated experimentally and numerically.

2. Literature Review

U.A. Khashaba et. al. [1] 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. T.N.Chakherlou et. al. [2] studied the effect of the clamping force variation in interference fitted double shear lap bolted joints of aluminium 2024-T3 under static and cyclic loads by experimentally and also FE analysis was performed to compare with experiments of the static loading. Tajeuna et. al.[3] 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. Zhi-Yu Wang et. al. [4] investigated the combined effect of bolted washer clamp-up and CFRP reinforcement on the tensile behaviour of the bolted connections regarding the rehabilitation of steel structures. M.P.Cavatorta et. al. [5] described a finite element simulation and experimental validation of a composite bolted joint loaded in bending and torsion. Kunliang Liu et. al. [6] 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. Tsukasa Katusmata et. al. [7] studied the failure behavior of CFRP bolted joint with cone washer and conventional CFRP joint by 3D FEM analysis with degradation rules and conducted the joint tensile test with AE monitoring. R.H. Oskouei et. al. [8] discussed the finite element modelling of aluminium alloy 7075T6 bolted plates, for this study a three-dimensional model of the joint was subjected to three different simulated clamping forces followed by different levels of longitudinal tensile load is considered. Sayed A. Nassar et. al. [9] was studied an experimental and analytical investigation of the behavior of a double bolted single lap shear composite joint. He used four tightening configurations in test of each double bolted joint and these configurations permit each of the two bolts to be either tight or loose. Murat Pakdil [10] studied the failure analysis of composite single bolted joints. For this experimental failure analysis was carried out to observe failure mechanism in glass fiber reinforced-epoxy laminated composite single bolted joints. 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. Faruk Sen et. al. [12] 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.

3. Experimental Analyses

The experimental analysis is carried out to see the effect of washer outer diameter size and preload on strength of double lap double bolted joint structures by using computerised universal testing machine of 400KN load carrying capacity. For this experimental study washer outer diameter size and preload is varied from 20mm to 30mm and 25KN to 35KN resp. 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 see the effect of washer outer diameter size and preload the other parameters of joint are kept constant. The dimensions of test joints specimens are shown in table 1 and table 2. To measure displacement occurred in the joint during the experiment the gauge length is marked on the GFRP plate. Experiments have been performed on the double lap single bolted joints by varying the parameters such as washer outer diameter size and preload and record the reading obtained.

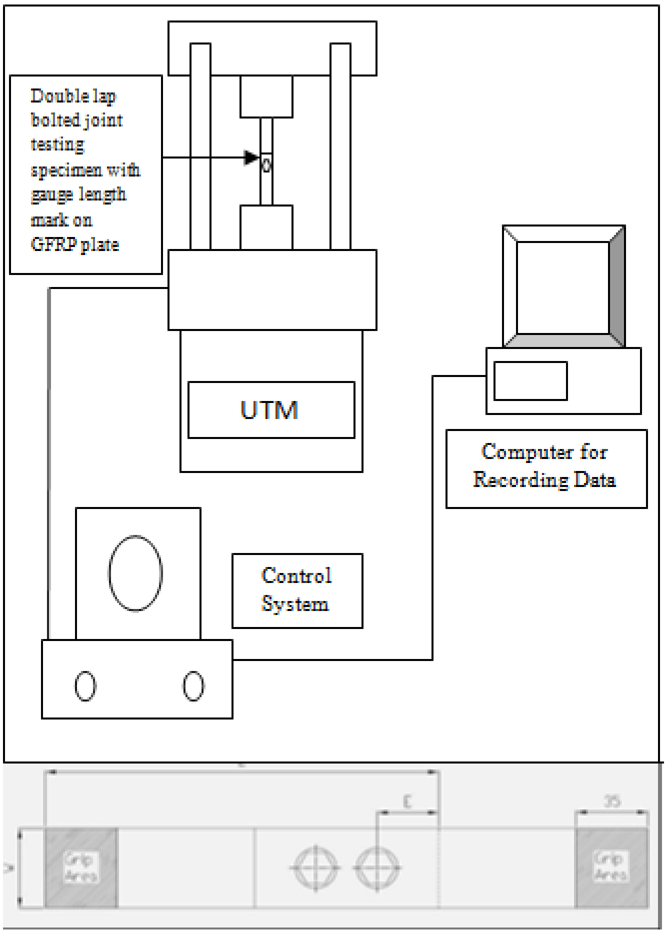


Figure 1: Experimental Setup

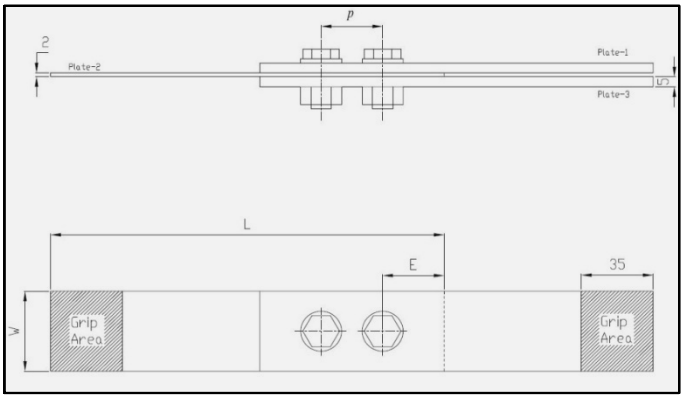


Figure 2: Double lap double bolted joint

Table 1: Dimensions of double bolted joint specimens for washer size

	L (mm)	W (mm)	D (mm)	W/D	E/D	p (mm)	D_w (mm)	Preload (KN)
A	192	40	10	4	3	30	20	50
B	192	40	10	4	3	30	23	50
C	192	40	10	4	3	30	30	50

Table 2: Dimensions of double bolted joint specimens for preload

	L (mm)	W (mm)	D (mm)	W/D	E/D	p (mm)	D_w (mm)	Preload (KN)
A	192	40	10	4	3	30	20	25
B	192	40	10	4	3	30	20	30
C	192	40	10	4	3	30	20	35

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]

4. Finite Element Analysis

4.1 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.

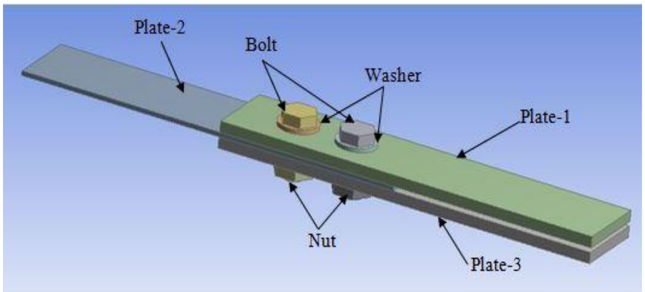


Figure 3: Double Lap Double Bolted Joint

4.2 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 3and Table 4.

Table 3: Material Property of 1045 steel

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 4: Material property of GFRP

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	

4.3 Contact Conditions

There are seven contact interactions are established for all contact surfaces in the finite element model are shown in table 5.

Table 5: Contact conditions

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

4.4 Meshing

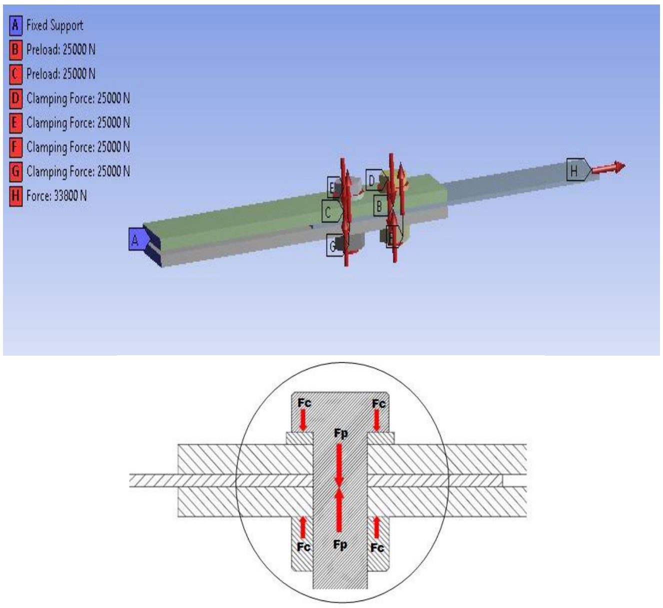
All components of bolted structure are meshed by using Hex Dominant method with Quad/ tri mesh type having mesh size 2mm with fine relevance and span angle centre. There are total 94067 nodes and 17733 elements are formed on meshing.

4.5 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.

4.6 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)
Figure 4: Fixed support and forces acting on bolted joint in FEA

5. Result and Discussion

Effect of washer outer diameter size

To find the effect of washer outer diameter size on joint strength of bolted joint, the washer outer diameter size is varied and other parameters are kept constant. The dimensions of joint specimen to see the effect of washer size on strength of joint are shown in table 1. The maximum strength (max. stress) value obtained for double bolted structures from experiment was validated using ANSYS and the values are shown in the table 6.

Table 6: Comparison between experimental and FEM results for diff. washer sizes

Washer size D_w (mm)	Peak load P (KN)	Displacement (mm)	Max. strength (MPa) by using	
			Experimental	FEM
20	33.80	1.5	827.71	959.23
23	33.36	1.8	816.93	929.76
30	32.56	1.9	797.34	912.93

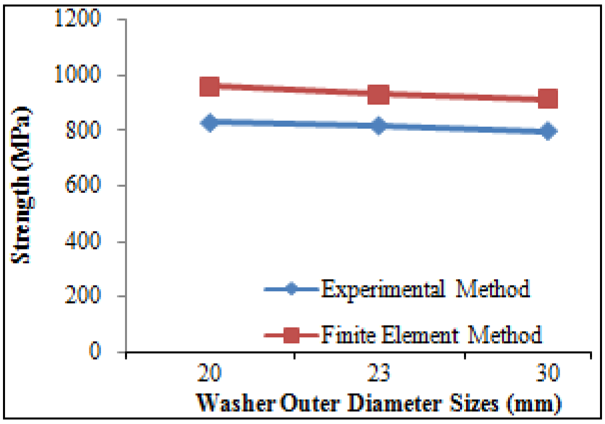


Figure 5: Comparative graph of strength analysis of different washer outer diameter sizes

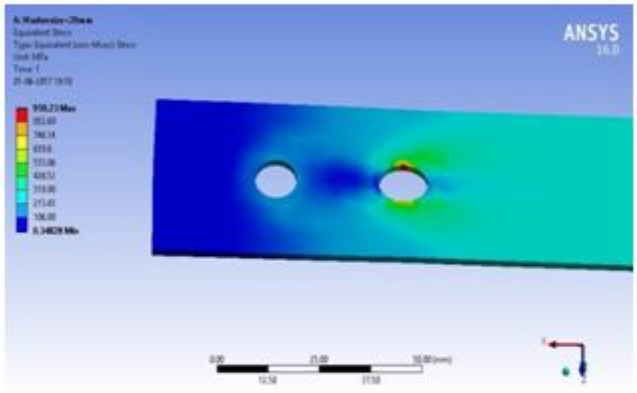


Figure 6: Simulation of FEA result for double bolted double lap joint with 20 mm washer size

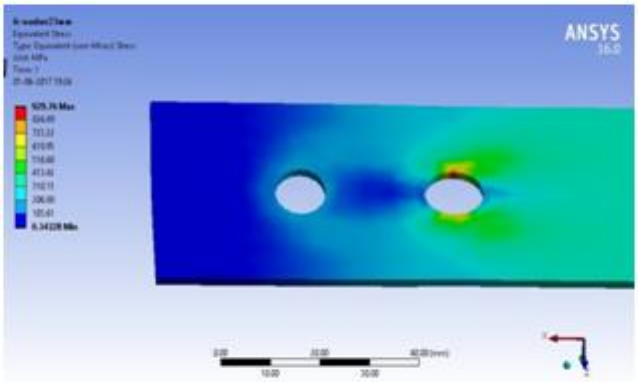


Figure 7: Simulation of FEA result for double bolted double lap joint with 23 mm washer size

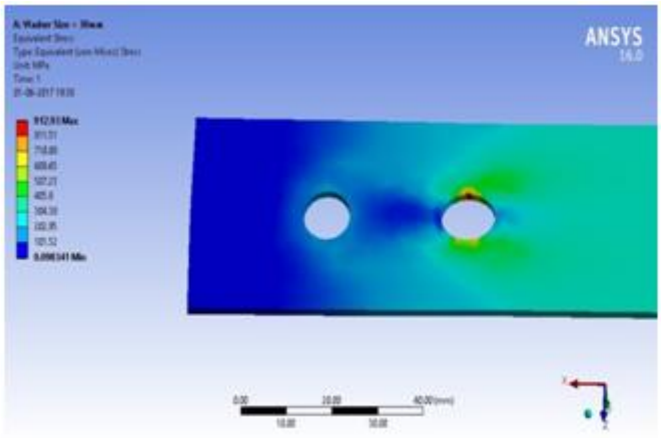


Figure 8: Simulation of FEA result for double bolted double lap joint with 30 mm washer size

Effect of Preload

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

$$F_P = \frac{M}{k D_b}$$

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 torqueses 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. The dimensions of joint specimens to see the effect of preload is shown in table 2. The maximum strength (max. stress) value obtained for double bolted structures from experiment was validated using ANSYS and the values are shown in the table 7.

Table 7: Comparison between experimental and FEM results for diff. Preload

Tightening Torque T (Nm)	Preload F_P (KN)	Peak load P (KN)	Displacement (mm)	Max. strength (MPa) by using	
				Experimental	FEM
50	25	33.80	1.5	827.71	959.23
60	30	34.56	1.8	846.32	983.22
70	35	35.12	1.65	860.03	1016.8

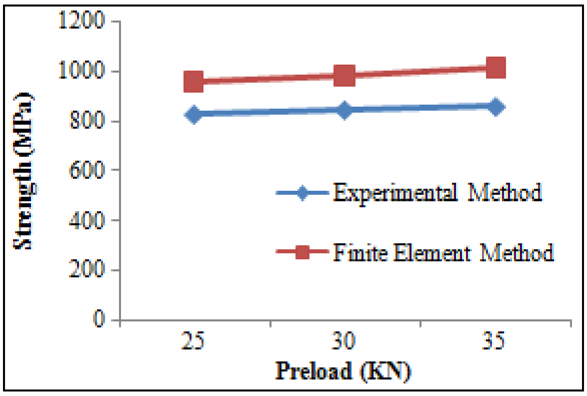


Figure 9: Comparative graph of strength analysis of double bolted structure for different preload

Figure 10: Torque Wrench

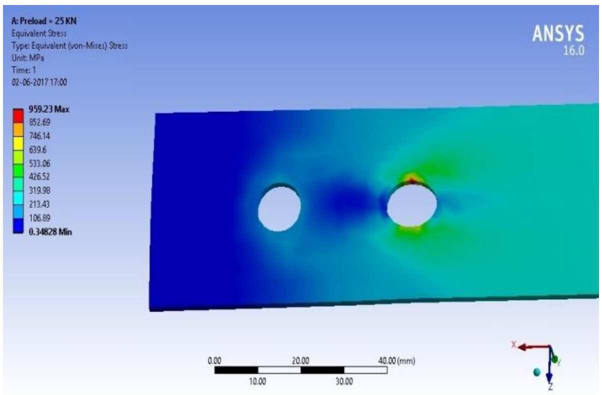


Figure 11: Simulation of FEA result for double bolted double lap joint with preload 25 KN

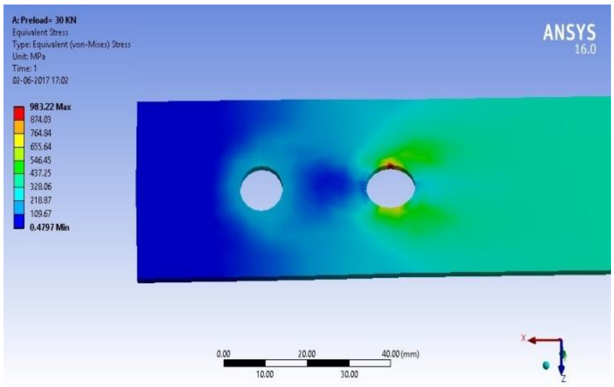


Figure 12: Simulation of FEA result for double bolted double lap joint with preload 30 KN

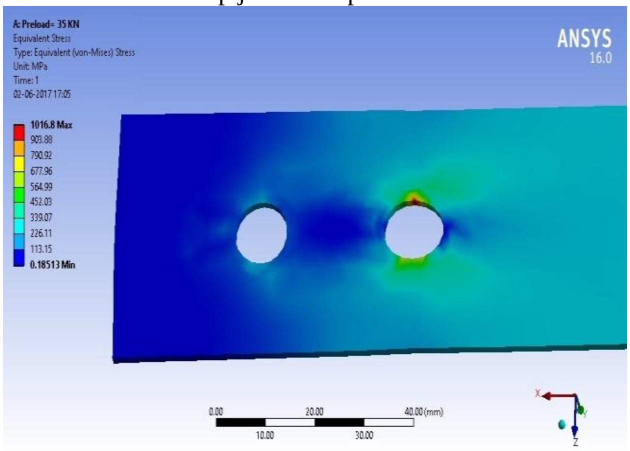


Figure 13: Simulation of FEA result for double bolted double lap joint with preload 35 KN

6. Conclusion

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

References

[1] U.A.Khashaba , H.E.M.Sallam , A.E.Al-Shorbagy, M.A. Sei, "Effect of washer size and tightening torque on the performance of bolted joints in composite structures", Journal of Composite structures, Vol.73, Issue 3 , Jun 2006, Pages 310-317.

[2] T.N. Chakherlou, Babak Abazadeh, "Investigating clamping force variations in Al2024-T3 interference fitted bolted joints under static and cyclic loading", Journal of Materials and designs, Vol.37, May 2012, Pages 128-136.

[3] Thérèse A.D. Tajeuna, Frédéric Légeron, Pierre Labossière, Marc Demers, Sébastien Langlois,"Effect of geometrical parameters of aluminum-to-steel bolted connections", Journal of Engineering Structures , Vol. 102,Nov. 2015, Pages 344-357.

[4] Zhi-Yu Wang, Ning Zhang, Qing-Yuan Wang, “Tensile behaviour of open-hole and bolted steel plates reinforced by CFRP strips”, Journal of Composite Part B: Engineering, Vol. 100, September 2016, Pages 101-113.

[5] M.P. Cavatorta, D.S. Paolino, L. Peroni, M. Rodino, “A finite element simulation and experimental validation of a composite bolted joint loaded in bending and torsion”,Journal of Composites Part A: Applied Science and Manufacturing, Vol.38, Issue 4, Apr. 2007, Pages 1251-1261.

[6] Kunliang Liu, Ying Tie, Cheng Li, “Effects Of Pre-Tightening Force And Connection Mode On The Strength And Progressive Damage Of Composite Laminates With Bolted Joints”, Journal of Materials Physics and Mechanics, Vol. 18, Oct.2013,Pages 18-27.

[7] Tsukasa Katsumata, Yoshihiro Mizutani, Akira Todoroki, Ryosuke Matsuzaki , “A Study on Failure Behavior of CFRP Bolted Joints with Cone Washers by Using AE Monitoring”, EWGAE , Sep. 2010.

[8] R.H. Oskouei, M. Keikhosravy, C. Soutis, “A finite element stress analysis of aircraft bolted joints loaded in tension”, The Aeronautical Journal, Vol. 114, June 2010.

[9] Sayed A. Nassar , Vinayshankar L., Virupaksha , Saravanan Ganeshmurthy, “Effect of Bolt Tightness on the behavior of Composite Joints”, Journal of Pressure Vessel Technology of ASME,Vol.129,Feb. 2007, Pages 43-51.

[10] Murat Pakdil, “Failure analysis of composite single bolted- joints subjected to bolt pretension”, Indian Journal of Engineering & Materials Sciences, Vol. 16, Apr 2009, Pages 79-85.

[11] Fengrui Liu, Jianyu Zhang, Libin Zhao, An Xin , Longwei Zhou,“ An analytical joint stiffness model for load transfer analysis in highly torqued multi-bolt composite joints with clearances”, Journal of Composite Structures , Vol. 131, Jun 2015, Pages 625-636.

[12] Faruk Sen, Onur Sayman, ResatnOzcan, Ramazan Siyahkoc, “Failure Response of Single Bolted Composite Joints Under Various Preload”, Indian Journal of Engineering & Materials Sciences, Vol. 17, Feb 2010, Pages,39-48.