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# Tensile strength of multi-material bolted double lap joints under static loading

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**Abstract.** This paper aims to study the mechanical behavior and failure mode of Al 6082-T6 & Polyvinyl Chloride (PVC) in double-lap bolted joints. To accomplish this, the effect of geometric parameters was investigated using ABAQUS/Standard. Multi-material bolted assemblies have recently gained increasing attention in the aerospace engineering field, due to enhanced design possibilities and positive size effects with regard to decreasing ply thickness. In this paper, the mechanical behavior of polymer and aluminum alloy bolted joints with double-lap bolted structure under quasi-static loading was studied numerically. In general, double lap joints were found to have greater load carrying capacities than single bolt joints (by 40%–49%). Also, double bolt joints with wider plates (increased width) can beneficially shift the failure mode from net-tension to bearing. The geometric parameters were found to play an important role in controlling the failure mode so that catastrophic failure modes of net-tension and shear-out can be prevented in bolted joint.

**Key words:** Bolted joints, Finite element analysis (FEA), Static behavior, multi-material assemblies.

## 1. Introduction

Mechanically fastened joints are used widely in multi-material structures. In comparison with bonded joints, there are no surface preparation issues for bolted joints, there is the option of disassembly for routine inspection and they are relatively insensitive to environmental conditions. The major challenge with mechanically fastened joints is that the introduction of a hole into a composite/polymer plate leads to a stress concentration, which cannot be relieved by plastic flow in the way that is possible in a metallic material.

Standard static tests show that in terms of strength retention, a mechanical joint made of an aluminum alloy will largely outperform a polymer that was intended to replace it in structural applications. These assessments have not prevented the ongoing success of highly plastic materials over metal alloys counterparts in aeronautic applications. Essentially, the top reasons for such success are the proven superiority of the long-term mechanical performance, if equal weight is considered, and the fact that fewer parts must be assembled, which reduces the final cost. The second reason is supported by the maturity and advances made in composite/polymer manufacturing, such as automatic fiber placement to produce massive complex composite structures in a single part (Dirk et al., 2012).

It was found that the mechanical properties of bolted joints such as ultimate load and failure modes are related to a few parameters. These include:

i) Design parameters, such as plate thickness, edge distance and end distance, bolt numbers and arrangement (Kweon et al., 2006);

ii) Material parameters, such as grade of the connected plate materials (Galos, 2020);

iii) Fastener parameters, such as clamping force (Sihn et al., 2007).

The typical failure modes for steel bolted joints subjected to shear are bolt shear failure, net section failure, and bearing failure (Wu et al., 2018). Fiber reinforced polymer (FRP) composites are promising construction materials consisting of polymer matrix and fibers. They have been increasingly used in engineering due to properties such as lightweight, high specific strength, and most importantly, high corrosion resistance to harsh environments (Amacher et al., 2014). Similarly, to steel bolted connections, the mechanical properties of bolted connections using FRP plates and steel bolts have been studied in literature. Four common failure modes for FRP bolted connections tested in shear were identified and reported in the literature (Wen et al., 2019), including net-tension failure, shear-out failure, cleavage failure and bearing failure. Among the failure, modes of steel and FRP bolted joints mentioned above, bearing failure is characterized by a progressive process, and capable of providing adequate warning before final failure.

## 2. Finite element modelling

According to structure sizes, a three dimensional model was generated using the commercial software Abaqus (Abaqus 6.13) in order to determine and to perform the analyses of stress field at contact zone.

### *2.1. Material*

The materials used for modeling the component flat of double lap joint is Aluminum alloy 6082-T6, and Polyvinyl chloride (PVC). There proprieties are taking from (Yibo *et al.*, 2013; (SpecialChem, 2017). The material for the bolt is high-strength and high-grade alloy steel (AJAX Steel Bolt Class 8.8 and UNBRAKO Steel Bolt Class 12.8). Typical Young's modulus and Poisson's ratio for this material are 210,000 MPa and 0.3 respectively.

### *2.1.1. Mechanical properties of Aluminum 6082T6*

Strength properties of the aluminum plates:

**Table 1. 6082-T6 aluminum alloy chemical composition**

| Si | Mg | Fe | Cu | Mn | Cr | Zn | Ti | Others | Al |
|---|---|---|---|---|---|---|---|---|---|
| 0.7-1.3 | 0.6-1.2 | ≤0.5 | ≤0.1 | 0.4-1 | ≤0.25 | 0.2 | ≤0.1 | 0.15 | Balance |

**Table 2. 6082-T6 aluminum alloy mechanical properties**

| Alloy | $\delta_h$ | $\delta_{p0.2}$ | $\delta$ |
|---|---|---|---|
| 6082-T6 | 310 | 260 | 8% |

**Table 3. Tensile test condition setting.**

| Sample | A | A | A | A | B | B | B | B |
|---|---|---|---|---|---|---|---|---|
| Strain rate/$s^{-1}$ | 0.001 | 0.01 | 0.1 | 1 | 10 | 20 | 50 | 100 |

### *2.1.2. Mechanical properties of polyvinyl chloride (PVC)*

Strength properties of the polymer chosen in this work (PVC):

**Table 4. Polyvinyl chloride (PVC) properties**

| Property | Ultimate tensile strength | Elongation at break | Elastic tensile modulus | Density | Poisson's ratio |
|---|---|---|---|---|---|
| value | 52 Mpa | 50-80% | 3.0-3.3 Gpa | 1.42-1.48 | 0.4 |

### *2.2. Specimen details*

The Figure 1 presents the geometry of the bolted assembly considered to this numerical analysis. (Benhamena, 2010).

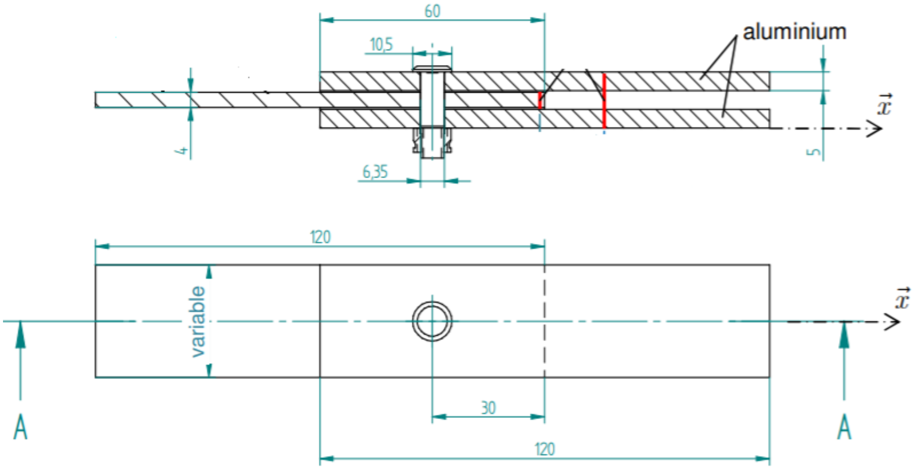

**Fig. 1. The double lap geometry and dimensions in mm**

In this modeling the fasteners (screw, nut counter-nut discs), are regarded as rigid bodies in the finite element model. Figure 3 shows the boundary conditions and the conditions of loading in statics.

Two contact pairs were established in the model. One was located between the polymer laminate and the aluminum metal plate, and the other was located between the polymer and bolt. A surface-to-surface discretization was employed for the contacts between bolts and plates, and a node-to-surface discretization was used for the contact between the plates to prevent element interpenetration at the edges of the parts.

The contact between the Hi-Lite bolt and the inner surface of the hole was then simulated using a surface-to-surface contact type. The contact property was applied to the plate-plate and hole-bolt contacts. The polymer laminate was the master surface for the plate-to-plate contact, and the bolt was chosen the slave surface for the hole-to-bolt contact. The contacts were solved using the penalty method with hard contact, friction, small sliding and finite sliding. Penalty contact was included between the aluminum alloy Hi-lock bolt and the polymer laminate along the bearing surface with a coefficient of friction of 0.1, and the plate-to-plate contact was 0.2.

The step time chosen for the simulation was 0.2 s, and final time is 1 s, in order to facilitate the analysis.

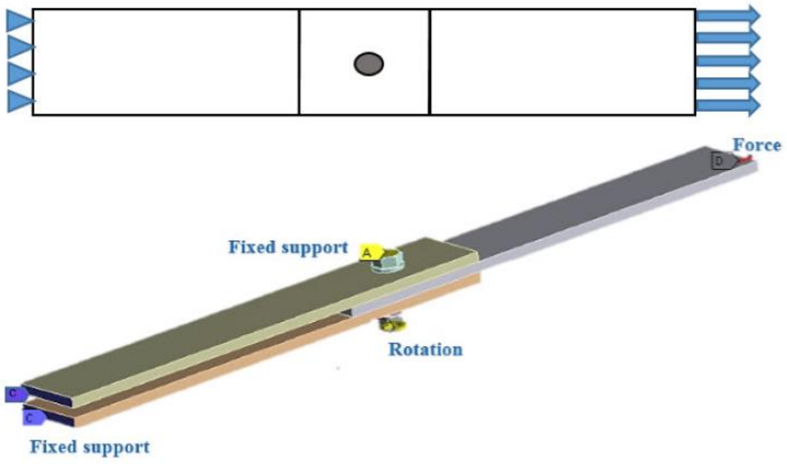

**Fig. 2. Boundary conditions and loading condition.**

The theory of incremental plasticity is used to define the elastoplastic parameters of the used materials. The iterative method of Newton–Raphson is used as an approach to solve nonlinear equations by finite elements method.

A typical 3D implicit finite element model for bolted joints is presented in Fig. 3.

The details of the finite elements model and the bolted assembly mesh are represented on Fig. 4.

One end of the plates was constrained and the tensile load was applied to the other end. Bolt clamping force (preload) was applied using the Bolt Load option in ABAQUS.

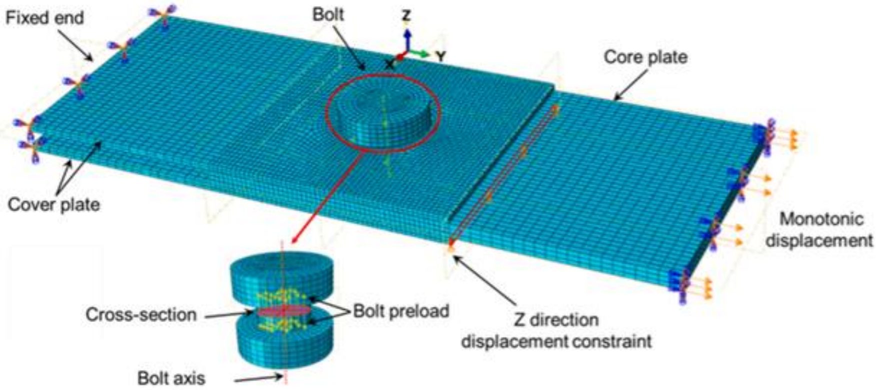

**Fig. 3. A typical FE model for double shear bolted joint with steel bolt**

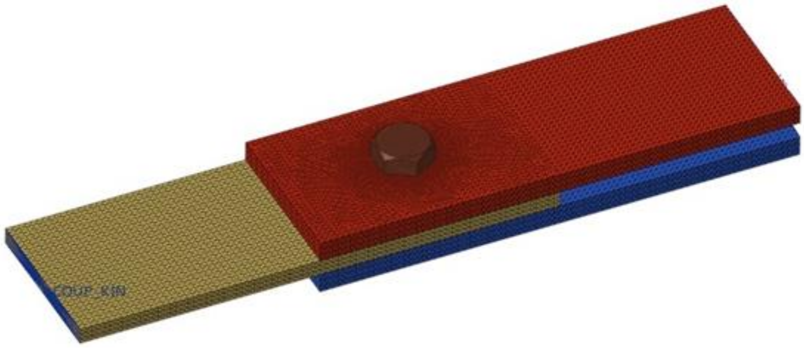

**Fig. 4. Finite elements detail model: the bolted assembly Mesh**

The considered mesh consists essentially of C3D8R elements type: 8-node 3D continuum elements, with reduced integration. The choice of this element type was motivated by various numerical studies and given the fact that the accuracy/calculation time of this element type is suitable for the study. Particular attention has been paid to the partitioning of the parts to have a mesh set and to have a continuity of the stress fields from one part to the other.

## 3. Results and discussion

The load-displacement curves of both geometries showed some interesting results. It was suggested that the load-displacement curves of the assembly exhibited three main stages. The load increased linearly at first arriving to a value of 2500N due to the joint load being reacted solely by static friction forces acting at the shear plane, then, a sliding occurred corresponding to that the large bolt-hole clearance was taken up and the bolt shank began to contact the laminates, when contact was established between the bolt and the laminates, the bolt started to transmit load and the load decreased causing the damage of the polymer.

Here, the typical force-displacement curve of the assembly was concluded in Fig. 6.

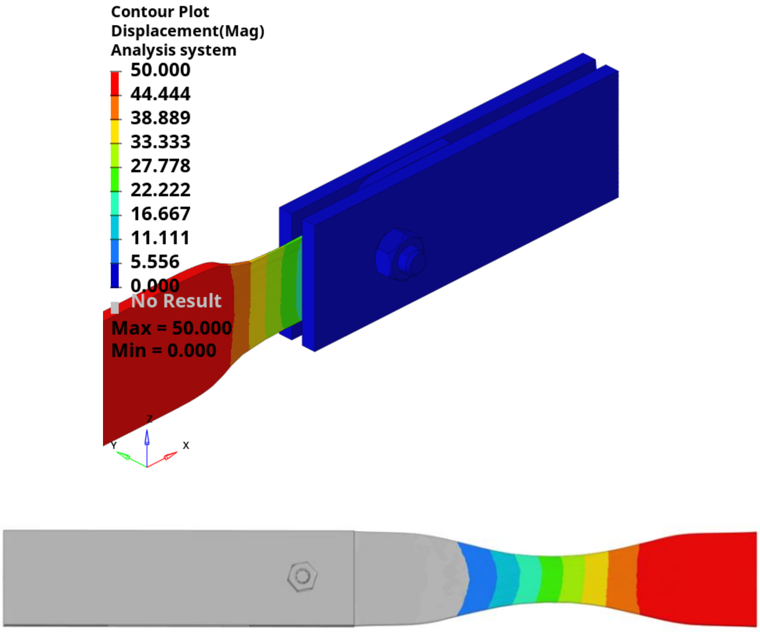

**Fig. 5. Numerical result showing the deformation of the geometry**

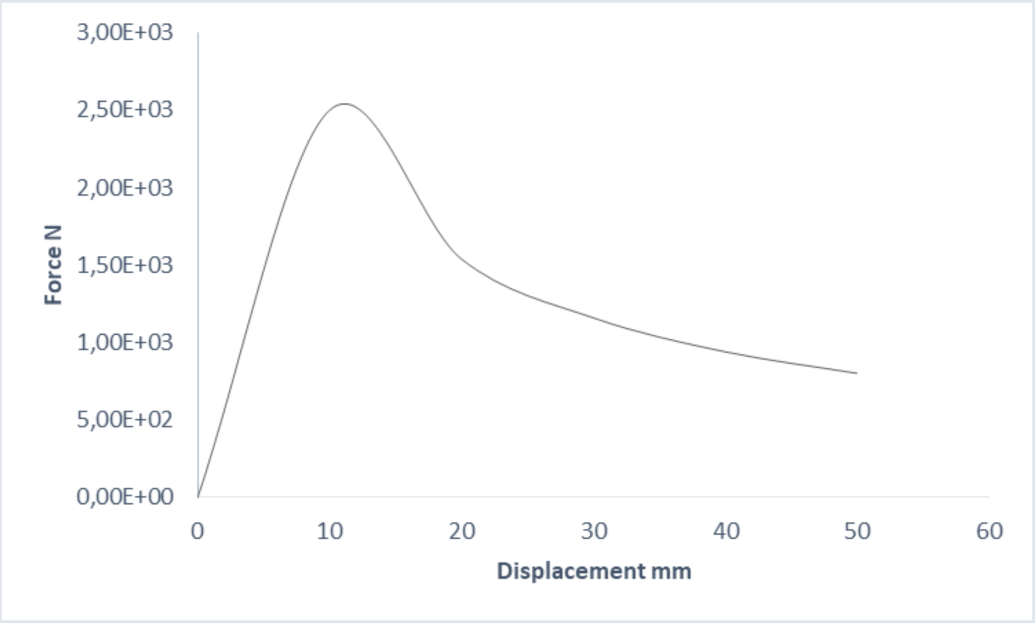

**Fig. 6. Relationship force-displacement for the whole assembly model along the load axes.**

It is found that the numerical models can run completely without convergence issues.

Transition stage begins with a value of 2500 N which is the maximum stress achieved in for this assembly, where the polymer laminate failure occurs. Afterwards, the damage continues to evolve, an interesting amount of polymer tensile failure is recorded. The joint starts to lose its stiffness gradually due to damage accumulation. Subsequently, a longitudinal tensile displacement of 50 mm was applied to the end of the middle plate through a quasi-static process.

The initiation of failure in the double bolt junctions occurred at the critical edge of the hole where there is a high stress concentration was almost 210MPa.

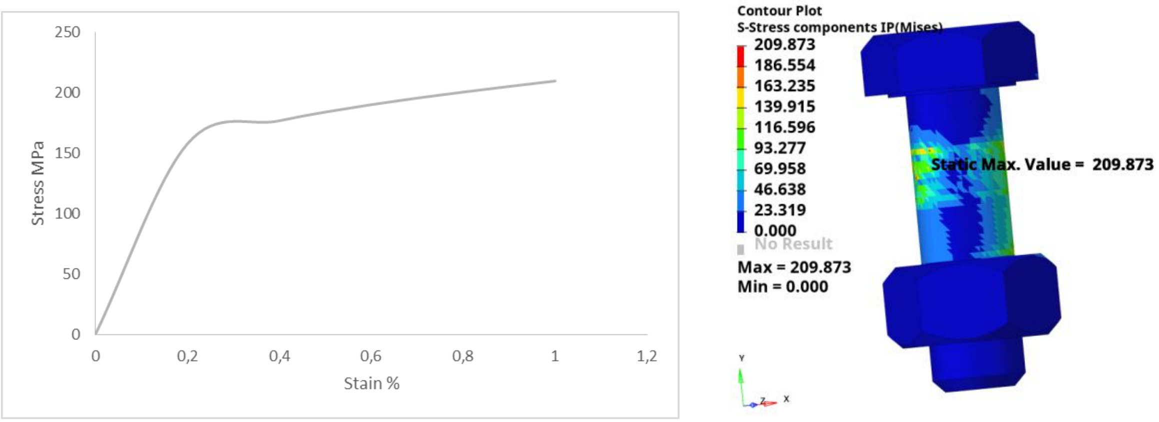

**Fig. 7. Numerical Stress strain curve of the bolt joint.**

## 4. Conclusion

A three-dimensional finite element model was developed to predict the tensile behavior of double lap bolted multi-material assembly of (Al6082T6/PVC). This is vital for the optimization of multi-material structure designs and can be seen as the contribution of this paper. The following conclusions were obtained:

- The results obtained from the simulation were in total agreement with other experimental studies found in the literature.
- The maximum value of load went up to 2500N, along with a maximum elongation of 50mm. however the middle plate, clearly showed an interesting variation in the model due to its plasticity threshold
- The Polymer/slave plate (PVC) went through a long plasticity phase, which explains why the aluminum plates didn't really show a remarkable transformation due to the highest rigidity of the Al 6082T6 compared to the polymer (PVC).
- The damage and failure of the joints were dominated by the damage and failure of the PVC.
- The stress distributions in the bolt depends crucially on its rigidity.

## 5. References

Amacher, R., Cugnoni, J., Botsis, J., Sorensen, L., Smith, W., & Dransfeld, C. (2014). Thin ply composites: Experimental characterization and modeling of size-effects. *Composites Science and Technology*, *101*, 121-132.

Benhamena, A. *Contribution à l'étude de l 'endommagement en Fretting Fatigue des assemblages par fixation: Cas des Assemblages Rivetés (Contribution to the Fretting Fatigue Damage Study of assemblies by fixation: Rivet Assemblies Case)* (Doctoral dissertation, PhD Thesis, Sidi Bel Abbes, Algeria 2010 (in French)).

Dirk, H. J. L., Ward, C., & Potter, K. D. (2012). The engineering aspects of automated prepreg layup: History, present and future. *Composites Part B: Engineering*, *43*(3), 997-1009.

Galos, J. (2020). Thin-ply composite laminates: a review. *Composite Structures*, *236*, 111920.

Kweon, J. H., Jung, J. W., Kim, T. H., Choi, J. H., & Kim, D. H. (2006). Failure of carbon composite-to-aluminum joints with combined mechanical fastening and adhesive bonding. *Composite structures*, *75*(1-4), 192-198.

Sihn, S., Kim, R. Y., Kawabe, K., & Tsai, S. W. (2007). Experimental studies of thin-ply laminated composites. *Composites Science and Technology*, *67*(6), 996-1008.

SpecialChem, (2017). Comprehensive Guide on Polyvinyl Chloride (PVC). Available Online at: https://omnexus.specialchem.com/selection-guide/polyvinyl-chloride-pvc-plastic.

Wen, X., Wan, M., Huang, C., & Lei, M. (2019). Strength and fracture toughness of TC21 alloy with multi-level lamellar microstructure. *Materials Science and Engineering: A*, *740*, 121-129.

Wu, X., Fuller, J. D., Longana, M. L., & Wisnom, M. R. (2018). Reduced notch sensitivity in pseudo-ductile CFRP thin ply angle-ply laminates with central 0 plies. *Composites Part A: Applied Science and Manufacturing*, *111*, 62-72.

Yibo, P., Gang, W., Tianxing, Z., Shangfeng, P., & Yiming, R. (2013). Dynamic mechanical behaviors of 6082-T6 aluminum alloy. *Advances in Mechanical Engineering*, *5*, 878016.