

Failure Analysis of T800 Carbon Fiber Composite Joint Structure With Double Bolts

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Abstract. In this paper, the progressive damage model of T800 carbon fiber composite double-bolt joint based on Hashin criterion was established based on the finite element analysis. By changing the bolt diameter, the numerical simulation of the strength change of the joint was carried out. The damage evolution process was studied and the corresponding verification test research was carried out. Finally, the damage and failure process of the T800 carbon fiber composite double-bolt joint is given, and the strength optimization design scheme is proposed.

1. Introduction

When the carbon fiber composite materials are used in aircraft structures, many separate connection parts are designed.¹²³ These separation and connection parts often have the characteristics of complex structure, uneven load distribution, and multiple stress concentrations, which also become the difficulties in the structural design of aircraft.⁴⁵⁶⁷ In order to make the important parts of the connecting parts bear reasonable force and improve the structural reliability of the aircraft, it is necessary to study the mechanical properties of the

carbon fiber composite material connecting parts.⁸⁹¹⁰¹¹ Based on this situation, the paper analyzes the failure situation of T800 carbon fiber composite double-bolt joints through a combination of finite element simulation analysis and experimental verification.

2. Finite element simulation analysis

The finite element model of the double-bolt connection structure is established, and the apertures are 4mm, 6mm, and 8mm respectively. Figure 1 shows the cloud diagram of the stress and time corresponding to the stress at the hole edge of the connector with a diameter of 4 mm.

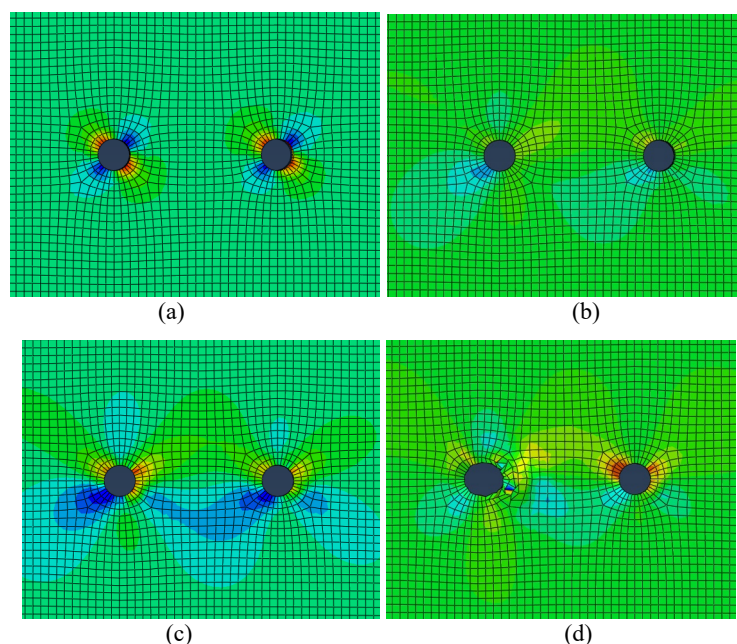


Figure 1. The stress change history of the double-bolt joint when the hole diameter is 4 mm

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It can be found from the above Figure 1 (a) that for the lower layer of the laminate, when the preloading force acts on the two bolts, it has the same effect on the laminate, at 315° of the two circular holes and its There is a phenomenon of stress concentration in the 135° direction of the extension line. With the expansion of the simulation, the stress concentration caused by the bolt pre-tightening force disappears rapidly. Corresponding to Figures 1 (b) and 1 (c) It is that the stress dispersion occurs again in the 90° , 210° and 330° directions of the

circular hole. With the continuous loading, the corresponding 30° , 150° and 270° in Figure 1 (d), the stress is relatively concentrated in the direction, and there is even a stress concentration in the first two directions. Finally, under the action of the external load, the right side of the left circular hole is the first to have regional extrusion damage, and the connector fails.

When the hole diameter is 6mm, the state cloud diagram of the stress and time corresponding to the hole edge of the connector is shown in Figure 2.

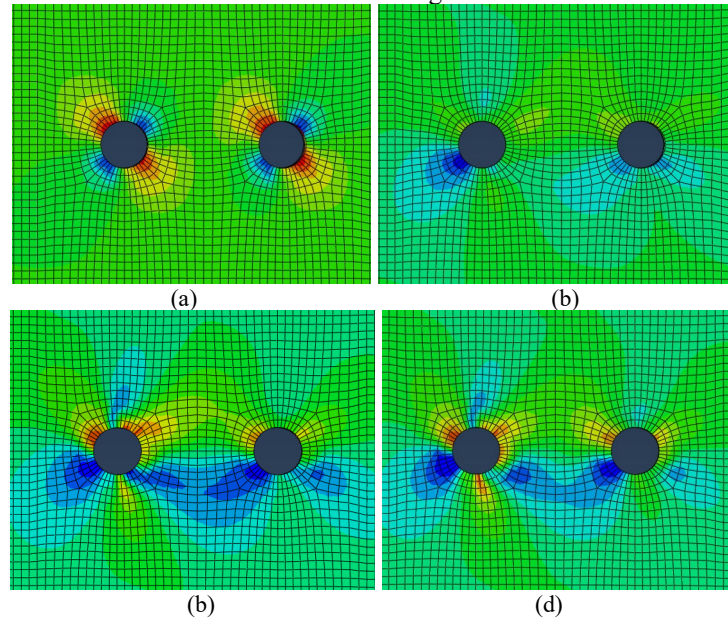


Figure 2. The stress change history of the double-bolt joint when the hole diameter is 6 mm

Figure 2 (a) shows that the characteristics of the lower layer of the composite laminate with a 6mm aperture are the same as those of the 4mm one, and stress concentration occurs in the direction of 135° of the two circular holes and its extension line 315° , but the area of radiation is smaller than 4mm is wider, and the Figure 2 (b) and Figure 2 (c) are also from the beginning of stretching, the stress decreases rapidly, followed by the difference in the 90° , 210° and 330° directions around

the two circular holes The degree of stress dispersion occurs, and finally stress concentration occurs to different degrees in the opposite 30° , 150° and 270° directions. Surprisingly, there is no damage to the distorted mesh in the above process.

When the aperture diameter is 8mm, the state cloud diagram corresponding to the stress and time of the hole edge of the connector is shown in Figure 3.

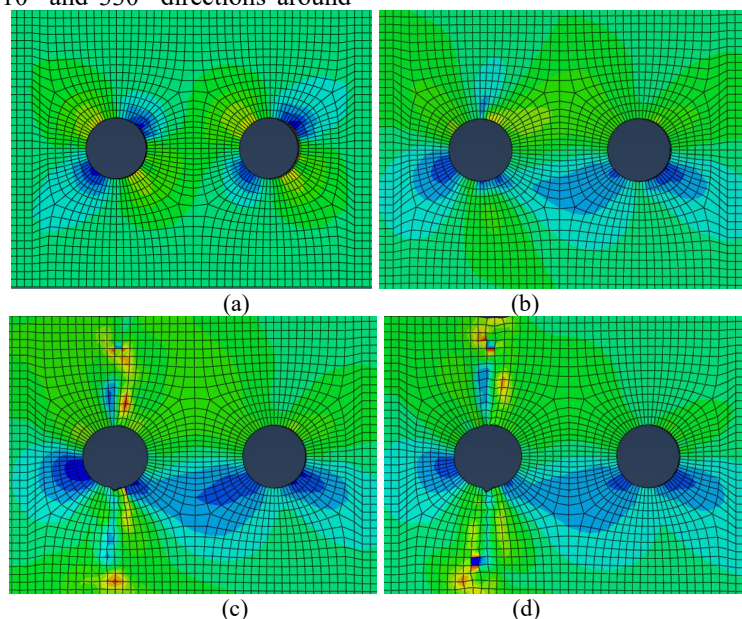


Figure 3. The stress change history of the double-bolt joint when the hole diameter is 8 mm

From the above figures, there no special stress distribution can be seen until a small part appears in the 90° and 270° directions of the left circular hole in the Figure 3(d). The stress concentration area develops to the stress-damaged part in Figure 3(b) that expands outward along the directions of 90° and 270°. In Figure 3(d), the left circular hole breaks, and the cracks are along 90° and 270°. Orient up to the cut-off with the edge of the laminate board.

According to the stress distribution on the upper and lower plate layers of the connector under the above three different aperture conditions, it can be seen that the stress state generated by the preload is mostly X-type, but with the beginning of the test, the stress state is more complicated and does not have obvious Characteristic, when the diameter of the connecting bolt is small (4mm and 6mm), the failure mode is the extrusion failure close to the plate boundary, and when the connecting bolt is changed to 8mm, the failure mode is the failure of the plate that crosses the vertical line of the center of the circle.

3. Experimental verification

The material of the test piece is T800 high temperature epoxy resin carbon fiber. Uniaxial tensile testing of composite connectors according to ASTM-D5961M-2017. The specific dimensions of the test pieces are shown in Table 1.

Table 1. Machining dimensions of the test piece (mm)

Length	Thickness	Width	Bore diameter	End Distance	Row	Connection
150	2.4	36	4/6/8	20	20	Double Bolt Single Shear

The diameters of the bolts are 4mm, 6mm and 8mm respectively, and the morphology of the test piece is shown in the Figure 4.

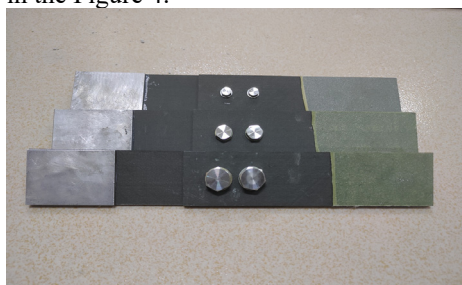
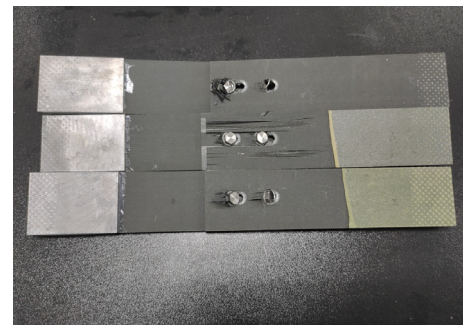
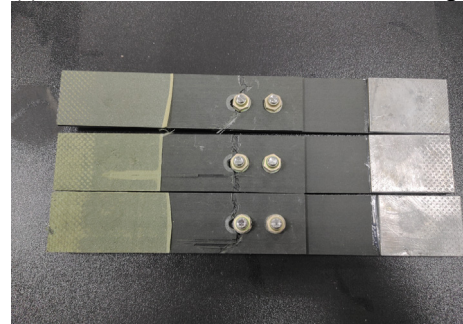


Figure 4. Specifications and diameters of double-bolt connectors

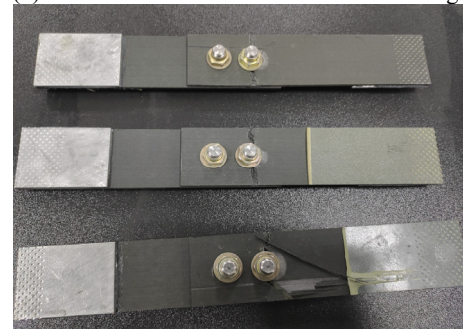
The damage morphology of the test piece after stretching is shown in the Figure 5.



(a)4mm Diameter Double Bolt Failure Damage



(b)6mm Diameter Double Bolt Failure Damage



(c)8mm Diameter Double Bolt Failure Damage

Figure 5. The damage morphology of the different diameter

It can be seen from the damage topography: only the 4mm bolt diameter has a large slip and deformation, and the damage is in the form of debonding of the interface along the fiber direction caused by the stress concentration at the connection of the circular hole, and the subsequent two sizes of connection. The pieces were fractured. The larger the diameter of the selected bolt, the larger the ultimate stress that the whole can withstand under the same strain state.

4. Results and Discussion

The failure damage of double-bolt connections includes many types, and the most important form of damage is delamination damage. The delamination is caused by the interlaminar stress in the laminate near the free edge (the edge of the hole containing the orifice). The interlaminar stress has both interlaminar normal stress and shear stress. When they reach a certain limit value, they will lead to stratification. When analyzing the interlaminar force of the test laminate, the interlaminar normal stress is much higher than the shear stress, and the delamination damage is mainly controlled by the interlaminar normal stress. The interlaminar stress at the edge of the hole is much higher than the interlaminar

stress at the outer edge, so the local stiffness of the interlaminar decreases when the damage propagates.

From the perspective of the damage form of fracture damage, the connection structure of double-bolt single-shear is relatively strong, but general fracture damage occurs in the 90° and 270° directions at the left circular hole of the lower plate. During the fracture process, the phenomenon of stress redistribution is obvious. Before the fibers of the laminate are fractured, the load on the fibers in the laminate is much greater than that on the matrix, so after the fibers are suddenly broken, the force on the fibers is transferred to the matrix, and the matrix stress is redistributed at this time.

There is a confounding effect in the form of fracture failure of composite materials, which should be fully utilized to improve the connection strength and reliability of T800 carbon fiber composite material connectors.

References

1. Wang Q, Jia P R, Zhang L, Wang G & Zeng L L. (2020). Failure analysis of countersunk bolt connection of carbon fiber reinforced composites. *Journal of Aeronautical Materials* (06),59-70.
2. Sun Y. (2016). Strength analysis of carbon fiber composite connection structure and its influencing factors (Master's Thesis, Harbin Institute of Technology). <https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201701&filename=1016913421.nh>.
3. Li L J. (2018). Progressive damage failure analysis and optimization design of composite bolted connections (Master's thesis, Xi'an University of Science and Technology). <https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201802&filename=1018882599.nh>.
4. Chen B. (2009) A preliminary study on generalized strength criteria for advanced composite laminates. (Master's Thesis, Shanghai Jiaotong University).
5. Qu K. (2018) Research on failure and damage of composite bolted joints. (Master's thesis, Jinan University). <https://kns-cnki-net-s.libyc.nudt.edu.cn/KCMS/detail/detail.aspx?dbname=CMFD201802&filename=1018888850.nh>.
6. Li C X. (2019). Analysis of typical mechanical properties of GLARE laminate multi-nail connection (Master's thesis, Harbin Institute of Technology). <https://kns-cnki-net-s.libyc.nudt.edu.cn/KCMS/detail/detail.aspx?dbname=CMFD202001&filename=1019647138.nh>.
7. Wang H J, Yang J, Liu X D, Liu X J. (2007) Research progress on influencing factors of mechanical connection strength of composite materials. *Materials Reports*, (S3):438-440.
8. Wang H J, Yang J, Liu X D, Liu X J. (2008) Experimental study on the influence of geometric parameters on bolt strength of glass fiber fabric/epoxy laminate. *FRP/Composites*, (01):3-5+29.
9. Tang Y L. (2015). Analysis of failure strength and main influencing factors of carbon fiber composite connection structure (Ph.D. dissertation, Harbin Institute of Technology) <https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFDLAST2016&filename=1015957364.nh>.
10. Liu J M, Wan X P, Wang W Z. (2014) Influence of nail head on failure mode of composite single-lap structure. *Mechanical Strength*, (05): 734-738. DOI: 10.16579/j.issn.1001.9669.2014.05.020.
11. Zuo Y J. (2018). Dynamic and static damage and failure of interference mating bolted connection of composite/titanium alloy structure (Ph.D. dissertation, Northwestern Polytechnical University) <https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFDLAST2020&filename=1020706817.nh>.