Analysis on the Influence of Assembly Gap on CFRP Assembly Stress Based on Finite Element Method

Qilin Jiang$^{1,2}$, Junming Hou$^{1,3,*}$, Xiwu Fang$^2$ and Hongrui Wang$^2$

$^1$School of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing China
$^2$School of Mechanical Engineering, Nanjing Institute of Technology, Nanjing China
$^3$Industrial Center, Nanjing Institute of Technology, Nanjing China

*Corresponding author

Abstract. Due to the material properties and forming process of composite laminates, it is difficult to avoid smaller assembly gaps in the assembly process of laminates. In assembly process, liquid gaskets are generally used to compensate the smaller assembly gaps between laminates. Therefore, this paper established the equivalent assembly model of the laminated plate, and used the finite element analysis method to conduct numerical analysis and quantitative research on the mechanical influence of the assembly gap on the laminated plate assembly on the basis of analyzing the typical structure of the wing box. And the results of finite element method are compared with the experiment. This work provides a theoretical support to ensure the assembly quality of composite laminates.

Keywords: Assembly gap; Assembly stress; CFRP; Finite element method.

1. Introduction

Interstitial compensation of composite components during aircraft assembly has always been a concern of researchers and engineers [1] and the reference [2] points out that 0.005 inch clearance is allowed in composite components assembly process. Liquid gaskets, solid gaskets, layered gaskets, and sacrificial layers are the gaskets that are often used in assembly of composite components.

The performance of mechanical joints has a large impact on the performance of the entire structure, especially for composite structures. In general, it is often necessary to attach the components (high-lock bolts, rivets, etc.) to the mounting gasket (liquid or solid gasket) where there is a high concentration of stress. Its ability to redistribute loads of the composite structure is much worse than that of metallic materials. In response to this situation, many researchers have studied the load transfer performance of composite mechanical joints [3-15]. Therefore, the stress concentration caused by the gasket should also be included in the scope of study. The thermo-mechanical fatigue properties of liquid gaskets in aircraft composite-aluminum hybrid mechanical joints were studied, and the load of commercial aircraft structures were also simulated in ref [16].

It is found that the structural mechanical stiffness did not decrease significantly, there was no obvious damage on the bearing surface, and the stiffness of joint decreased when the thickness of the gasket increased. Then, for a certain size of the gap, the size (span) of the joint surface should be considered on whether to add a gasket [17]. For small gaps and short joints, the stress and strain will be relatively large. So the stress in the composite components is a criterion for whether a gasket should be applied, and the stress is related to the applied fastening force.
Therefore, more research of the limit value of the stress and its impact on assembly quality is needed. At present, the stratified load criterion needs to be established, and the basic problem is how to determine the stress caused by the structural joint load (clamping force) under the consideration of the gasket.

2. Establishment of Finite Element Model

Studying the assembly relationship of CFRP and the stress generated in the assembly through the test method will make the test cycle longer and the efficiency lower. Therefore, the finite element method is used to analyze the internal stress under the compression force, which can better study the stress in the assembly process and has a good reference significance for the generation and compensation of assembly error.

According to the assembly state of the site, the test piece is simplified to the structure shown in FIGURE I, and the finite element meshes are also divided.

![Figure 1. Fixture constraint at both ends of assembly.](image1)

By analyzing the stress of components, the boundary conditions and load diagram of the assembly were preliminarily established. The fixed constraints were established at both ends of the specimen, and the bolt load was applied when the fixed support at both ends of the assembly was satisfied.

![Figure 2. Fixing constraints at both ends of the assembly.](image2)

Carbon fiber reinforced composite material X850 specimens were simulated. The matrix material of the composite specimen was epoxy resin. The size of the specimen was 135mm in length and 36 mm in width.

Given the pretightening force of high-lock bolt $F=7840N$, the parameters of experimental clearance were selected in advance as 0.2mm, 0.3mm and 0.5mm, and the assembly parts without and without filling gaps were analyzed respectively.

![Figure 3. Apply bolt pretightening force.](image3)
3. Finite Element Simulation Result Analysis
FIGURE IV and FIGURE V respectively show the stress state of the assembly specimen when the gap is 0.2mm and the stress state of the assembly specimen in the direction of the assembly force of the high-lock bolt (along the direction of thickness). The unit of the stress value analyzed is KPa.

![Figure 4](image)

**Figure 4.** Test piece stress at 0.2mm gap.

![Figure 5](image)

**Figure 5.** Stress along the thickness direction at 0.2 mm gap.

3.1. Stress analysis of hole wall thickness
In the case of no gasket, the node on the direction of hole wall thickness of the specimen was selected for analysis. The stress in the direction of specimen thickness is analyzed and the result is shown in FIGURE VII-IX. Through the finite element analysis results, it can be seen that the internal stress of the specimen is smaller than the external stress, and the stress value is concave distribution. In addition, the external measurement data of the strain gauge can be used to calculate the internal stress of the specimen theoretically during the assembly experiment, and the damage subroutine can be combined with finite element analysis to analyze and judge whether the specimen is damaged during the loading.

![Figure 6](image)

**Figure 6.** Stress of the hole wall along the thickness direction at 0.2 mm gap.
3.2. Stress analysis in the direction of principal stress

When the experimental clearance parameters 0.2mm, 0.3mm and 0.5mm, force analysis was carried out on the assembly parts with the unfilled gap and the filled gap, respectively. FIGURE X and FIGURE XI respectively show the stress state of the unfilled gap and the filling gap with the gap of 0.2mm.

Figure 7. Stress of the hole wall along the thickness direction at a gap of 0.3 mm.

Figure 8. Node stress along the thickness direction of the hole wall at 0.5 mm gap.

Figure 9. Stress cloud diagram in the direction at 0.2mm clearance.

Figure 10. Stress cloud in the direction under a 0.2mm gasket.
The stress of the assembly with a gap of 0.2 mm, 0.3 mm and 0.5 mm was compared and analyzed. By analyzing the stress state of the representative middle straight line on the surface of the specimen, it can be known that the stress state under the two conditions of gap and ungap. The stress values under the 0.2 mm assembly gap did not change much, and the line types tend to be uniform. A sudden change in stress occurs around the connecting hole under the 0.3 mm assembly gap. The stress value is significantly higher than that of the gap filling when the fitting is not filled, and the trend is further expanded under the 0.5 mm assembly gap, as shown in FIGURE XII-XIV.

![Figure 11. Comparison of 0.2mm ASSEMBLY GAP interstitial stress.](image1)

![Figure 12. Comparison of 0.3mm ASSEMBLY GAP interstitial stress.](image2)

![Figure 13. Comparison of 0.5mm ASSEMBLY GAP interstitial stress.](image3)

3.3. Comparison of unfilled and interstitial stress under different gaps

Through comparative analysis, the assembly stress of the composite specimen increases when the assembly gap increases, as shown in FIGURE XV and FIGURE XVI. However, in the case of interstitial, the stress value of the specimen does not follow the gasket. The increase in thickness shows a downward trend. The interstitial compensation will reduce the stress value of the fitting to a certain extent. The stress will decrease with the increase of the thickness of the gasket within a certain range,
but the stress of the interstitial compensation specimen will increase as the gap increases. As shown in the case where the gap is 0.5 mm as shown in FIGURE XVI, it is necessary to further analyze and explore the interstitial range and strategy.

**Figure 14.** Stress values under 0.2mm, 0.3mm, 0.5mm ASSEMBLY GAP without gap filled.

![Stress graph](image1)

**Figure 15.** Stress value under 0.2mm, 0.3mm, 0.5mm assembly GAP with gap filled.

### 4. Test Verification
Carbon fiber reinforced composite material X850 was selected as the test piece material for composite components, and the matrix material for composite components was epoxy resin. The size of the test piece for prepare hot-pressing tank molding was 135mm in length, 36mm in width, and the pressure position of the test piece thickness is 5.0mm. The test device can be seen in FIGURE XVII.

**Figure 16.** Schematic diagram of test equipment.

The st-01 force sensor with sensitivity of 2.00 mv/V was selected for the collection of stress data, as shown in FIGURE XVIII.

**Figure 17.** Force sensor.
The stress measurement experiment results of CFRP plate which is connected by the mechanical joints are in accordance with the finite element simulation results.

5. Conclusion

• Under the condition of no gap filled, the stress area of the double-solid support assembly specimen is mainly distributed at the gap fulcrum of the assembly and the gap fulcrum around the connection hole is mainly subject to bending tensile stress. The larger the assembly gap around the connection hole is subject to bending compressive stress, the greater the stress the specimen will be subjected to.

• According to the analysis of different gap spans, in the case of smaller gap spans, gasket compensation should be considered to avoid large assembly stress. In the same gap, with the increase of gap spans, the assembly gap in the area around the hole will be eliminated, and the assembly stress at the edge of the gap will decrease accordingly.

• Under the condition of clearance compensation, the stress of composite specimens is compared. Under the three clearance conditions of 0.2mm, 0.3mm and 0.5mm, the stress curves of composite specimens have similar trends. Compared with the test piece, the assembly stress has obvious improvement when the gaps are not filled. And the unit damage coefficient is low, and the assembly quality is obviously improved.

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