# MECHANICAL PROPERTY ANALYSIS AND TEST VERIFICATION OF OPENING COMPOSITE LAMINATE

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**ABSTRACT**

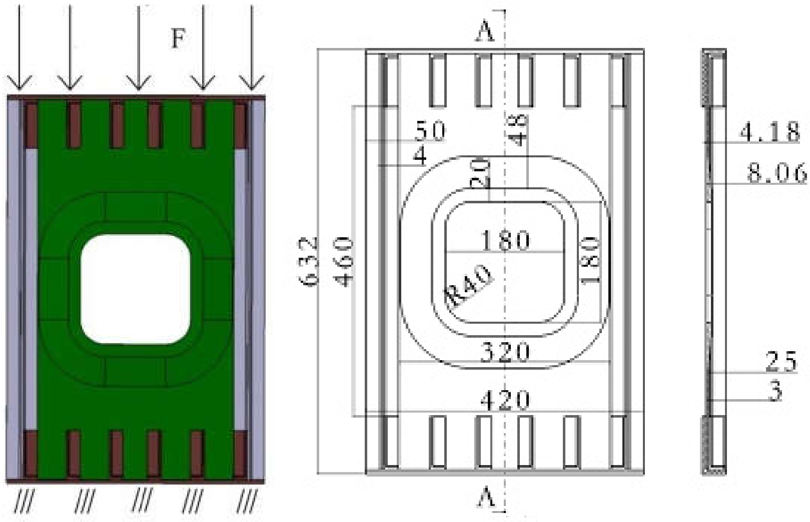
The use of advanced composite materials can significantly reduce the quality of the structure, improve flight performance, the use of the ratio has become a measure of advanced aircraft, one of the important criteria. Owing to design requirements, it is often desirable to provide openings in the laminate that reduce the load carrying capacity of the composite structure. In this paper, we use the method of intercalation reinforcement to increase the opening area of the laminated plate and create the finite element analysis model. The displacement and strain distributions of the open laminates were obtained by the static load calculation using the compressive load, and the damage mode of the structure was predicted. The physical test and verification of the open laminates were designed and finished. Through the combination of simulation analysis and experimental verification, the static strength evaluation of the open laminated structure was carried out, and the bearing capacity of the structure was obtained, which provided a reference for the subsequent design and improvement of the composite structure.

## 1 INTRODUCTION

During the use of the aircraft, equipment maintenance, fuel filling and other operations, the need for composite wall panels in the design of various openings. Since the opening significantly reduces the structural load carrying capacity, it is usually necessary to reinforce the peripheral area of the composite opening[1]. Variable thickness and thick plate structure make the mechanical analysis of composite wall become more complex[2]. Kou Changhe[3] studied the scheme of strengthening the round mouth with symmetric layer, and obtained the existence of the optimal strengthening radius. Eiblmeier[4] in-depth analysis of the stability of laminated panels with rounded corners. Mahdi[5] has carried on the simulation analysis and the experimental verification for the carrying capacity of the opening wall plate before and after strengthening. In this paper, the method of intercalated reinforced slope transition is adopted to strengthen the open area of the laminated plate. The bearing capacity of the structure is verified by the combination of simulation and experiment.

## 2 TEST PIECE

As shown in Fig. 1 (a), the test piece is supported at the end and the loading end is simply supported. Open wall panels for the laminated plate parts, side trusses with aluminum alloy material. The general thickness of the laminate wall is 4.18mm, the thickness of the opening area is 8.06mm, and the opening is 180mm square, as shown in Fig.1 (b). Composite materials are mainly used high-performance one-way zone, in order to improve the damage tolerance and to keep the outer surface layer smooth, the test surface laying a group of ± 45 ° braided fabric[6], test piece stacking sequence shown in Table 1.




( a )  ( b )

Figure 1: Schematic illustration of the opening wall panels.

| position | Laying direction | Number of layers | Single layer thickness/mm | Total thickness/mm |
|---|---|---|---|---|
| General area | [(+45)/(0)/+45/0/-45/90/45/0/-45/+45/0/-45/0]s | 26 | 0.22/0.15 | 4.18 |
| Strengthening area | [(+45)/(0)/(+45)/(0)/+45/-45/0/+45/-45/0/90/0/+45/-45/0/+45/-45/0/+45/-45/0/+45/-45/90/0]s | 50 | 0.22/0.15 | 8.06 |

Table 1: Parts detailed laminate.

## 3 SIMULATION ANALYSIS

### 3.1 Finite element modeling

In this paper, the open-ended wall plate subjected to axial compression load is taken as the research object, and the finite element model is established to simulate the opening wall of the composite material. As the test pieces are thin shell structure, so using Quad4 meshing, see Figure 2. The mesh length is about 2mm, which includes 43584 nodes and 54912 cells. After the mesh is created, the unit direction is checked, and the direction of the element affects the thickening direction of the panel. It is necessary to confirm that the unit normal meets the design requirements and the thickness distribution of the opening wall of the composite material is shown in Fig3.

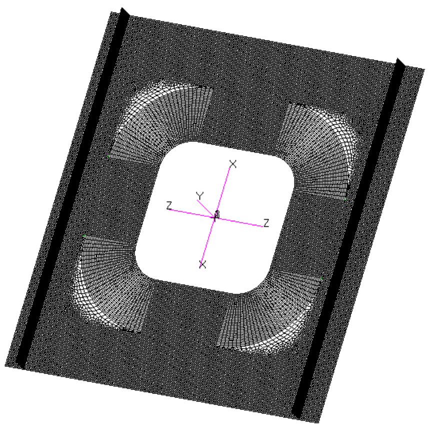


Figure 2: Open wall grid.

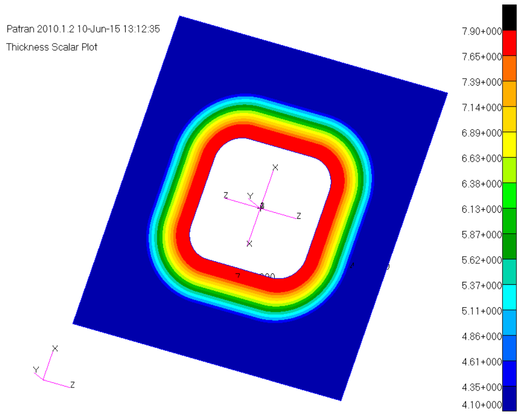



Figure 3: Thickness distribution.

### 3.2 Boundary conditions

At the top of the open-wall panel simulation model, the concentrated load is uniformly distributed on the top line and the buckling load is 1N. The static analysis is carried out step by step, and the load side constraints are 2,3,4,5,6 degrees of freedom, 2,3,4,5,6 degrees of freedom, as shown in Figure 4.

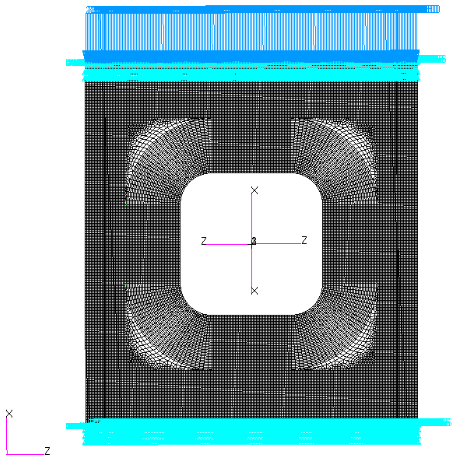


Figure 4: Boundary Condition of Simulation Model for Open Wall.

### 3.3 Calculation results

The linear buckling simulation was carried out by commercial finite element analysis software. The first-order buckling factor is 175,000 and the buckling load is 175kN when the total load of 1N is applied to the open-wall structure, and the buckling occurs in the middle of the opening.

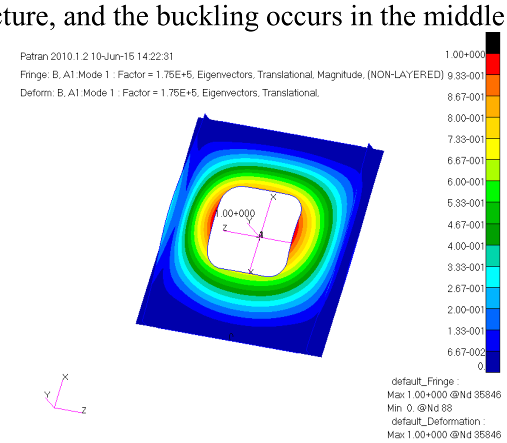
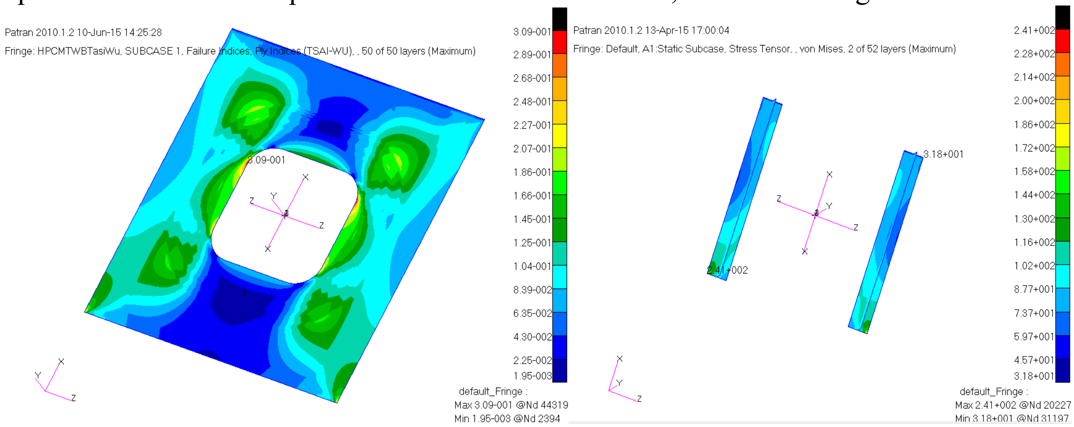



Figure 5: Buckling diagram.

The maximum Tsai-Wu criterion factor is 0.309. As shown in Fig 6 (a), when the coefficient is less than 1, the composite structure has not been destroyed. At this point the maximum stress of aluminum alloy parts is 241MPa, as shown in Figure 6 (b), has not yet reached the aluminum alloy strength limit. At this point the maximum displacement of 0.711mm structure, as shown in Figure 7.




( a ) ( b )

Figure 6: Structural response under buckling load.

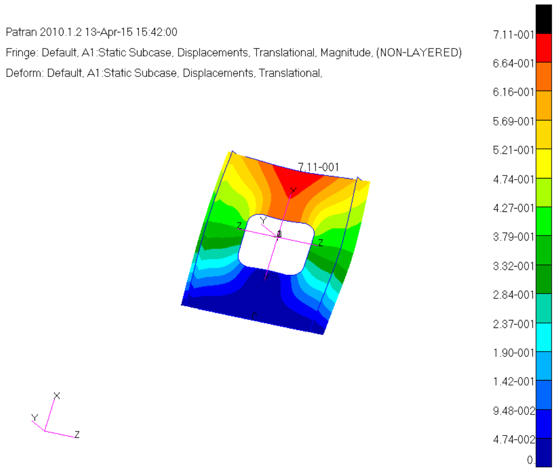
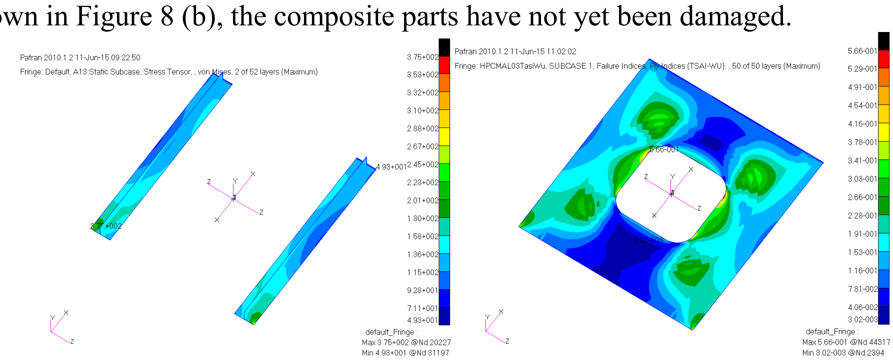



Figure 7: Displacement of structure under buckling load.

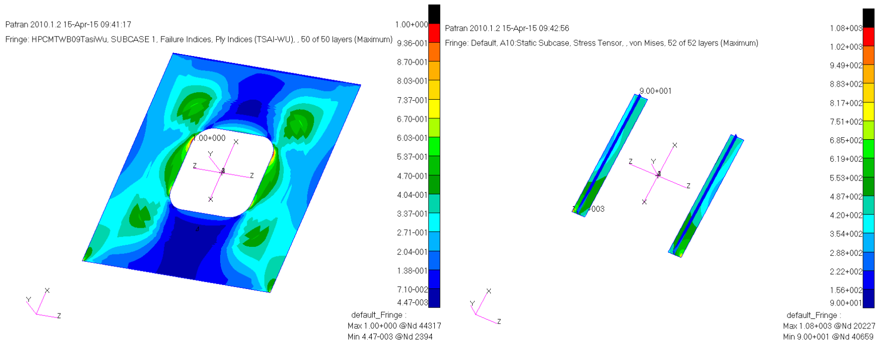
When the load reached 271.9kN, the maximum stress of the aluminum alloy structure is 375MPa, see Figure 8 (a), reached the yield stress. At this point the maximum Tsai-Wu criterion coefficient of 0.566, as shown in Figure 8 (b), the composite parts have not yet been damaged.




( a ) ( b )

Figure 8: Structural response when part reaches strength limit.

When the load is 400.6kN, the maximum Tsai-Wu criterion factor is 1, as shown in Fig.9 (a). In this case, the maximum stress of the aluminum alloy structure is 1080 MPa. As shown in Fig. 9 (b), the ultimate stress is exceeded, so that the aluminum alloy member will be damaged before the composite material.



( a ) ( b )

Figure 9: The structural response of the maximum Tsai-Wu criterion coefficient is 1.

Unsteady load of the opening wall is 175kN, which occurs in the middle of the opening. At this time, the maximum CAI - Wu criterion coefficient of the laminated plate structure is 0.309, which has not been destroyed. The maximum stress of aluminum alloy parts is 241MPa, the same failure value. In conclusion, the simulation results show that the buckling failure will take place first.

## 4 EXPERIMENTAL VERIFICATION

### 4.1 basic requirements

Structural test system includes test pieces, measuring equipment, test load module, etc., in the course of the test, to be recorded in real time force, displacement and structural strain. The test system to test to confirm the status of equipment and test pieces of the initial tension to reduce the possible excess clearance to check the loading system coordination, measuring equipment status, the extension of the cylinder to meet the requirements of the test before the official start Check and record the initial state of the test piece.

The strain and displacement of the test piece were measured. On the one hand, check the measurement equipment, on the other hand a preliminary understanding of structural deformation and strain levels, in advance to estimate the load at which the deformation beyond the linear range.

Component-level test pieces Static tests are loaded under computer control and are carried out step by step in a pre-arranged sequence of tests. Load point control error of not more than 1%, when applied to a certain level of load should be completed displacement, strain measurement, and then the next step.

The opening panel is pre-tested with one piece to expose the problem and reduce the risk. Check whether the loading is eccentric, deformation is reasonable. In the pre-test after commissioning qualified, and then carry out a formal test.

### 4.2 Support method

In the simulation analysis, the bottom of the test piece is fixedly supported. In order to minimize the displacement of the bottom of the test piece, to ensure that the physical test and simulation analysis conditions are the same, steel fixture is used to support the test piece. In order to ensure the vertical loading of the open-wall test, the top loading end of the test piece is subjected to the hinge restraint to limit the displacement of the end surface to the normal direction of the panel surface, as shown in Fig 10.

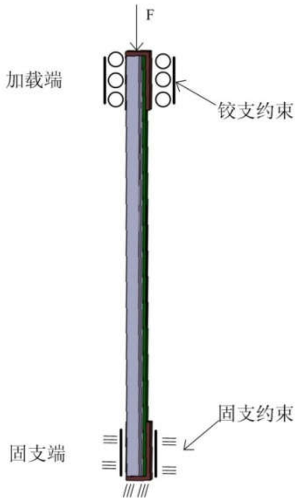



Figure 10: Open siding constraints.

The top of the opening wall test is loaded by the fixed support cylinder. The actuator is connected with the test piece through the trapezoid loading block. The load is evenly applied to the test piece, and the bottom is fixedly connected with the test bench through the test fixture, as shown in Fig 11.

Figure 11: Physical testing of open siding.

### 4.3 Loading load

From the numerical simulation analysis of the test piece, we can see that the breaking load of opening wall is about 175kN. Considering the capability and accuracy of the actuator and the equipment of the test unit, the open wall test is carried out with 250kN actuator.

The single load increase is 5kN until the test piece loses its load capacity. After a single load, it needs to wait for the data to be stable before sampling, indicating the damage load and the loading end displacement.

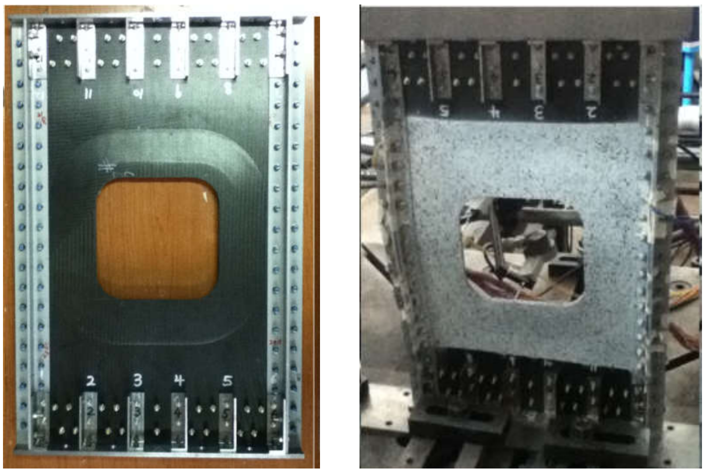
### 4.4 Measurement requirements

Typical structure Static test is to test the structural design, manufacturing process is one of the important means of qualified for structural strength analysis and structural design improvements to provide experimental basis. The important measurement parameters of the structural static test include strain and displacement. Through the measurement of the above parameters, the response of the typical structure under the static load is analyzed to verify whether the structure meets the design requirements of strength and rigidity.

According to the layout map to carry out patch, measurement, measurement, including the strain strain measurement of structural strain, according to measuring point layout to collect displacement data. Measurement relative error control in ± 1%, loading point control error is less than 1% absolute value.

### 4.5 test results

The test results show that the open-wall panel failure load is 232.8kN, and the state of the open-wall test piece before and after the test is shown in Fig 12. It can be seen from the figure that the compressive load is applied to the opening wall, and the whole wall of the opening is buckled and the buckling occurs in the middle of the large opening. The load-displacement curve of the open-wall test is shown in Fig 13.



( a ) ( b )

Figure 12: The state of the test piece before and after the test.

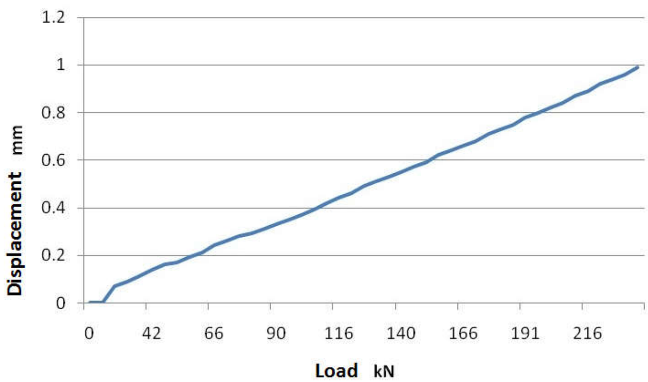



Figure 13: Load - displacement curve of open - wall test.

## 5 CONCLUSIONS

( 1 ) The simulation results of the open wall are consistent with the physical tests, and the failure modes are all buckling, which proves the reliability of the simulation analysis.

( 2 ) The failure mode of the open-wall panel is the overall damage with high bearing efficiency, which indicates that the opening reinforcement of the slope is reasonable and the bearing capacity of the structure is improved.

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