

An Experimental Study on Bolts Connection Strength of Composite Laminated Boards

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Abstract. Assembly is the key link in the whole manufacturing process and it is also the link prone to deviation. In the process of production, assembly deviation is easily caused by tolerance accumulation due to the precision of parts processing and assembly technology. For the sake of safety, it is necessary to check the strength of the padded connections and make a finite element analysis of the connection properties of the composite connections with and without shim. According to whether or not the shim is bonded to the connecting plate during the test, the compensation shim is divided into two forms: structural shim and non-structural shim. In addition, the two types of compensation shims are analysed and discussed.

1. Test introduction

In order to verify the bearing capacity of the connections with compensating shim, the connection strength test was carried out according to ASTM D5961M-05 standard. In order to eliminate the influence of humidity and heat on the properties of the composite materials, the environment involved in the test is controlled at room temperature. The test load is shown in figure 1.

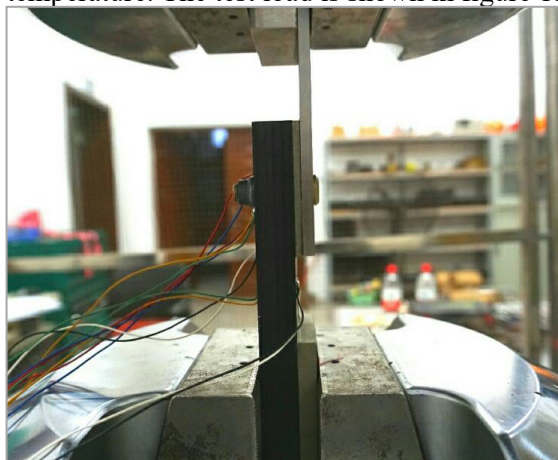


Fig.1. Test diagram



The test piece is of single nail and single shear configuration, and there are two sets of connection forms: normal connector and super-differential pad attachment which is seen in Table 1.

Table 1 Information of the test

| Test type | Name | Information | Quantity |
|-------------------|------|---------------|----------|
| Test without shim | C50 | Without shim | 5 |
| Test with shim | C51 | With 3mm shim | 5 |

One end of the joint is composite material, the other end is titanium alloy. To eliminate the clearance, the gasket and the laminated plate are fixed together by glue. The concrete structure and geometric dimensions of the specimen is shown in fig.2 and fig.3

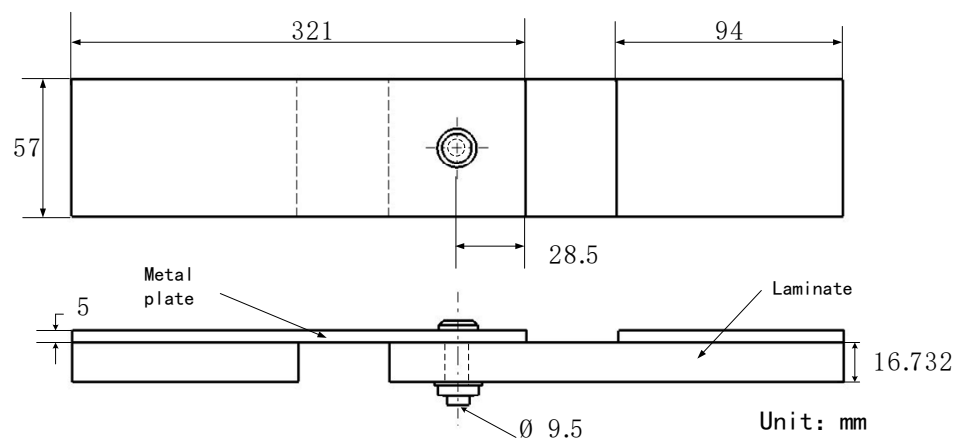


Fig.2. Connection without shim

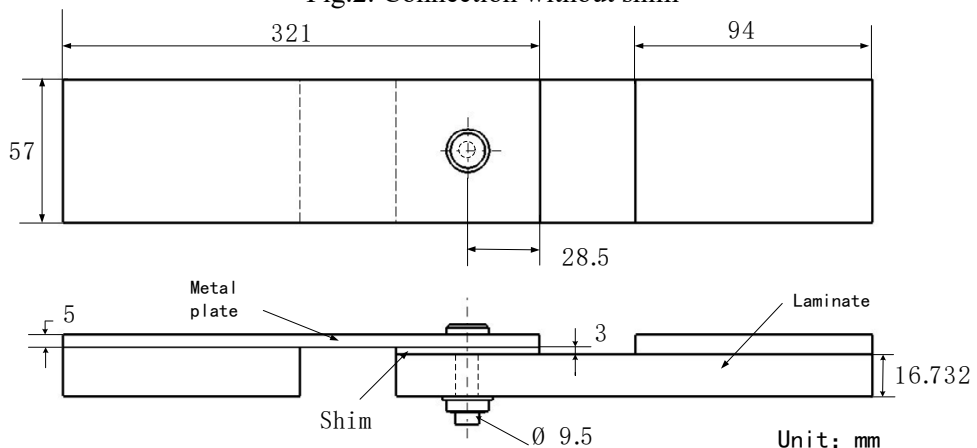


Fig.3. Connection with 3mm-shim

The composite laminated plates have a total of 89 layers. The specific layering sequence is:
 [45/-45/45/-45/0/-45/45/-45/45/0/-45/45/0/45/-45/0/-45/45/90/45/-45/90/90/-45/45/90/45/-45/0/-
 45/45/0/45/-45/0/45/-45/45/-45/0/-45/45/-45/45/45/-45/0/0/0/45/0/0/-45/0/45/0/0/0/-45/90/-
 45/0/0/0/45/0/-45/0/0/45/0/0/0/-45/45/-45/0/0/45/-45/90/45/-45/0/0/45/0/-45/45]

Table 2 to table 4 lists the properties of single layer plates of composite materials and the mechanical properties of metal materials involved in the test.

Table2 The rigidity performance of composite single layer plate

| Longitudinal modulus E_{11} /GPa | Transverse modulus E_{22} /GPa | Thickness modulus E_{33} /GPa | Shear modulus G_{12} /GPa | Shear modulus G_{23} /GPa | Poisson's ratio |
|------------------------------------|----------------------------------|---------------------------------|-----------------------------|-----------------------------|-----------------|
| 175 | 8.05 | 10 | 4.37 | 3.90 | 0.32 |

Table3 The strength performance of composite single layer plate

| Longitudinal tensile strength Xt/MPa | Transverse Tensile strength Yt/MPa | Longitudinal compression strength Xc/MPa | Transverse compression strength Yc/MPa | longitudinal-transverse shear strength S ₁₂ /MPa | Interlaminar shear strength S ₂₃ /MPa |
|---|---------------------------------------|---|---|--|---|
| 2786 | 86.4 | 1602 | 212.8 | 112 | 52 |

Table4 Performance parameters of metal materials

| Type | material | Elasticity modulus MPa | Poisson's ratio |
|-----------|----------------|------------------------|-----------------|
| Lap plate | Titanium alloy | 110000 | 0.29 |
| Shim | Aluminum alloy | 70000 | 0.3 |

2. Analysis of test results

2.1. Bending effect

When the single shear head is under tensile load, there are obvious secondary bending moment effects in mechanical connection of composite materials since the bolt is inclined and torsion. In order to explore the effect of additional bending moment caused by shims, a strain gauge is attached to edge of the hole of laminated plate, as shown in Fig.4.

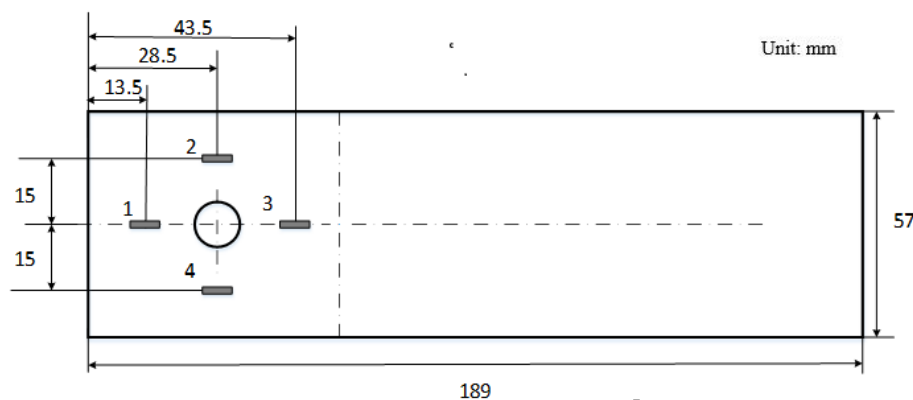


Fig.4. The position of the strain gauge

Table 5. The strain results under 20kN Load (Unit: $\mu\epsilon$)

| Number | 1 | 2 | 3 | 4 |
|--------|------|------|------|------|
| C50 | -133 | -540 | -747 | -448 |
| C51 | -119 | -480 | -982 | -471 |

As can be seen in Table 5, due to the secondary bending effect, the strain values of No.1 to No.4 are all negative and they are compressed. No.2 and No.4 are in symmetric positions and their strain values are almost equal. As the bending degree of the structure increases from the free end to the clamped end, the number of No.3 is significantly greater than that of No.1. Comparing the strain values of the two groups of specimens, it can be seen that the values of No.1,2 and 4 differ little, while in No.3, the compression effect is more obvious, and the strain value increases by about 30%. It can be seen that the existence of the shim makes the bending effect of structure more obvious. The strain value of No.3 has changed significantly as the position of the strain gauge No.3 is the main influence area of bending effect.

2.2. Load-displacement curve

The displacement loading method was adopted in the test, and the 30% drop in load was taken as the failure criterion of the structure. The load displacement curves measured by the two groups of tests are shown in Fig.5 and Fig.6.

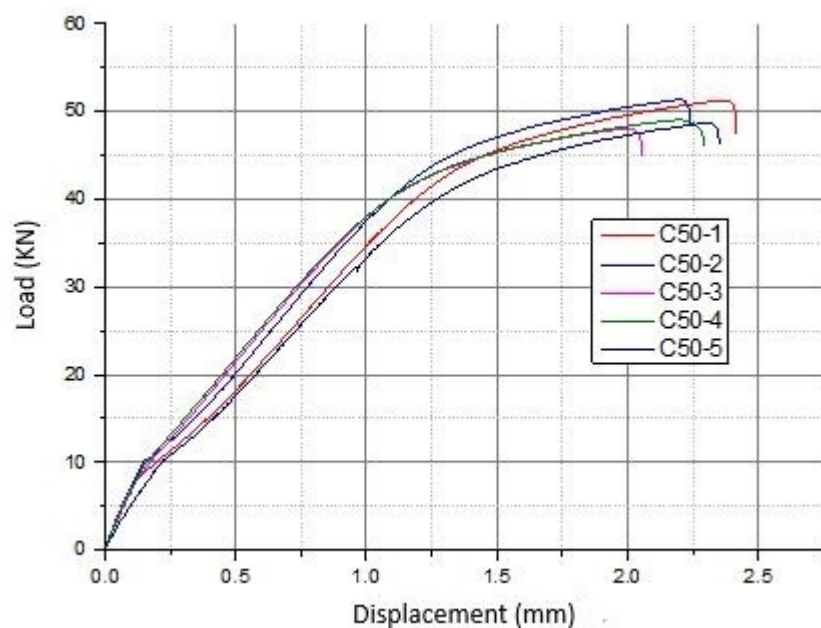


Fig.5. Load-displacement curve of Test C50

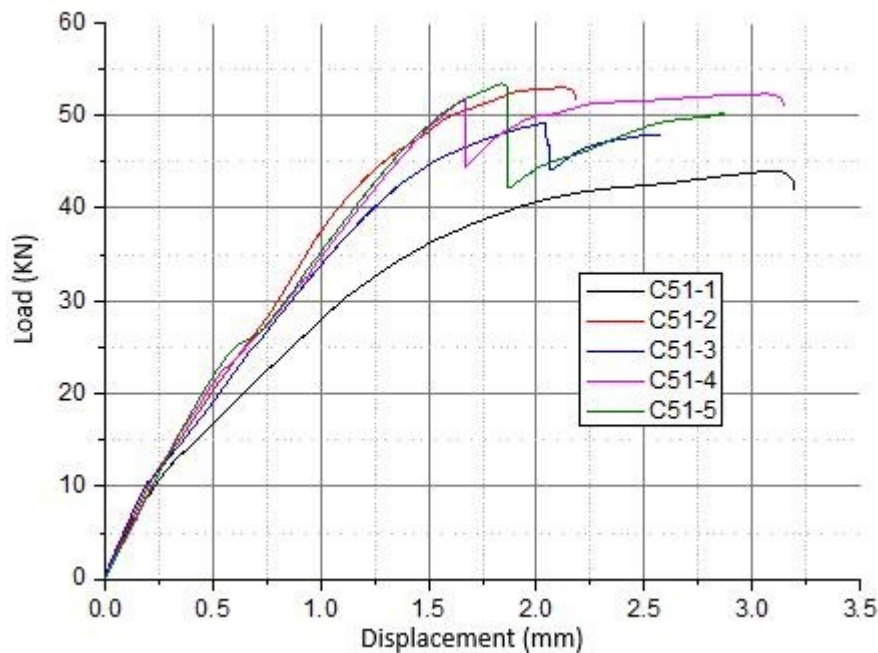


Fig.6. Load-displacement curve of Test C51

3. Analysis of the test results

It can be seen that the curve is roughly divided into three stages and is generally non-linear:

- At the initial stage of the test, the stiffness of the joints is larger because of overcoming the static friction between the joints.
- When it is loaded to about 10 kN, relative sliding occurs between the lap plates, the static friction becomes sliding friction, and the curve stiffness drops into the linear segment.
- When the load reaches about 38 kN, due to the accumulation of local damage of laminated plates and the yield of bolts, the curve stiffness gradually decreases, showing obvious non-linearity.
- When loaded to around 49 kN, the bolts reach the strength limit, break and fail, and the joints lose the bearing capacity.

Fig.6 shows the load displacement curve of the oversize shim joint. Compared with the load displacement curve of the test C50, the initial stage of the C51 curve has almost no high linear stiffness stage. Main reason lies in the initial stage of C50, static friction exists between titanium alloy and laminated plates, and in C51, static friction mainly exist in the titanium alloy and aluminum alloy. The static friction coefficient of the former is larger than that of the latter, so the initial stage of the test curve of C50 shows greater linear stiffness.

It was observed that the curves of the test pieces c51-3, c51-4 and c51-5 dropped suddenly after reaching a certain load, and then the curves continued to rise slowly. After a period of loading, the bolts broke off and the joints failed.

Combined with experimental phenomenon, the reason why the curve drops suddenly is that the structure of test pieces changes due to the degumming of the shim. After degumming, the shim is almost no longer loaded, so the bolt is under greater load and the overall stiffness of the test piece decreases. The curve rises slowly until the bolt reaches the tensile limit and the test piece finally breaks.

The performance changes of c51-3, c51-4 and c51-5 test pieces after shim shedding were statistically compared, as shown in Table 6.

Table.6.The performance changes of test pieces before and after shim shedding

| Name | The peak load/kN | | Rate of change after shim shedding |
|-------|-------------------------|------------------------|--|
| | Before shim shedding | After shim shedding | |
| C51-3 | 49.19 | 47.97 | -2.48% |
| C51-4 | 51.80 | 52.31 | 0.99% |
| C51-5 | 53.42 | 50.17 | -6.1% |

It can be found that the load peak of the test pieces is generally lower than that after the shim falls off. From Fig.6 the c51-1 test piece did not show obvious jitter during loading, but the final failure load and linear segment stiffness were relatively low. The reason is that it perhaps has been detached at the initial stage of the test, and the detached shim is basically unloaded during the loading process. The performance of C51-2 to C51-5 are relatively stable during loading, and the damaged shims are still attached to the laminated plate.

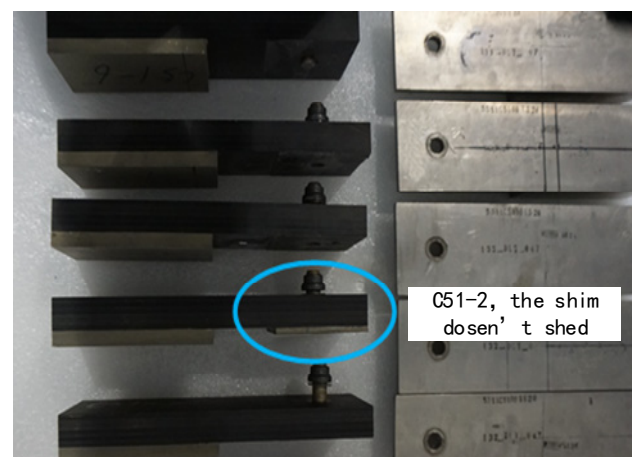


Fig.7. Picture of C51-2

4. Conclusion

- a) For the mechanical joints of composite materials with single nailing and single shear configuration, the bolts have bending effect due to structural eccentricity. When the shim is added, the eccentricity of the structure changes and the joint performance is affected.
- b) In summary, the connection performance of the structure is affected to a large extent by whether the shim is bonded to the lap plate for the oversize shim fitting. When the shim is degummed, the structural form of the joint changes, and the shim no longer carries load. The bearing capacity of the joint and the rigidity of the joint all decrease to some extent.

References

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