

Investigation into Bearing Capacity of Composite Bolted Joints with Different Shim

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Abstract. The mechanical behaviors of composite bolted joints which are typical connection units of aircraft structures might change due to the application of liquid shim or laminated shim with different thickness. In this paper, the bearing capacity of composite bolted joints with different shim are studied numerically by three-dimensional nonlinear finite element (FE) method, and the extended Chang-Lessard failure criteria is incorporated into FE model to predict the progressive damage of composite bolted joints. Finally, the numerical results are verified experimentally. It is concluded that the stiffness and strength of the composite bolted joints decrease with an increasing shim thickness, and the composite bolted joints with laminated shim get better bearing capacity than the liquid shim series with same geometry size.

Introduction

Due to manufacturing and assembling errors, fit-up gap often appears at the interface between two components of composite aircraft structures, and the gap is often filled with either liquid shim or laminated shim. The mechanical behaviors of composite structures might change due to the application of liquid shim and laminated shim. Simplified composite bolted joints with shim adhering to one surface of composite plates are often introduced to analyze the change. In this paper, force-displacement behaviors which are used to evaluate the bearing capacity of composite bolted joints with different shim are obtained numerically and experimentally. Three-dimensional nonlinear finite element method incorporated Chang-Lessard failure criteria is introduced. And also, the magnitude of secondary of composite bolted joints with different shim are studied.

Finite element model

As shown in Fig.1, two IMS-977-2 composite plates are jointed by a HST12 Hi-Lite fastener in the form of single-lap, and liquid shim or laminated shim is required to adhere firmly to one of the mating surfaces. And the geometrical features of composite plates are prepared in accordance with ASTM D 5961/D 5961M-08 [1]. The composite plates are modelled with one solid element per ply, and each ply is modeled by eight-node three dimensional solid elements (C3D8R), as shown in Fig.2,

linear reduced integration formulation with an advantage of avoiding shear locking in the case of bending. The bolt, washer, and nut are modelled as one unit in order to limit the number of contact surfaces and save computing time. Furthermore, a new set of failure criteria proposed by Álvaro Olmedo[2] are introduced to predict composite failure, it is an extension of Chang–Lessard criteria[3] considering a three-dimensional stress and out-of-plane failure.

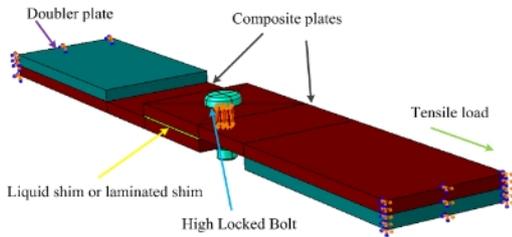


Fig.1 Composite bolted joint

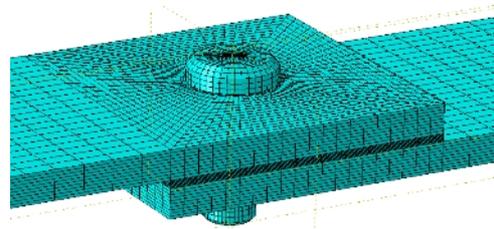


Fig.2 Mesh of FE model

Experiment test

The tensile experiment was carried out on a CMT5504 Electronic universal testing machines made by SANS as shown in Fig.3, and its max testing force was 100 kN. Chuck moved at a speed of 0.4 mm/min to simulate quasi-static loading, and it stopped after the load dropped about 30% from the max value. The test procedure corresponded to the guidelines given in ASTM D5961/D5961M.



Figure .3 Experimental test

Result and Discussion

Although numerical difference between FE results and experimental results still exists as shown in Fig.4, which may be produced by the difference of degradation rules, loading method, mechanical properties of composite components etc. between experiment and FE analysis, both the load–displacement curves of FE results and experiment test present similar variation tendency for liquid shim series and laminated shim series.

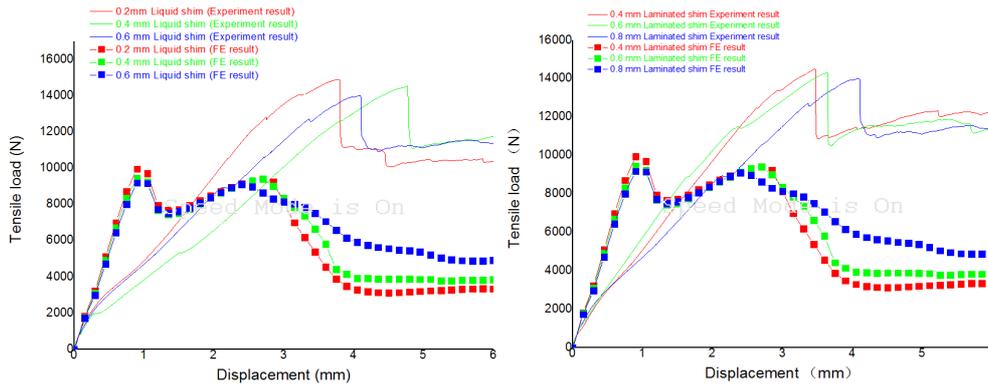


Fig.4 Load–displacement response of composite assembly structures

In the linear stage of curves, both the thickness of liquid shim and laminated shim influence the slope of straight line which stands for the stiffness of composite bolted joints. With the increase of shim thickness, the stiffness of composite bolted joints decreases in linear stage. Moreover, the peak of tensile load which reflects the strength of composite assembly structures decreases as the increase of shim thickness. And the explanation for this phenomenon is that higher shim thickness leads to higher eccentricity of load path which could aggravate secondary bending [4][5][6][7][8].

Under the tensile load, the bending of composite plates and the rotating of bolt turn out as shown in Fig.5 (a) which can be simplified to Fig.5 (b). Then non-uniform contact stress distribution through the thickness of the composite components turns out, which will cause the damage of composite plates and the fracture of fasteners. The thicker shim thickness increases the length of OB in Fig. 5 (b), and moment M_2 will magnify naturally with invariable position of point O. So the relative displacement of two composite components increases under the same tensile force, of course, the stiffness of composite bolted joints decreases with thicker shim.

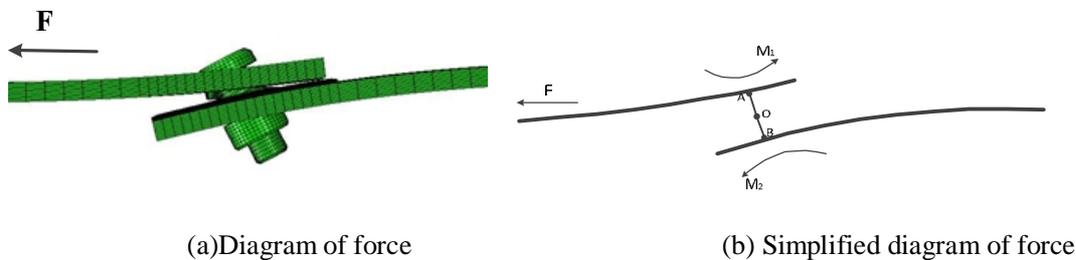
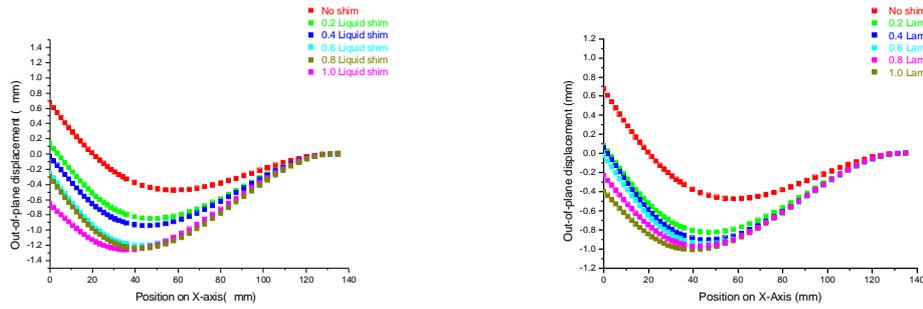


Fig.5 Force diagram of composite assembly structure

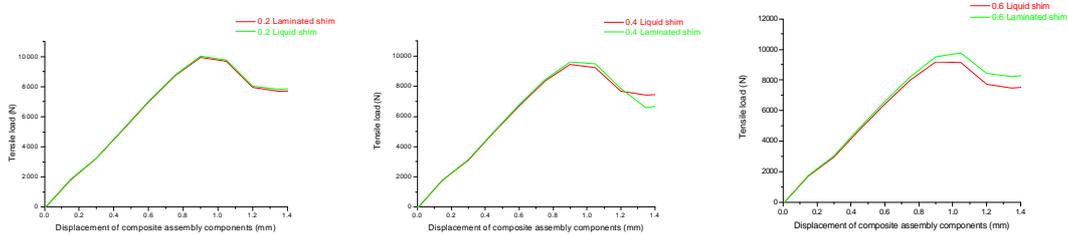
Furthermore, the introduction of shim alters the asymmetric bending of two composite plates. In other words, the magnitude of secondary bending appears different. The lateral displacement of the composite bolted joints as shown in following Fig.6 can highlight the magnitude of secondary bending. It could be concluded that the lateral displacement of composite bolted joints rises with the increase of shim thickness.



(a) Out-of-plane displacement of liquid shim series (b) Out-of-plane displacement of laminated series

Fig.6 Out-of-plane displacement

Comparing the load–displacement response of liquid shim series and laminated shim series with equal geometry size, the authors find that laminated series get higher stiffness and strength as shown in Fig.7. For 0.2 series, the peak load of laminated shim series is 1.1% higher than liquid shim series, and the value varied to 9.2% for 0.6 series. What can interpret this phenomenon is that laminated shim owns higher modulus than liquid shim. So composite bolted joints with laminated shim present a better bearing capacity, lower magnitude of secondary bending. This could be proved by out-of-plane displacement response shown in Fig.6 which could highlight the magnitude of secondary bending. It is found that the maximum out-of-plane displacement of liquid shim series is higher than laminated shim series, by 11.5% and 24.2% for 0.2mm and 1.0mm shim series. The difference becomes larger as the increase of shim thickness.



(a) 0.2 mm shim series (b) 0.4 mm shim series (c)0.6mm shim series

Fig.7 Comparing of liquid shim series and laminated shim series

Conclusions

The mechanical behaviors of composite bolted joints with different shim are studied by three-dimensional nonlinear finite element methods incorporated extended Chang-Lessard failure criteria and experimental test. And the FE results are in agreement with the experimental results. It is concluded that the bearing capacity of composite bolted joints decrease as the thickness of shim increases. What could explain the phenomenon is that the usage of shim alters the location of moment center, the magnitude of secondary and the tilt of bolt. Compared to composite bolted joints with liquid shim, laminated shim series possess higher bearing capacity due to the higher modulus of laminated shim.

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