Research Progress of Secondary Bending in Composite Joints

Fa Yuan, Yuan Guoqing, David Hui
School of Aerospace Engineering and Applied Mechanics, Tongji University, Shanghai, China.

1 Introduction

The high proportion of composite in the A380, B787 and A350 aircraft structure has made the application a trend that composite become the fact without dispute. Any structure inevitably exist linking problem. With the advantages of high reliability and transfer large loading, etc, composite mechanical joints often get used in main stucture. It is very important to analyze the influence of various factors to joints strength and quantitative forecast joints strength of failure mode method in order to strengthen the joints and improve the efficiency of the joints. The strength and failure mode of composite bolt joints has much to do with the cooperation precision between the bolt holes and the bolt, laminate size, layer proportion and order, fasteners preloaded force, enviromental condition. Many researchers have been researching composite joints by analytical method, numerical method and testing method on the research in past decades because of the importance of the problem and made a lot of encouraging research results. This paper reviews the research progress of the concept of secondary bending, analytical methods, numerical methods and test methods of secondary bending and the future several research directions are discussed in this paper.

2 Definition of secondary bending in composite joints

With the load of tension or compression in single lap joint primarily, because of the distance between the shear surface of the bolt and acting face of the joint under the load, when simplified to the shear surface will add a bending moment, the stress, strain response and the deformation caused by axial tension or compression which caused by the bending moment are secondary. This phenomenon is called secondary bending. The definition of SB can be given in either strains [1] or stresses [2] and simplified according to,

$$\mathrm{SB}=\frac{\varepsilon_b-\varepsilon_t}{\varepsilon_b+\varepsilon_t}=\frac{\varepsilon_{bend}}{\varepsilon_{ax}}\sim\frac{\sigma_{bend}}{\sigma_{ax}} \qquad (1)$$

where the subscripts b and t denotes the bottom and top surface of the plate, and bend and ax denotes quantities pertaining to bending and tension only, respectively. It is assumed that bending strain in the direction of thickness for linear change along the board in formula (1). In fact near the hole where the bolts and the hole have the complexity of the contact behavior, so the linear assumptions are not actual and discrepant. In addition, the measure position and the load conditions also effect the secondary bending according to formula (1).

3 Analytical analysis of secondary bending by NLM

Calculations with the neutral line model (NLM) were already made long ago for comparison of different riveted joints by Schijve J. [3]and Hartman A, Schijve J.[4]. As shown in figure 1 of a single lap joint ,part Ⅰ can be regard as a beam under eccentric tension and will produce the plane bending. Part II can also be regard as twice the thickness of the beam under the eccentric tension. Getting bending stress calculation according to the beam theory, secondary bending effect is figured out.

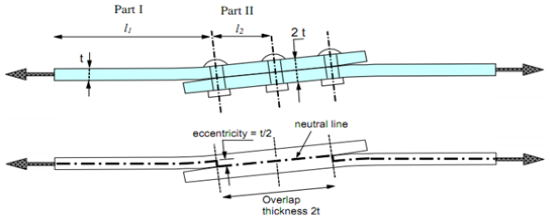

Fig. 1 The NLM of a single lap joint.

In fact every single lap joint, no matter how the materials, or the asymmetry in thickness exists asymmetry, when the plane under the tension or compression there would be secondary bending exist. When the bending behavior can be simplified to plane bending problem, the above neutral line model is applicable.

4 Numerical analysis of secondary bending

The numerical simulation of secondary bending is mainly considered the behavior of the contact with 3D finite element analysis, with the software Marc[5],Ansys[6],etc. But the efficiency of 3D finite element analysis is not high,

it is very difficult to analysis of secondary bending in multi fastener, single joints. P.J. Gray, C.T. McCarthy [7] developed a total bolt joints model, in the paper the load distribution, the clearance between bolt and hole , tightening torque, friction, secondary bending and the third bending can be simulated for the influence to the joints performance. The comparison between 3D FEA results and experimental results show that the model has enough accuracy and high efficiency, it can save time by 97% than 3D finite element. Osama K[8] presents a numerical procedure for the analysis of riveted splice joints, taking into account the effect of the secondary bending and plates/rivet interaction. The joint is idealized by two separate layers that are linked by beam connectors with variable circular cross-sections. Rotational spring elements are used to partially restrain the rivet heads in the plane. Gap elements are used to simulate the in-plane load transfer between the rivets and spliced plates.

5 Experimental research of secondary bending

The majority of previous investigations have been researched by means of experiment. M.A. McCarthy[5] used strain gauges to measure the strains on both sides of the plate, then calculate secondary bending by formula (1). Johan[9] used digital speckle photography to measure the lateral displacement caused by secondary bending, then analyze secondary bending quantitative. Osama[8] used photo-elastic test method to measure the strain caused by secondary bending, and made the comparison between the experiment results and FEA results.

6 Some future research direction

It is significant to explore the theory of secondary bending, it can enhance people awareness of mechanical joints and the understanding of secondary bending level.

From what have been discussed above, 3D finite element analysis mode and the model of single-lap joint by beam and shell element can analyze secondary bending in mechanical joints, but it only applied to the single-lap joints. In fact the actual structure sometimes are not the typical problems caused by secondary bending, there may be secondary bending caused by other kind of structure. As a result, the analysis method deserve further research.

Further development of high efficiency, high precision analysis of complex mechanical joints of numerical simulation methods is also very meaningful.

References

1. Segerfröjd G, Blom AF. Fatigue behavior of mechanical joints: a state-of-the-art overview. In: Proceedings of the seventh international fatigue congress; 1999.
2. Jarfall L. Shear loaded fastener installations. Int J Vehicle Des 1986;7: 337–80.
3. Schijve J. Some elementary calculations on secondary bending in simple lap joints. National Aerospace Laboratory, NLR, Amsterdam, Technical Report 72036; 1972.
4. Hartman A, Schijve J. The effect of secondary bending on the fatigue strength of 2024-T3. National Aerospace Laboratory, NLR, Amsterdam, Technical Report 69116; 1969.
5. M.A. McCarthy, C.T. McCarthy, V.P. Lawlor, W.F. Stanley. Three-dimensional finite element analysis of single-bolt, single-lap composite bolted joints: part I—model development and validation. Composite Structures 71 (2005) 140–158.
6. Cai Tianshu. Analysis of composites bolted joints and study of secondary bending effect. Master's Thesis of Wuhan University of Technology，2010.5.
7. P.J. Gray, C.T. McCarthy. A global bolted joint model for finite element analysis of load distributions in multi-bolt composite joints. Composites: Part B 41 (2010) 317–325.
8. Osama K. Bedair, Graeme F. Eastaugh, A numerical model for analysis of riveted splice joints accounting for secondary bending and plates/rivet interaction. Thin-Walled Structures 45(2007) 251-258.
9. Johan Ekh, Joakin Schön, L.Gunnar Melin, Secondary bending in multi fastener,composite-to-aluminium single-bolt, single-lap composite bolted joints. Composites: Part B 36(2005) 195-208.