Load distributions analysis of muti-pin composite joints: single-lap

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Abstract. In this paper, finite element model of muti-pin composite joint is established. Composite laminate of joint is treated as one whole plate. Matlab program is adopted to calculate equivalent material properties of composite laminate. Load distributions of single-lap composite joint are investigated, and simulation results show excellent agreement with experiments. Compared with FE model whose composite laminate material properties are given layer by layer, new FE model not only ensured calculation accuracy but also reduced model building time.

1. Introduction

With wide application of composites, composite components are usually fasted to other structural components by mechanical means. The current investigation [1-3] shows that failure of single-bolt, single-lap composite joint firstly occurs at the maximum stress point. But in practical application, composite laminates are fastened by muti-pin/bolt, and load distribution of pin usually is different. Large load distribution difference results in reduction of joint efficiencies [4]. So load distribution investigation of muti-pin composite joint is quite important.

Three-dimensional finite element analysis is rather time-consuming and simpler method compared with the spring-based method. A simplified method for determining the effects of bolt-hole clearance on the load distribution in composite multi-bolt joints is presented in literature [5]. The method is validated against three-dimensional finite element models.

In this paper, a new FE model is established for load distribution investigation of muti-pin composite joint. In FE model, composite laminate is treated as one whole plate whose equivalent engineering material properties including modulus and Poisson's ratio are calculated by Matlab program developed by author. Matlab program is verified by experiments in literature [6].

To test and verify the new FE model, load distributions of single-lap and multi-bolt composite joints are investigated. At the same time FE model whose composite laminate material properties are given layer by layer is also created. Simulation results of two FE models and experimental results are compared with each other.

2. Equivalent material properties of laminates

A new FE model is developed in this paper, composite laminate in FE model is treated as one whole plate. Equivalent material properties of laminate are calculated by Matlab program according to equations in literature [7].

To verify program of equivalent material properties, a numerical example is chosen in literature [4]. In numerical example the composite laminate is manufactured from HTA/6376, a high-strength carbon fiber–epoxy material currently used in primary structures in the European aircraft industry. The unidirectional stiffness properties are shown in table 1. Stacking sequence of laminate is [45° /0° /-45° /90°]$_{5s}$. Equivalent material properties of laminate are shown in table 2.

Table 1. Unidirectional stiffness properties for HTA/6376.

E_{11} (GPa)	E_{22} (GPa)	E_{22} (GPa)	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)	υ_{12}	υ_{13}	υ_{23}
140	10	10	5.2	5.2	3.9	0.3	0.3	0.5

Table 2. Comparison of equivalent material properties of laminates.

Equivalent material properties	E_x (GPa)	E_y (GPa)	E_z (GPa)	G_{xy} (GPa)	G_{xz} (GPa)	G_{yz} (GPa)	υ_{xy}	υ_{xz}	υ_{yz}
Reference value	54.25	54.25	12.59	20.72	4.55	4.55	0.309	0.332	0.332
Matlab	54.249	54.249	12.587	20.722	4.550	4.550	0.309	0.3326	0.3326
Error (%)	0.002	0.002	0.024	0.010	0.000	0.000	0.000	0.181	0.181

Table 2 indicates that the error of equivalent material engineering constants calculated by Matlab program is quite small, so that the program can be used to calculate the material properties of three-dimensional laminate.

3. Numerical study

In this section, load distributions of muti-bolt composite joints are investigated by equivalent material properties (EMP) FE model. Simulation results are compared with experiments in literature [8].

### 3.1. Geometry, FE model and boundary condition
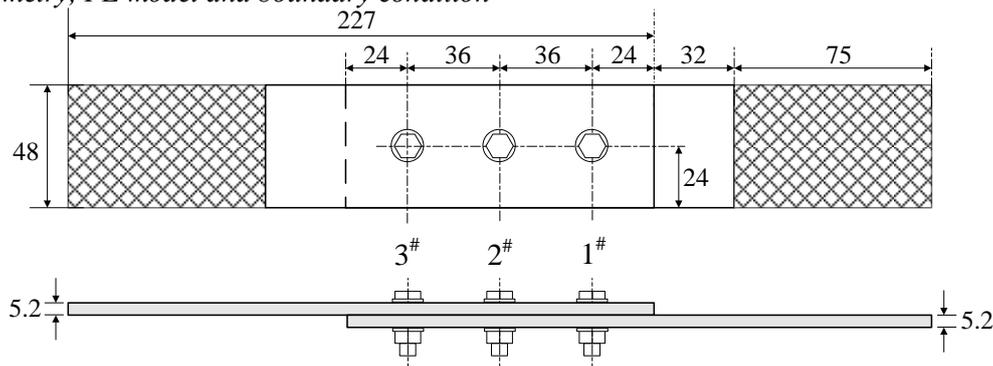
Figure 1. Joint configurations with three pins (mm): single-lap.

As shown in figure 1, the joint has three bolts and all the bolts are in single-column. Geometric parameters can be seen in figure 1. Diameter of bolt is 8mm. Composite laminates have stacking sequences [45° /0° /-45° /90°]$_{ns}$, thickness of each ply is 0.13mm. Unidirectional stiffness properties are shown in table 1. By using Matlab program, equivalent material properties of laminates can be obtained. The titanium bolt was modeled with isotropic material properties, with material constant E_x=110GPa, υ_b=0.29.
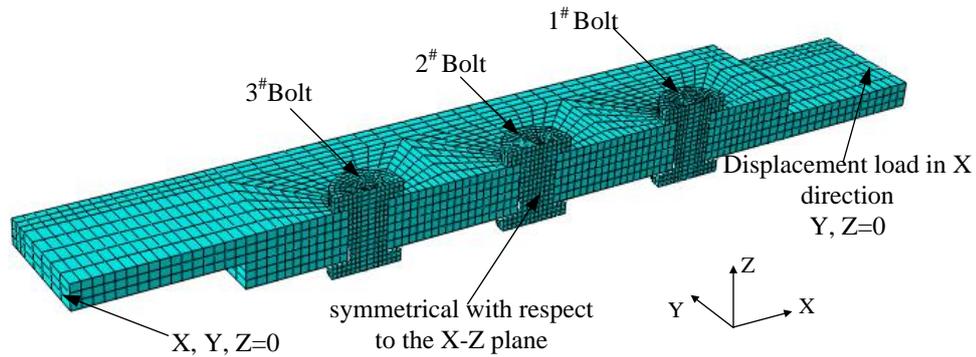
Figure 2. Mesh of FE model and boundary conditions: single-lap.

According to geometric parameters of joints, the FE model is established in ABAQUS shown in figure 2. In this model, bolt and washer are simplified as one component. Bolt torque is 0.5Nm. To compare with experiments in literature [8], Bolt–hole clearances in FE model are 0. The laminates are modeled using three-dimensional solid elements with reduced integration which is C3D8R in ABAQUS. Since single-lap joint is symmetrical about X-Z plane, only one half of joint is modeled. One end of joint is fixed, and displacement load in X direction is carried out on the other end of joint.

3.2. Model validation
FE simulation stress contour by EMP method is shown in figure 3.

To compare 3D FE method and EMP method, two FE models are established, and simulation results and experimental results [8] of load distribution are shown in figure 4. Simulation results show an excellent agreement with experiments.

As shown in figure 3, stress distributions of bolts are quite different, which can be seen from figure 4, too. For example, maximum bolt loads of bolt 1 and 3 in single-lap joint are 4.6KN and 5.5KN.
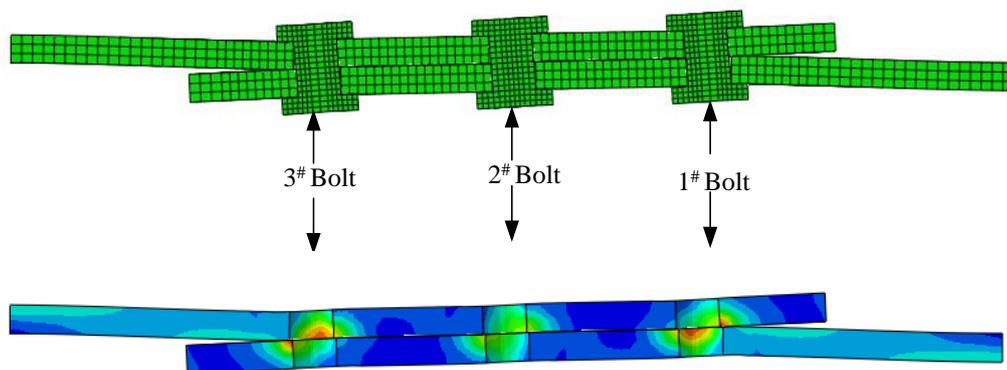

**Figure 3.** Stress contour of single-lap joint.
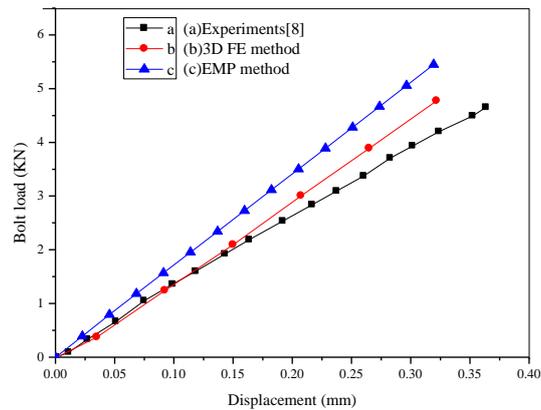
Bolt 1
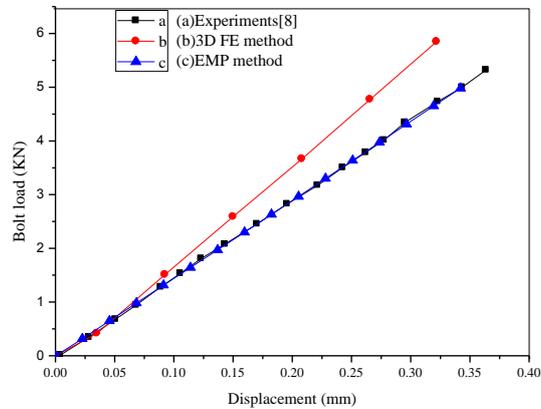
Bolt 2
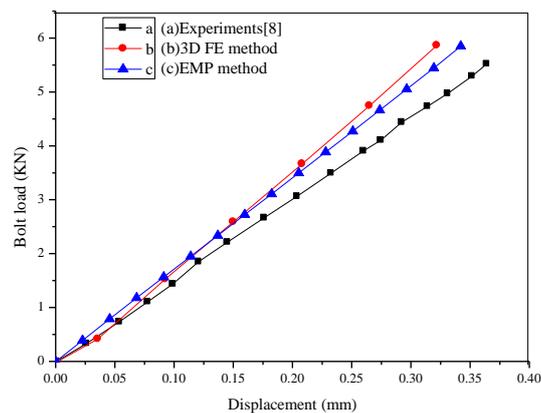
Bolt 3

Single-lap joint

Figure 4. Load distribution comparison of experiments, 3D FE method and EMP method
(a)   Experiments[8] (b) 3D FE method (c) EMP method.

4. Discussion

Composite laminates are modeled layer by layer in traditional FE method. In this paper, composite laminates are modeled as one whole plate. Equivalent material properties of laminates are calculated by Matlab program which is verified by experiments. Error of Matlab program is quite small.

Based on EMP method, FE model of single-lap is established. Simulation results have an excellent agreement with experiments. Error of simulation result is caused by simplification of bolt and washer, which are simplified as one whole bolt. But the error is small, and the accuracy is good enough. Compared with 3D FE model, calculation accuracy based on EMP method is higher. Meanwhile, since laminate is treated as one whole plate, complication of model building is decreased greatly.

5. Conclusions

In this paper, a new FE model for muti-pin composite joint is developed. In FE model, composite laminate is simplified as one whole plate whose equivalent properties are calculated by Matlab written by author.

From the experimental results and finite element analysis, it can be concluded that:

EMP FE model agrees with the experimental observations quantitatively. Compared with 3D FE model, since composite laminates are treated as one plate, model building time decreases obviously. EMP FE model is a rather time-consuming and simpler method for load distribution investigation.

References

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