INFLUENCE OF DIFFERENT STRUCTURAL PARAMETERS ON THE MECHANICAL PROPERTIES OF COMPOSITE THIN-WALLED STRUCTURE

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ABSTRACT

A complex structure and/or joint may increase the strength of composite thin-walled structure, but may also increase the structural mass and complexity. Thus a good understanding of the influence of different structures and joints on the mechanical properties is necessary for the structural optimisations. The basic mechanical parameters of C/SiC composite laminate were obtained from the 'cell model' based on the microscopic observations and were then used to establish the simplified macroscopic structural Finite Element (FE) models. Two types of typical thin-walled composite structures, i.e. composite plate and composite stiffened plate, and two types of typical thin-walled composite joint structures, i.e. rivets and bolts, were studied in this paper. For each type, the FE models with different key parameters were established and thus gave the relations between the mechanical properties and the parametric variables. The key parameters affecting the mechanical property and their influences on the mechanical property have been revealed, a surrogate model taking these key parameters into account is being established using response surface method for the structural optimizations.

1 INTRODUCTION

Thin-walled structures of composite material are being used in the advanced flight vehicles. These structures will suffer severe thermo-mechanical loadings during the flight [1,2]. The structures as well as the joints of composite thin-walled structure affect the mechanical properties [3,4]. A complex structure and/or joint may increase the strength of structures, but may also make the flight vehicles more heavy and the manufacture process more complex. Thus the balance between the strength of structures and the mass and complexity must be taken into account. A good understanding of the influence of different structures and joints on the mechanical properties of composite thin-walled structure could help find out the key parameters that should be taken into account as well as the parameters that could be neglected for the structural design, and hence provide necessary support for the general design of flight vehicles. In order to achieve the aforementioned purpose, the mechanical properties of composite thin-walled structures with different parameters including various structures and joints were studied in this paper.

2 ESTABLISHMENT OF FINITE ELEMENT MODEL

C/SiC plain weave composite was studied in this paper. It is difficult to take the mesoscopic woven structures into account in the macroscopic finite element model due to the extreme huge calculations which exceeds the capability of some commonly used workstation or consumes too much time. Acquiring the basic mechanical parameters of composite material from the mesoscopic model, i.e. cell model [5], and establishing the macroscopic model by using the acquired mechanical properties is a commonly used strategy to simplify the macroscopic model and thus reduce calculations time.

The cell model was established according to the microscopic observations on the studied C/SiC composite material. The geometry model of a single carbon fibre was created using CATIA software. This model was then used to establish the geometry of carbon fibres in a cell model (Figure 1.a) by using a series of geometric operations in Ansys software. The bounding volume was filled with matrix to obtain a complete cell model (Figure 1.b). In view of the symmetry of such a cell model, a quarter of the original cell model (Figure 1.c) was used for the mechanical simulation (Figures 1.d and e) performed with Ansys software. The mechanical parameters (Table 1) obtained from cell model were then used to define the mechanical properties of laminate for the macroscopic composite model. The material is defined as orthotropic and homogeneous for the macroscopic model. The authors may refer to [6] for the details of the model establishment.

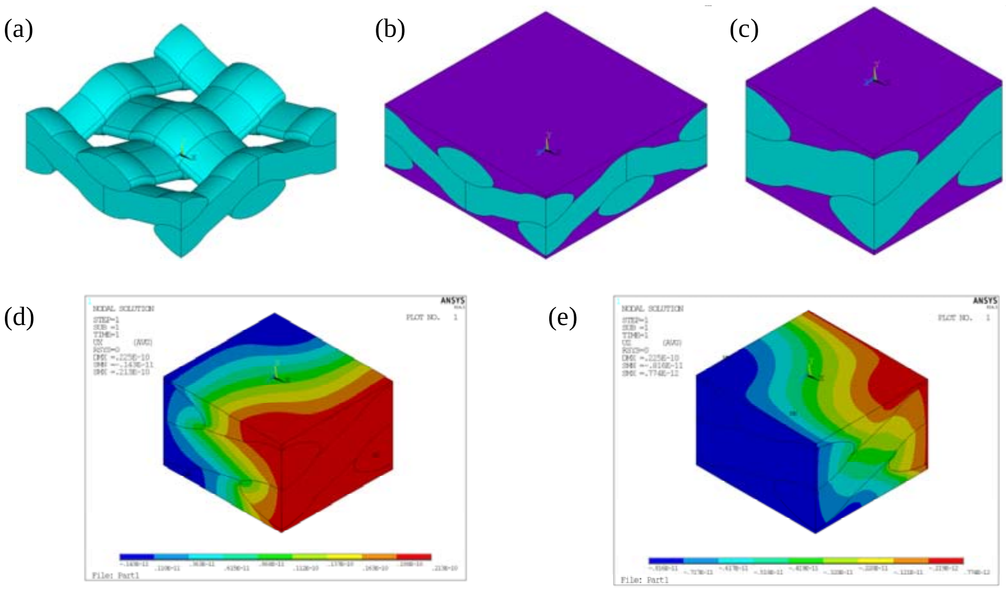

Figure 1: (a) Geometry of carbon fiber in a cell model; (b) a complete cell model; (c) a quarter of the original cell model; displacement fields of the quarter cell model in the direction of (d) X and (e) Y.

Parameters		Values
E_x	[GPa]	107.06
E_y	[GPa]	18.80
E_x	[GPa]	107.06
G_{xz}	[GPa]	56.48
G_{yz}	[GPa]	31.60
G_{xy}	[GPa]	31.60

Table 1: Basic mechanical parameters of laminate

3 INFLUENCE OF STRUCTURES ON MECHANICAL PROPERTIES

Two typical composite thin-walled structures, i.e. composite plate and composite stiffened plate, were studied in this paper. For each type of thin-walled structure, a standard rectangle composite plate model was established. The four edges of plate were clamped and a unit pressure loading was applied on the surface of the plate in order to simulate the service loadings. The rectangle plate models with different parameters were then established for FE simulation to compare the mechanical property with the standard model. The maximum Von Mises stress of the plate was used to characterize the mechanical property: a lower maximum Von Mises stress emphasizes a higher strength to resist the service loadings.

3.1 Composite plate

The influences of two key parameters, i.e. plate thickness and insufficient deposition, on the mechanical property, i.e. the maximum Von Mises stress (Figure 2.a), were studied.

With the increasing of plate thickness, the maximum Von Mises stress decreases (Figure 2.b). Thus increasing the plate thickness is beneficial to the improvement of mechanical property, although the mass of structures increases with the increasing of plate thickness.

In this paper, the elastic modulus of the laminate with insufficient deposition is defined as 50% of the standard elastic modulus of laminate in Table 1. The maximum Von Mises stress of composite plates with different percentages of insufficient deposition laminates are compared in Figure 2.c. The increasing of the maximum Von Mises with the increasing of insufficient deposition implies that the insufficient deposition reduces the strength to resist the service loadings.

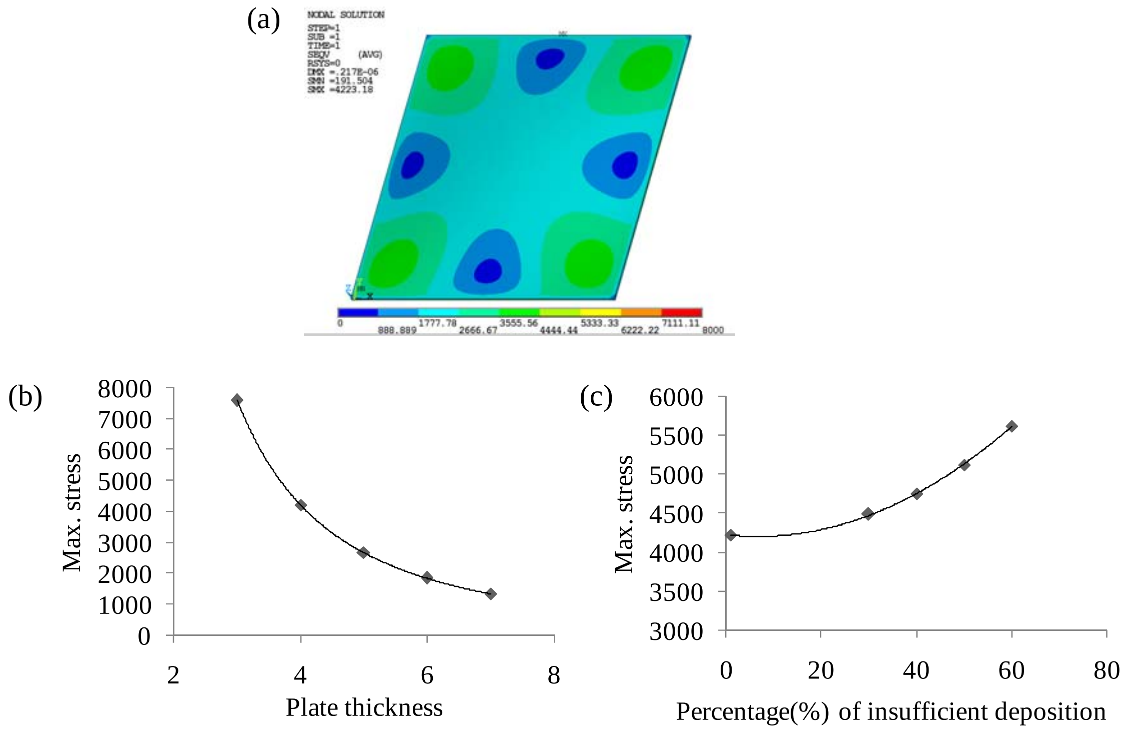

Figure 2: (a) A standard Von Mises stress field of composite plate model; the Von Mises stress as functions of (b) plate thickness and (c) insufficient deposition.

3.2 Composite stiffened plate

A standard composite stiffened plate model was established (Figure 3.a). The maximum Von Mises stress (Figure 3.b) is located at the top of the stiffening diaphragm rather than at the plate area. It implies that the stiffening diaphragm is useful to increase the resistance to the surface loading.

The influences of four key parameters, i.e. the distance between stiffening diaphragms (spate distance, 'SD' in Figure 3.a), layer number, insufficient deposition and ply orientation angles, on the mechanical properties, i.e. the maximum Von Mises stress, were studied (Figures 3.c-f).

With the increasing of separate distance (Figure 3.c) and the insufficient deposition (Figure 3.d), the maximum Von Mises stress increases linearly. Thus increasing the separate distance and the insufficient deposition lower the mechanical property of composite stiffened plate. While with the increasing of layer number (Figure 3.e), the maximum Von Mises stress decreases. Thus increasing the layer number improves the mechanical property of composite stiffened plate although it makes the structures heavier. The maximum Von Mises stress almost have no changes in the case of three typical different ply orientation angels, i.e. 0/45, 0/90, 0/30/60 (Figure 3.f), thus the ply orientation angles have no influence on the mechanical property in the present study.

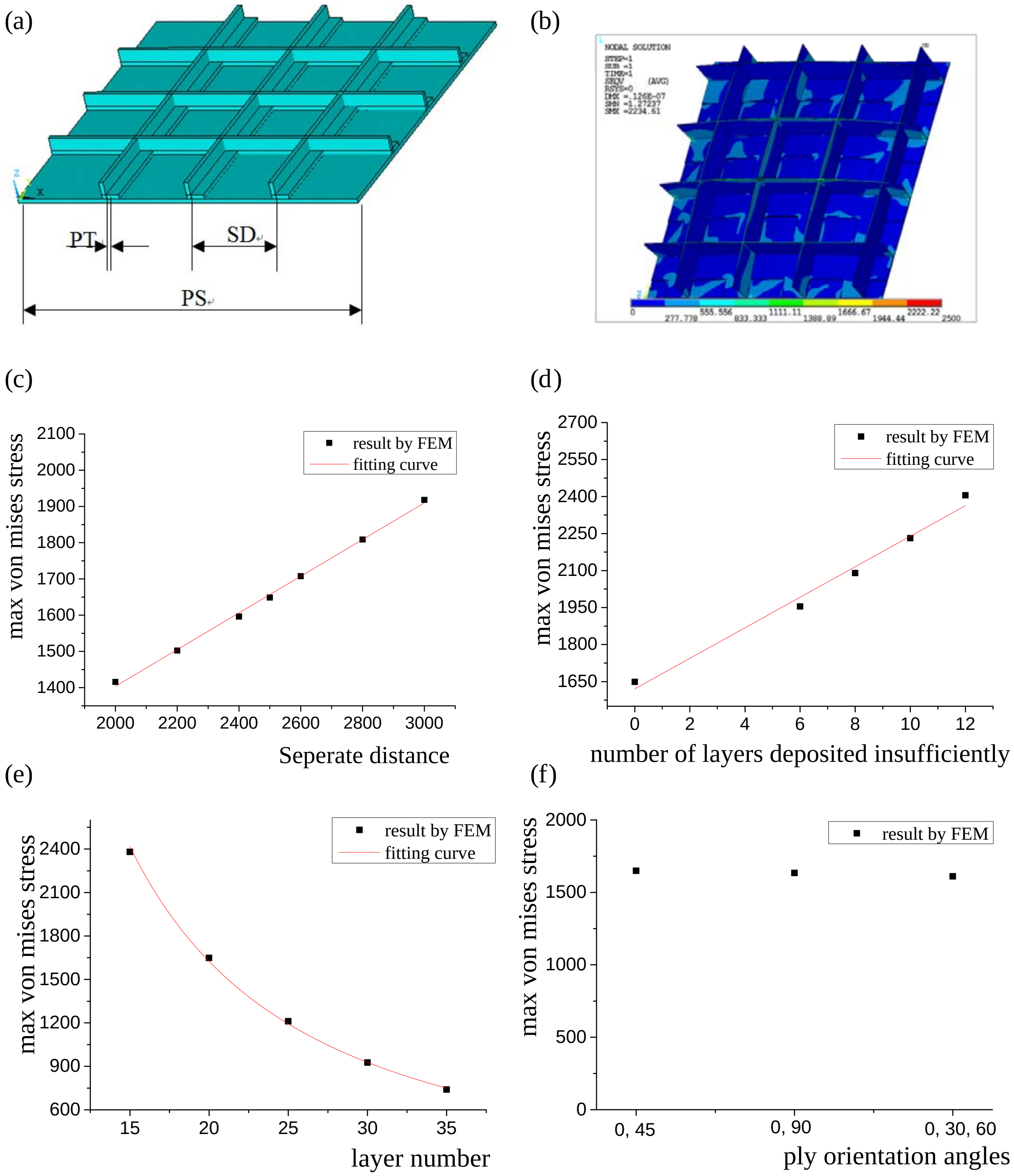

Figure 3: (a) The standard composite stiffened plate model; (b) the Von Mises stress field of the standard composite stiffened plate model; the maximum Von Mises stress as functions of (c) separate distance, (d) number of insufficiently deposited layers, (e) layer number, and (f) ply orientation angles.

4 INFLUENCE OF JOINTS ON MECHANICAL PROPERTIES

Two typical joints for composite thin-walled structure, i.e. bolts and rivets, were studied respectively. Rivets could connect the plates without additional weight while bolts are often used under tangential load in which case the rivets are easy to fall off.

4.1 Rivet

A standard composite joint structure model with rivets was established (Figure 4.a). Two rectangle plates (100×20×5 mm) were connected with several rivets. The influences of two key parameters, i.e.

the number of rivets and the diameter of rivet, on the maximum Von Mises stress, were studied. Two different sizes of rivets, i.e. 2 mm and 4 mm, were used separately. In each case, different numbers (4-12) of rivets were taken into account. Two types of loadings were applied on the plate separately, i.e. a) under a unit surface pressure (along the axis of rivet) (Figure 4.b) and b) under a unit tangential load (Figure 4.c). The FE simulation results show that: a) the maximum Von Mises stress under surface loading is much higher than that under tangential load (Figures 4.d and e), thus the former loading case is focused in the following analysis; b) the maximum Von Mises stress is located on the border between rivets and rectangle plate.

Figure 4.f shows the relations between the maximum Von Mises stress and the number of rivets in the case of two different rivet diameters. When the number of rivets is below than eight, the maximum Von Mises stress decreases with the increasing of rivet number and/or rivet diameter. However, when the number of rivets exceeds nine, the maximum Von Mises stress have few changes with the increasing of rivet number. It implies that a suitable number of rivets should be adopted in the engineering applications: if the number is not enough, the stress will be higher and thus reduce the mechanical property; if too many rivets are applied, it will not be useful for the improvement of mechanical property but increase the complexity of structures.

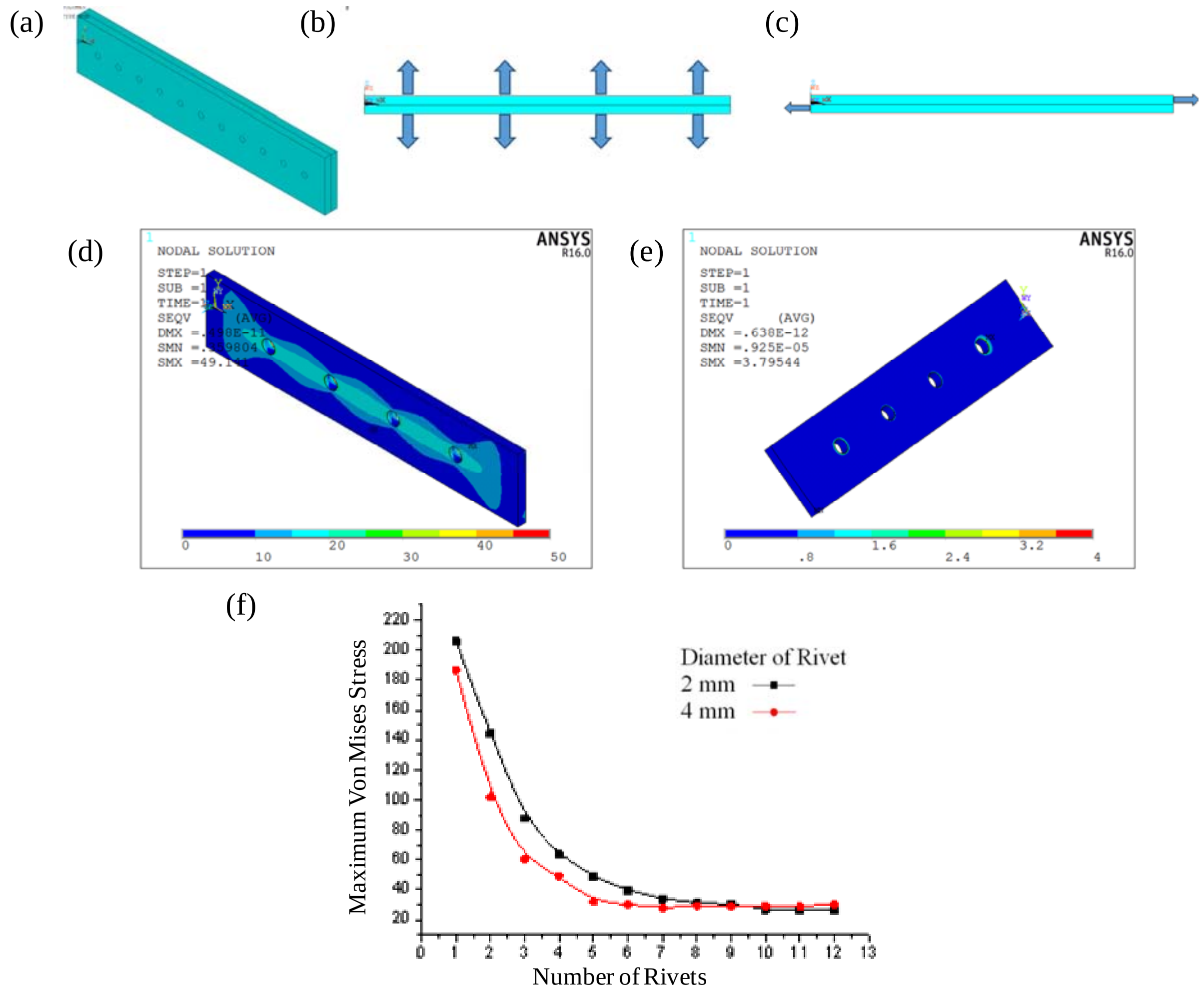

Figure 4: (a) The standard joint structure model with rivets; two loading cases for the structure: (b) under a unit surface pressure (along the axis of rivet) and (c) under a unit tangential load; Von Mises stress fields under (d) surface pressure and (e) tangential load; (f) the maximum Von Mises stress under a unit surface pressure as functions of number of rivets in the case of different diameters.

4.2 Bolt

Similar with the composite joint structure model with rivets in 4.1, the composite joint structure model with bolts compose two rectangle plates (100×20×5 mm) connected by bolt. Standard rivets (pitch of screw thread = 1.25 mm) with two different diameters, i.e. 8 mm (M8) and 10 mm (M10), were used separately. The joint with a single rivet was established at first (Figure 5.a). Two typical loadings, i.e. surface pressure (along the axis of bolt) and tangential load, were applied respectively. The stress field (Figure 5.b) shows that the maximum Von Mises stress located on the border between the bolt and plate rather than at the thread tooth. Thus the thread tooth is not taken into account in the following analysis in order to simplify the model.

The joint structure with different number (1~3) of bolts were tested under two typical loadings, i.e. a unit tangential load (Figure 5.c) and a unit surface pressure (along the axis of bolt) (Figure 5.d). Figures 5.e and f give the relations between the maximum Von Mises stress and the number of bolts under different loadings. The maximum Von Mises stress under surface pressure (Figure 5.f) is much higher than that under tangential load (Figure 5.e). A larger size of bolts or a larger number of bolts decreases the maximum Von Mises stress in both loading cases however it will make the structure much heavier and more complex.

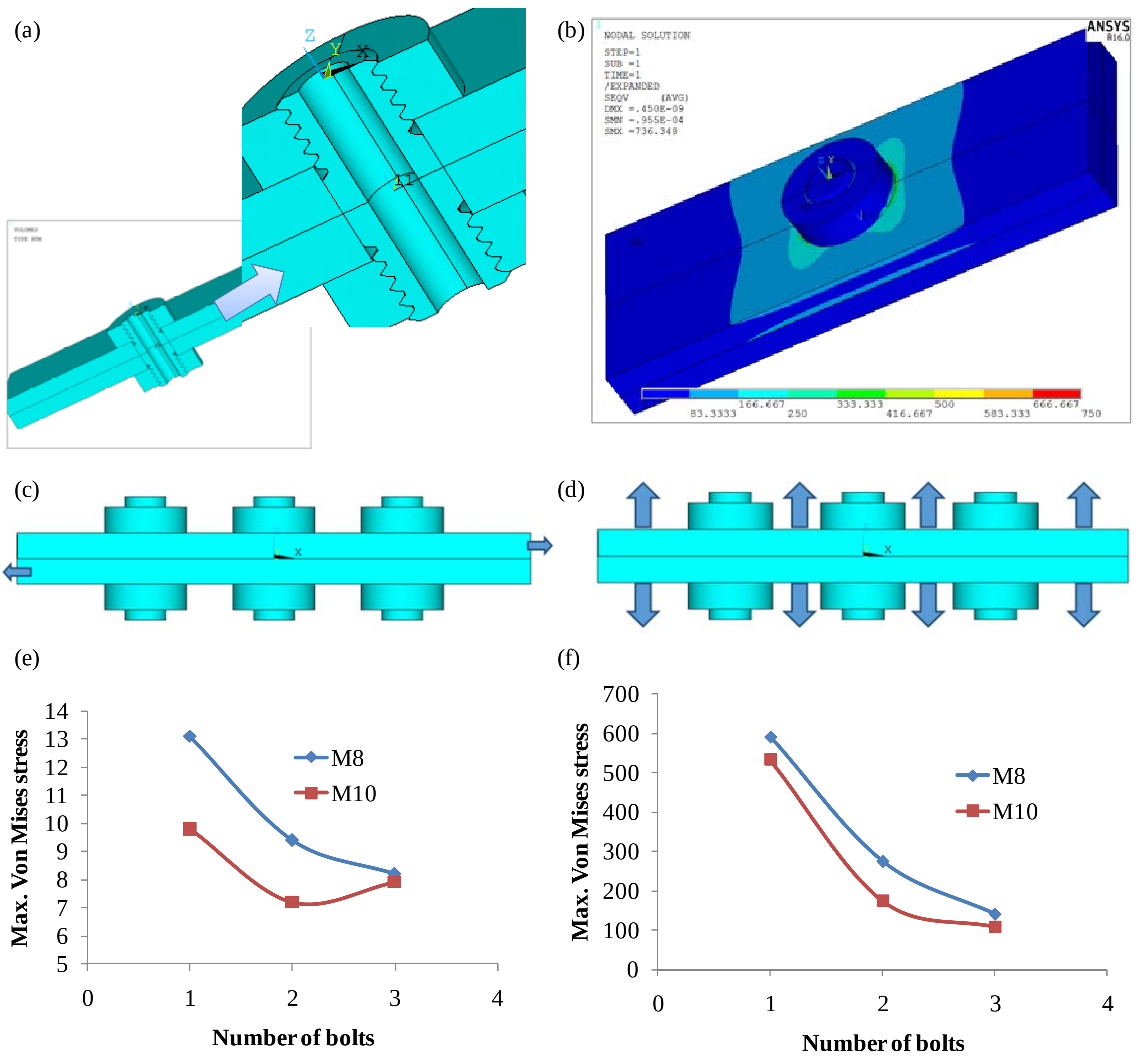

Figure 5: (a) A single bolt model with thread tooth; (b) the Von Mises stress field of (a); two loading cases for the bolt structure: (c) under a unit tangential load and (d) under a unit surface pressure (along the axis of bolt); the maximum Von Mises stress as functions of bolt number in the case of different diameters under (e) a unit tangential load and (f) a unit surface pressure.

5 CONCLUSIONS

In order to study the influence of different parameters on the mechanical properties of composite thin-walled structure, the simplified macroscopic FE models with different key parameters were established. The basic mechanical parameters of laminate in the macroscopic model were obtained from the 'cell model' based on the microscopic observations.

1) For composite plate, increasing the thickness of plate improves the mechanical property although the mass of plate increases; while the insufficient deposition is harmful for the mechanical property.
2) For composite stiffened plate, increasing the layer number, decreasing the distance between stiffening diaphragms and/or the number of insufficient deposition are beneficial for the mechanical property, while the ply orientation angle almost has no influence on the mechanical property.
3) For the joint structure with rivet, there exist a key number of rivets: below which increasing the number of rivets improves the mechanical property of structure, while above which the increasing the number of rivets has few influence on the mechanical property. In additional, a larger rivet decreases the maximum stress of structures in the studied case.
4) For the joint structure with bolt, the maximum Von Mises stress located on the border between the bolt and plate rather than at the thread tooth. A larger size of bolts or a larger number of bolts decreases the maximum stress however it will make the structure much heavier and more complex.

The key parameters affecting the mechanical property and their influences on the mechanical property have been found, a surrogate model [7] taking these key parameters into account is being established using response surface method for the structural optimizations.

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