Finite element analysis of space truss sandwich structure

Xu Cui\textsuperscript{1,a}, Shan Jin\textsuperscript{2,b}, Changlin Zhao \textsuperscript{3,e*}

\textsuperscript{1} Shenyang Aerospace University, ShenYang, China
\textsuperscript{2} Shenyang Aerospace University, ShenYang, China
\textsuperscript{3} Shenyang Aerospace University, ShenYang, China
\textsuperscript{a}email: 13644047111@163.com, \textsuperscript{b}email: 15804058679@163.com,
\textsuperscript{e*}Corresponding author: \textsuperscript{e}email: 1872757155@qq.com

Abstract: In this paper, three kinds of carbon fiber reinforced epoxy resin (CF / EP) composites, including square, kagome and triangular grid sandwich structures, are analyzed by using ANSYS finite element analysis software. Through the comparison of the analysis results, the surface yield and core failure are the main failure mechanisms in three kinds of three-dimensional finite element models. The average bending loads of square, kagome and triangular grid sandwich structures are 18.0\%, 19.7\% and 24.6\%, respectively. Therefore, the finite element analysis shows that more failures will occur due to the local collapse of the indenter.

1. Introduction
In recent years, the new composite sandwich panel structure appeared in the world. Compared with other structures, sandwich structure has superior bending stiffness / strength \cite{1}, high stiffness and high strength weight ratio \cite{2-4}. Therefore, sandwich structures are more and more widely used as lightweight materials in aerospace engineering.

There are a lot of literatures about finite element analysis of sandwich structures. Liu et al. \cite{5} analyzed and modeled the sandwich beams with pin reinforcement core and truss core under bending force. Zhu \cite{6} analyzed and studied the overall stability of honeycomb sandwich structure composite based on NASTRAN. Zhang, Liu et al. \cite{7} analyzed the grid structure with the finite element method, and carried out the static analysis and natural vibration analysis of three types of roof grid structures (square pyramid grid, two-way orthogonal orthogonal space grid and positive space evacuated quadrangular pyramid grid) under the action of uniform load, local load (half span uniform load), and the stability analysis of three types of vertical load-bearing grid wall. Compared with the results of finite element method, it is shown that the accuracy of sandwich plate method is relatively high as a simplified calculation method. Based on the mechanical theory of composite materials, Yu, Zhao et al. \cite{8} took the sandwich structure as a homogeneous single material plate structure for finite element analysis by obtaining the equivalent material characteristic parameters of composite sandwich structure. Through comparison, it is concluded that the finite element analysis of composite sandwich structure is more economical, effective and feasible.
2. Results & Discussion

2.1. Finite element analysis

Based on the finite element analysis software ANSYS, the finite element model of sandwich structure was established. The following analysis focuses on the sandwich structure. The finite element analysis method was used to characterize the principal directional stress distribution of materials in sandwich structures. The sandwich part consists of a CF / EP composite core (length: 320mm, width: 104mm) and two skins with a thickness of 1mm, and the wall thickness in the core is 3mm. The finite element model is shown in Fig. 1(a). The core and two skins are glued together. It is assumed that there was a perfect union between the skin and core of the mesh. A symmetrical constraint was applied to the bottom of the support, and a pressure P was applied to the indenter. As shown in Fig. 1(b), the 3D eight-node solid element SOLIDE 46 is used as a mesh for CF/EP composite model. The support is fixed and the head loading is quasi-static force loading. The interface between the skin and the core is an ideal interface, regardless of interface debonded. The contact between the indenter and the post and the panel is a face-to-face contact.

In this study, the Tsai-Hill failure criteria [9,10], as shown in Equation (1), was used to characterize the damage area of the sandwich structure. Composites will be failed if $\sigma_1$, $\sigma_2$ or $\tau_{12}$ satisfies Equation (1).

$$
\frac{(\sigma_1/X_t)^2 + (\sigma_2/Y_t)^2 - (\sigma_1\sigma_2/\tau_{12})^2}{X_t/Y_t} = 1
$$

$\sigma_1$ and $\sigma_2$ are the on-axis stresses in the longitudinal and transverse directions; $\tau_{12}$ is the on-axis in-plane shear stress; $X_t$ is the longitudinal tensile stress; $Y_t$ is the transverse direction; and $S$ is the in-plane shear strength.

The stress distributions in the main direction of the fully sandwich structure when subjected to bending loads of 9200 N, 10000 N, and 11000N are shown in Fig 2, Fig 3, and Fig 4, respectively, and the failure factors and stress distributions are shown.

![Fig. 1 FEM model of sandwich parts (a) Sandwich structure model; (b) FEM mesh model](image-url)
Fig. 2 Full sandwich structure with square core stress distribution: (a) 1\textsuperscript{st} principal stress; (b) 2\textsuperscript{nd} principal stress; (c) 3\textsuperscript{rd} principal stress

Fig. 3 Full sandwich structure with Kagome core stress distribution: (a) 1\textsuperscript{st} principal stress; (b) 2\textsuperscript{nd} principal stress; (c) 3\textsuperscript{rd} principal stress
Fig. 4 Full sandwich structure with triangular core stress distribution: (a) 1st principal stress; (b) 2nd principal stress; (c) 3rd principal stress

It can be noted that full sandwich structure’s maximum stress 104 MPa, 171 MPa and 102 MPa, respectively in accordance to the distribution of the 1st principal stresses. It appears a common phenomenon from the stress distribution of three different lattice grids cores shown in Fig.5, 6 and 7. Results indicate that stress concentration is located at the loading region as well as supporting region (in bottom skin). We also know that top skin commonly suffers from compressive stress. In contrast, the bottom skin is subjected to tensile stress during bending loads. There is also a tendency of failures to occur near the indenter, which indicates that the indenter makes the top skin more susceptible to stress concentrations developed in the top surface region.
Fig. 5 Square core stress distribution: (a) 1\textsuperscript{st} principal stress; (b) 2\textsuperscript{nd} principal stress; (c) 3\textsuperscript{rd} principal stress

Fig. 6 Kagome core stress distribution: (a) 1\textsuperscript{st} principal stress; (b) 2\textsuperscript{nd} principal stress; (c) 3\textsuperscript{rd} principal stress
The full sandwich structure was subject to 9200 N of stress with the square grid core receiving up to 90.4 MPa which is higher than the other structures in Fig. 5(a). The Top skin beneath the indenter was bent more severe than the other specimens. The 1st principal stress concentrations also reached 69.7 MPa in many regions, located by supports and an indenter. The analytical model predicts surface yield and core failure damage as the dominant model.

From Fig. 7, it can be seen that the stress distribution of the sandwich structure under 11000 N indicates failure elements and stress distribution. Some failures shown can be used to predict that the sandwich structure starts to enter the matrix cracking deformation stage when the equivalent stresses of some elements reaches just below 11,000 N yield strength. However, no defective elements are present on bottom skin. We also find that, the number of failed elements on the top skin is much higher than those of the bottom skin. The number of core shear cracks is then followed up by several damages on the top skin as shown in Fig. 7(c), and the maximum stress at the core sandwich structure is 45.1 MPa under 11000 N. Although there are no failed elements on the bottom skin, the principal stress appears to be in the damaged area in Fig. 10(a). The number of core shear fractures appears to be followed by extensive damage to the skin. In summary, the failure mechanism on the epidermis is surface yielding, and core shear failure dominates the failure mechanism in the triangular grid core.
Fig. 8 Bottom skin in square core stress distribution: (a) 1\textsuperscript{st} principal stress; (b) 2\textsuperscript{nd} principal stress; (c) 3\textsuperscript{rd} principal stress.

Fig. 9 Bottom skin in Kagome core stress distribution: (a) 1\textsuperscript{st} principal stress; (b) 2\textsuperscript{nd} principal stress; (c) 3\textsuperscript{rd} principal stress.
As the stress concentrations develop to a certain extent, the sandwich structure will completely lose its bearing capacity and eventually collapse. Face yielding and core failure are the dominant factors in the failure mechanism of all three 3D finite element models. The results of failure element analyses are compared with experiments on the sandwich structure in three-point bending. The average bending loads are 18.0% (square grid core), 19.7% (Kagome grid core), and 24.6% (triangular grid core). Therefore, the FEA indicates that more failures occur due to the localized collapse of the indenter.

3. Conclusions
According to Tsai Hill failure criterion, the three-dimensional finite element models of three different sandwich structures are established. The finite element analysis shows that the surface yield and core shear failure play a leading role in the sandwich grid structure, and the damage times and damage times of the top skin are the important reasons for the structure failure mechanism.

Through the finite element analysis, the failure mode and failure location of the two-dimensional grid structure are obtained, and the conclusion that the triangular mandrel has the best mechanical properties in several structures is obtained, which has guiding significance for the preparation and large-scale production of sandwich structure.

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