# The Failure Behavior of Composite Honeycomb Sandwich Structure with Stringer Reinforcement and Interfacial Debonding

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## Abstract

As an efficient lightweight structure, composite honeycomb sandwich panel has been widely used in many industries. The composite honeycomb sandwich structure with stringer reinforcement is a new type of sandwich structure. This paper investigated the damage and failure behavior of composite honeycomb sandwich structure with stringer reinforcement under in-plane compression condition. Some critical damage modes and failure behavior of composite sandwich structure with stringer reinforcement were revealed. Three different kinds of debonding damage of interface between sheet and core were considered, the failure modes as well as the whole failure process were obtained by numerical simulation.

**Keywords:** Sandwich structure, Stringer reinforcement, Composite, Interfacial Debonding, Failure

## Introduction

Advanced sandwich structure is usually a large thickness of honeycomb core bonded with composite sheets. With larger in-plane stiffness and strength, the composite material faceplate is mainly used to bear the axial load, bending moment and shearing action, while the honeycomb core, subject to bending and shear load, is mainly used to maintain the stability the relative position of sheets and transfer lateral load. With the advantages of high specific stiffness and specific strength, the structure can get high flexural stiffness and compressive yield strength under the condition of low specific gravity[1].

The faceplate and core of advanced sandwich structure are anisotropic, which is a very important characteristic. Through the reasonable design of the composite faceplate or rational choose of the core structure, optimization sandwich structure can be designed and manufactured to meet the specific needs of various engineering applications[2]. The composite honeycomb sandwich structure with stringer reinforcement is a new type of sandwich structure, whose purpose is to further balance improve the axial and bending specific stiffness and specific strength of the structure, at the same time increase the reliability of the structure.

Due to the characteristics of manufacturing technology and the intrinsic properties of the materials, the debonding defect is easy to occur in the interface between the core and the sheets during service life [3]. As a result, the strength under static load will be decreased. Moreover, the failure mode of the sandwich structure will be more complicated, and the defects will seriously affect the accuracy of strength prediction. For the composite honeycomb sandwich structure with stringer reinforcement, the effect of stiffener on the failure modes of sandwich structure is worth studying.

## The equivalent of the material parameters and numerical model

There are two main simulation methods for the sandwich structure[4]. For hierarchical model, each single layer of the structure is considered respectively, and the constraints according to continuity for each interface also should be given appropriately to meet the requirements of stresses generality for adjacent layers. For the equivalent single-layer model, the sheet and core are replaced by a single-layer with certain thickness. The unified expression of displacement field is given along whole thickness direction by using the deformation theory of plate and shell. For the hierarchical

model, it has a large number of independent variables, while for the equivalent single-layer model, as the independent variables are less, it is commonly used in finite element method.
To simplify the analysis, the equivalent single-layer model is adopted. The selected aluminum honeycomb core of the sandwich structure is transformed to homogeneous orthotropic material in finite element modeling. There are a variety of equivalent ways for the elastic parameters of honeycomb core[5]. The equivalent elastic parameters of hexagonal honeycomb core proposed by Zhao Jin-Sen[6] are adopted in this paper to derivate formula and calculate the equivalent material parameters of the simplified model. The equivalent formulas are as follows:

$$\left.\begin{aligned} E_{cx} &= E_{cy} = \frac{4}{\sqrt{3}} E_s \left(1 - 3\frac{t^2}{l^2}\right)\frac{t^3}{l^3} \\ E_{cz} &= \frac{2}{\sqrt{3}} E_s \frac{t}{l} \\ G_{cxy} &= \frac{\sqrt{3}}{3} E_s \left(1 - \frac{t^2}{l^2}\right)\frac{t^3}{l^3} \\ G_{cxz} &= G_{cyz} = \frac{\sqrt{3}}{3}\left(\frac{t}{l}\right) G_s \\ \nu_{12} &= 1 - 4\frac{t^2}{l^2} \end{aligned}\right\} \tag{1}$$

Where Es and Gs are elastic parameters of the honeycomb core, l and t are wall length and wall thickness of a unit cell of the honeycomb core.

The equivalent properties of honeycomb core are given in Table 1 below.

**Tab.1 The equivalent properties of honeycomb core**

| Elastic Parameter（Gpa） | | | | | | Poisson's ratio |
|---|---|---|---|---|---|---|
| $E_1$ | $E_2$ | $E_3$ | $G_{12}$ | $G_{13}$ | $G_{23}$ | $\nu_{12}$ |
| 0.31 | 0.31 | 1003 | 0.078 | 189 | 189 | 0.99 |

The traditional composite honeycomb sandwich structure consists of two composite sheets, adhesive layer and aluminum honeycomb core. For the stringer reinforced sandwich structure discussed in this paper, two buried aluminum stiffeners are contained. The adhesive layer is simulated by cohesive element in finite element analysis.
The overall dimensions of the two kinds of sandwich structure are uniform, the length is 90 mm, the width is 50 mm, and the total thickness of 15 mm, among which, the thickness of the honeycomb core is 12 mm, the thickness of adhesive layer is 0.1mm, and both of the thickness of the upper and lower sheets are 1.4 mm. The components size meets the requirements of ASTM C364-99 standard. the upper and lower faceplates are composite laminates for the two kind of sandwich structure, whose length and width directions are defined as x and y axis, respectively. The composite laminates has a total of 10 layers, the thickness of each layer is 0.14 mm, and the stacking sequence is [0/0/45/-45/90]s . The material parameters of the composite laminates are shown in table 2. In addition, the two buried aluminium stiffeners are 90mm in length, 4mm in width, and 12mm in height. The distance from the two stiffeners to the center line of the sandwich structure is 12 mm. The material parameters of the aluminium stiffeners are shown in table 3.

**Tab.2 Properties of T300/QY8911**

| Elastic Parameter（Gpa） | | | | |
|---|---|---|---|---|
| $E_1$ | $E_2=E_3$ | $G_{12}=G_{13}$ | $G_{23}$ | $\nu_{12}$ |
| 126 | 10.7 | 4.47 | 3.57 | 0.33 |
| Strength Parameter（Mpa） | | | | |
| $X_T$ | $X_C$ | $X_T$ | $Y_C$ | $S$ |
| 1548 | 1226 | 55.5 | 218 | 89.9 |

**Tab.3 Properties of the aluminum stringer**

| Properties (units) | Young's modulus (GPa) | Poisson's ratio $\nu_{12}$ |
|---|---|---|
| Aluminum stringer | 69.5 | 0.33 |

## The failure analysis of the sandwich structure

*The linear buckling analysis*

Lanczos vector method is adopted to analyze and compare the linear buckling deformation characteristics of composite honeycomb sandwich structure without reinforcement and with stringer reinforcement, respectively. The main buckling modes of two kinds of sandwich structure are calculated, which are shown in figure 1.

In figure 1, we can see that the mainly buckling modes of the two kinds of sandwich structure are different under in-plane compression condition. global buckling instability mainly occurs to the sandwich structure without reinforcement, while partial buckling mainly occurs to the sandwich structure with stringer near the free boundary on both sides. Due to the existence of the stiffener, the buckling deformation of the honeycomb core is inhibited, and the overall stiffness of the structure is enhanced effectively. What's more, the buckling load of the sandwich structure with stringer is 525.71 KN, which is much higher than structure without reinforcement buckling load of 121.28 KN. Therefore, the stringer Reinforcement significantly improves the buckling bearing capacity of the composite honeycomb sandwich structure.

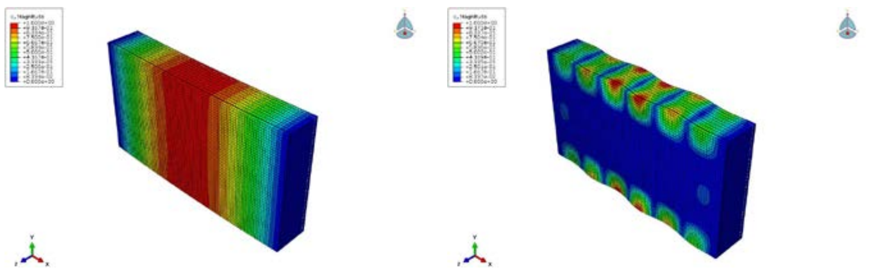

**Fig.1 The first buckling mode of the composite honeycomb sandwich structure with and without stringer reinforcement**

*The nonlinear failure analysis*

Figure 2 shows the load-displacement response of two different composite honeycomb sandwich structures under in-plane compression condition by nonlinear buckling analysis. Through observation, we know that the overall axial stiffness of the structure changed little, and axial compression stiffness approximate to linear under in-plane compression condition. After reaching limit loading points, failure damage occurs to both of the two kinds of sandwich structure, and the continue carrying capacity losts quickly. Trough comparison, we know that the limit load of the sandwich structure with stringer reinforcement is 190.03 KN, which is much higher than that of the structure without reinforcement as 87.52 KN. Therefore, the stringer Reinforcement effectively improves ultimate bearing capacity of the composite honeycomb sandwich structure. In addition, the specific strength of sandwich structure with stringer reinforcement is 1.05 times bigger than without reinforcement, which further evidences that composite honeycomb sandwich structure with stringer reinforcement has excellent structural performance.

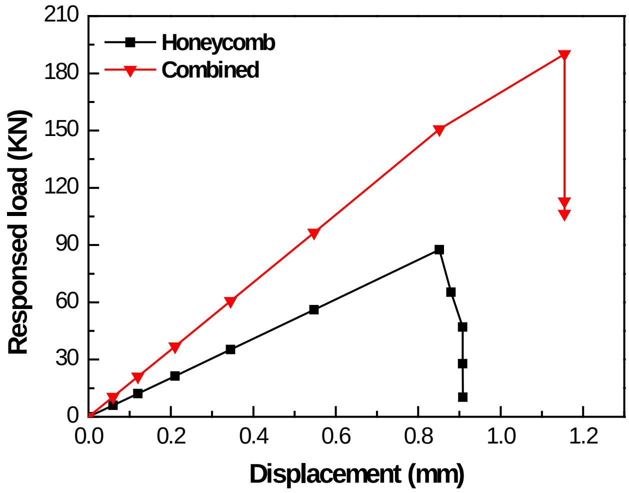


**Fig.2 The load-displacement response of two different composite honeycomb sandwich structures**

Comparing the results of nonlinear failure analysis and the linear buckling analysis respectively, we know that the linear buckling load is greater than the limit load for both of the two kinds of sandwich structure. Accordingly, the overall stability of composite honeycomb sandwich structures under in-plane compression condition is high, and the stiffness of the structure is further enhanced through stringer reinforcement. Therefore, the buckling failure is not the main failure modes of the structure, strength and damage are the main factors dominate the failure modes of sandwich plate in general.

*The failure analysis of the sandwich structure with through interfacial debonding*

Considering a through-the-width sheet/core interfacial debonding in middle area of the reinforced composite honeycomb sandwich structure, and the length of debonding is 30mm. Figure 3 shows the load-displacement response of reinforced sandwich structure with a through-the-width interfacial debonding by nonlinear analysis. Analysis shows that, the relationship between load and axial displacement keeps linear, and will lose load carrying capacity quickly when reaches the limit load. The limit load of the sandwich structure with stringer reinforcement and through interfacial debonding is 97.72KN, which is much lower than that of the perfect reinforced sandwich structure as 190.03 KN. Therefore, the through-the-width interfacial debonding reduces ultimate bearing capacity of the sandwich structure.

Figure 4 shows the out-plane displacement of the sandwich structure with stringer reinforcement under the limit load. The result shows that local buckling occurred in the debonding area, and lead to the final broken. Also, because the stiffener improves the overall stiffness, local buckling only occurs at the debonded sheet near both sides of free boundary.

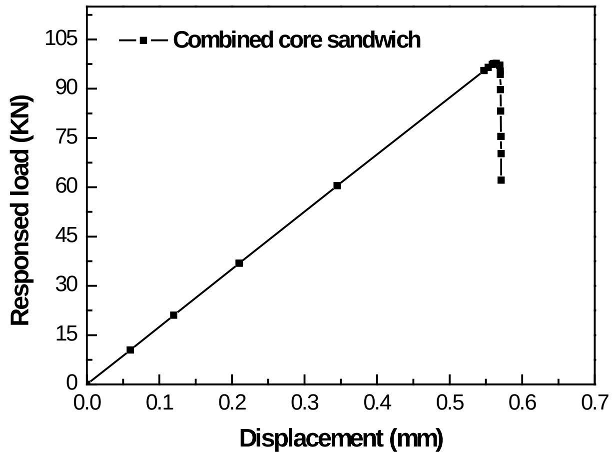


**Fig.3 The load-displacement response of sandwich structure with stringer reinforcement and through-the-width interfacial debonding**

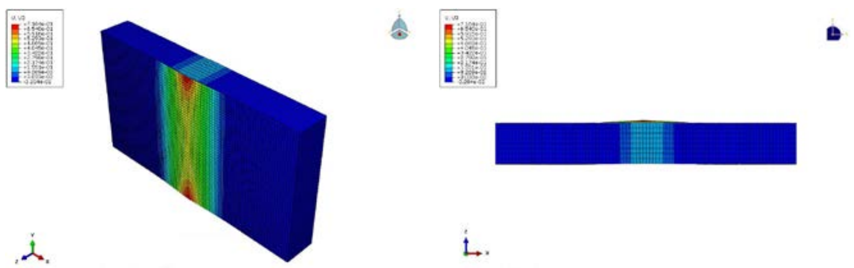

**Fig.4 The out-plane displacement of the sandwich structure with stringer reinforcement under the limit load**

Figure 5 shows a symmetrical through-the-width interfacial debonding propagation behavior located at both side of the core. Under compression load, partial buckling occurs in the upper and lower sheets in the zone of debonding. With the increase of compression load, the lower sheet in debonding area contacts the core quickly thus inhibits the failure and propagation of the adhesive layer. At the same time, the upper sheet in debonding area bulges outward, free buckling occurs. Because the stiffness of the stiffener is higher than the honeycomb core, the debonding propagation starts at the interface between sheet and stiffener. With the increase of the compression loading, the displacement of bulging outward increasing gradually and the debonding propagation gradually extends to the interface of sheet/core near the initial debonding propagation of sheet/stiffener.

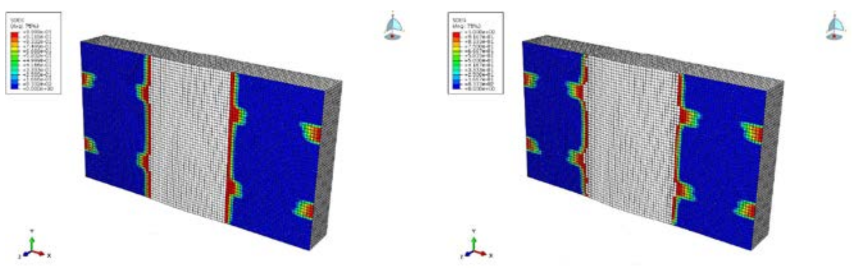

**Fig.5 The propagation of symmetrical through-the-width interfacial debonding in sandwich structure with stringer reinforcement**

## Conclusions

Reinforced by stringer reinforcement, the overall stiffness of the composite Honeycomb Sandwich Structure with Stringer Reinforcement is enhanced effectively, the buckling and ultimate bearing capacity are improved. Under in-plane compression condition, the buckling failure is not the main failure modes of the structure, while strength conditions are main factors controlling the sandwich structure damage in general. Due to the existence of interfacial debonding, local buckling will occur in the debonding area, and lead to the final broken. With the increase of the compression loading, the displacement of bulging outward increasing gradually and the debonding propagation gradually extends to the interface of sheet/core near the initial debonding propagation of sheet/stiffener.

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### References

Fan, Q. X. (1998) Honeycomb Sandwich Composite, *Journal of Beijing institute of light industry*, 2, 77-81.（In Chinese）

Liu, S. L., Guo, W. T. and Ma, Y. P. (2014) Mechanical Properties of Web-core Reinforced Sandwich Structures, *Development and application of materials*, 5, 62-67. （In Chinese）

Zhang, L. H., Han, Y., Wo, X., Y., Xia, Y., F. and Tan, F. (2006) Analysis on Process Defects of Honey Comb Sandwich, *Spacecraft Recovery &Remote Sensing*, 27, 1, 57-61 （In Chinese）

H., A. (2000). An alternative determination of transverse shear stiffnesses for sandwich and laminated plates. *International Journal of Solids & Structures,* 37, 25, 3503-3520(18).

Fu, M., H., Xu, O., T. and Chen, Y. (2015) An Overview of Equivalent Parameters Honeycomb Cores, *Material View*, *5, 024.* （In Chinese）

Zhao, J.,S. (2006) Research On Equivalent Models Of The Mechanical Function For Aluminium Honeycomb Sandwich Panel, *Nanjing University of Aeronautics and Astronautics The Graduate School* （In Chinese）

Bai, R. X. and Chen, H. R. (2002) Investigation Of Nonlinear Buckling Behavior Of Composite Sandwich Plates With Interfacial Delamin Ation And Matrix Micro-Cracks, *Journal of composite materials*, *19, 2*, 80-84. （In Chinese）