DEVELOPMENT OF THE LIGHTWEIGHT INSERTS FOR COMPOSITE SANDWICH PANELS WITH PYRAMIDAL TRUSS CORES

Ge Qi, Li Ma*, Jin-Shui Yang, Lin-Zhi Wu

Center for Composite Materials, Harbin Institute of Technology, Harbin 150001, PR China
Email: mali@hit.edu.cn, Web Page: http://homepage.hit.edu.cn/pages/mali

Keywords: sandwich panels, pyramidal truss cores, inserts

Abstract

Composite sandwich structures are widely used, due to the superior mechanical properties of high specific strength and high specific stiffness compared to solid structures. Composite sandwich panels with truss cores have both lightweight characteristics and multifunctional potential, which makes it possible to reduce the construction mass and increase the bear efficiency. Therefore, a large number of studies have been done on topological optimization, manufacture process and performance evaluation in recent years. However, in virtually, lightweight sandwich panels are not independent individuals, and these sandwich panels have to be connected to other devices. Despite certain types of inserts used for assembly within honeycomb sandwich panels, few studies or information on inserts within sandwich panels with truss cores are published. According to this, effective design of lightweight inserts within truss core sandwich structures have to be adequately treated. In this paper, several types of inserts are proposed for the condition that components or devices have to be connected to the surface of composite sandwich panels with pyramidal truss cores. Brief analysis are carried on to discuss the feasibility and validity of insert methods.

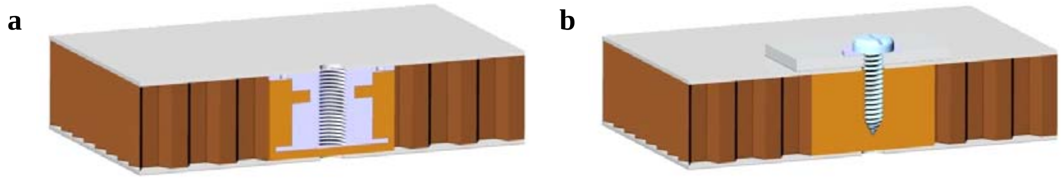
1. Introduction

Composite sandwich structures, consisting of two thin but stiff facesheets and ultra-low-density cellular material cores (foam, honeycomb, fold, corrugated, lattice, etc.), possess superior mechanical characteristics as well as multifunctional aspects, which are widely employed in engineering fields, ranging from aerospace industries to food technology [1]. Considerable experimental investigation and theoretical analysis show that the periodic materials gain higher mechanical behavior than stochastic materials [2], meanwhile lattice materials, the representative of stretching-dominated cellular solids, are much more weight-efficient, when compared to the bending-dominated ones including honeycomb and foam materials [3]. Furthermore, the unique cell topological architecture with connected and open internal space could be utilized for pre-embed component and device, including heat pipes, batteries as well as multi-ship modules, etc, contributing to multifunctionality with thermal control, electronic, and load bearing [4]. On the basis of this, it has led to a remarkable increase in interest in composite sandwich structures with lattice cores on the cell topology configuration [5-7], manufacture techniques [8-10] and mechanical behavior [11, 12], yet few literature is reported concerning the joint or joining techniques.

In virtually, as a ultra-lightweight structures in the ascendant, the reliability investigation on the joint or joining is inevitable for the purpose of application to engineering practice. The main reason is that the localized loads caused by mechanical joints such as bolts and rivets for assembly cannot be adequately transferred into the sandwich facesheets due to the weakness, softness and discretization of

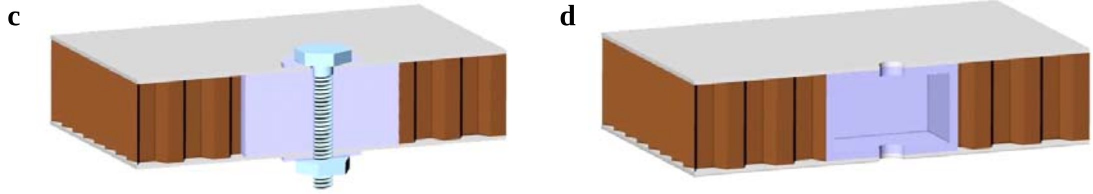
Excerpt from ISBN 978-3-00-053387-7

the cellular cores, resulting in local failure, delaminations or buckling of the sandwich constructions, before the construction ultimate strength. Consequently, in order to install a bolt or rivet and prevent the early failure, the joining or joints are generally achieved via the introduction of hard points, often in the form of metallic inserts, to sustain the fasteners, as well as cores reinforced with a potting compound. Multiple applications of insert in industrial engineering within the honeycomb sandwich structures are illustrated in Fig. 1. The threaded inserts glued into filled honeycomb cells (Fig. 1a), are usually required in the aerospace industries, for the purpose of load distribution uniformly with less stress concentration at the areas of fasteners.



Threaded insert, glued into filled cells

Blind hole in potted area



Through panel tube (e.g. metal, wood)

Through panel hollow profile

Figure 1. Illustration of different insert concepts within honeycomb sandwich panels.

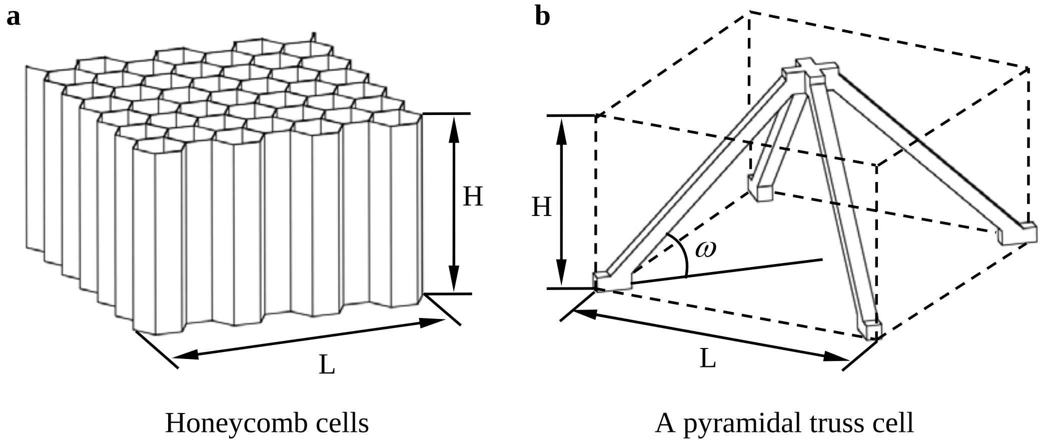
Despite of general employment of the threaded inserts within honeycomb sandwich panels, the available works shows a lack of calculation methods and most center on the experimental investigations. A high-order sandwich plate theory was suggested by Thomsen et al. to deal with stress distribution at the areas with inserts in honeycomb sandwich panels [13]. On a basis of the Thomsen model, different analysis methods were discussed by Smith et al. to explore the utility of reliability analysis in construction design [14]. In a recent study, a virtual testing framework was described to predict the progressive failure behavior on the purpose of reducing manpower and time of testing procedure [15]. Besides the theoretical and numerical analysis above, more experimental research were additionally reported based on a mass of testing results. Kim et al. [16] discussed the influence of insert shape on pull-out behavior, while Song et al. [17] experimentally tested the effect of honeycomb core geometry and facesheet stack sequence on static mechanical behavior. Raghu et al. [18] focused on the strength sensitivity relative to potting diameter as well. In case of industrial application, the Insert Design Handbook (IDH) [19] published by European Space Agency (ESA) provides comprehensive design concepts, manufacture guidelines and testing recommendations.

As implied above, even though the insert concept has been exploited for honeycomb sandwich structures, no literature is documented concerning the insert design within sandwich panels with a lattice core. Therefore, this paper presents tentative insert concepts adopted to sandwich panel with pyramidal truss cores, according to the analysis on topology configuration of pyramidal truss cores. Brief discussion is conducted to compare several design schemes, aiming to probe into the joining or joints problems involved in sandwich structures with lattice cores, as well as to extend the application to industrial engineering.

Excerpt from ISBN 978-3-00-053387-7

2. Topology Configuration Analysis of Cores

The typical schematic of honeycomb cells and a pyramidal truss cell with the same external size is shown in Fig. 2.



Honeycomb cells A pyramidal truss cell

Figure 2. Schematics of honeycomb cells and a pyramidal truss cell.

Evident architecture differences are listed bellow:

- **Symmetry:** Honeycomb cells are asymmetrical along thickness, while a single pyramidal cell is on the contrary.
- **Cell dimensions:** The distance between two nodes of the pyramidal truss cell is considerably larger than the subtense distance of honeycomb cells, causing that the amount of honeycomb cell exceeds pyramidal cells by far within the same area.
- **Closeness and openness:** Honeycomb cores are typical closed-cells, while the pyramidal truss cores are open and connected.
- **Variability:** The distance between two nodes of the pyramidal truss cell and the slenderness ratio of truss bars vary with the cell height if the angle ω does not change, while honeycomb cells remain invariant.

Based on the comparison above, the insert concepts adopted to honeycomb sandwich panels cannot be directly applied to pyramidal truss core structures, therefore, new design guidelines and manufacture methods need to be suggested.

3. INSERT DESIGN SCHEMES

Since the purpose of inserts is uniform local loads distribution and stress concentration reduction, a metallic insert, with enough areas bonded to facesheets and truss bars, would be available to fulfill the joining requirement for assembly. Several insert methods are illustrated in Fig. 3.

As it is showed, in regard to the discrete cell distribution as well as the long node space, the insert design concepts would varies for different joining location. For the architecture of the pyramidal truss cell, the central node is one characteristic location to sustain fasteners to connect, based on which, three types of inserts, including a pyramidal insert (Fig. 3a), two quadrangular inserts (Fig. 3b) and two cylinder inserts (Fig. 3c) are designed.

Excerpt from ISBN 978-3-00-053387-7

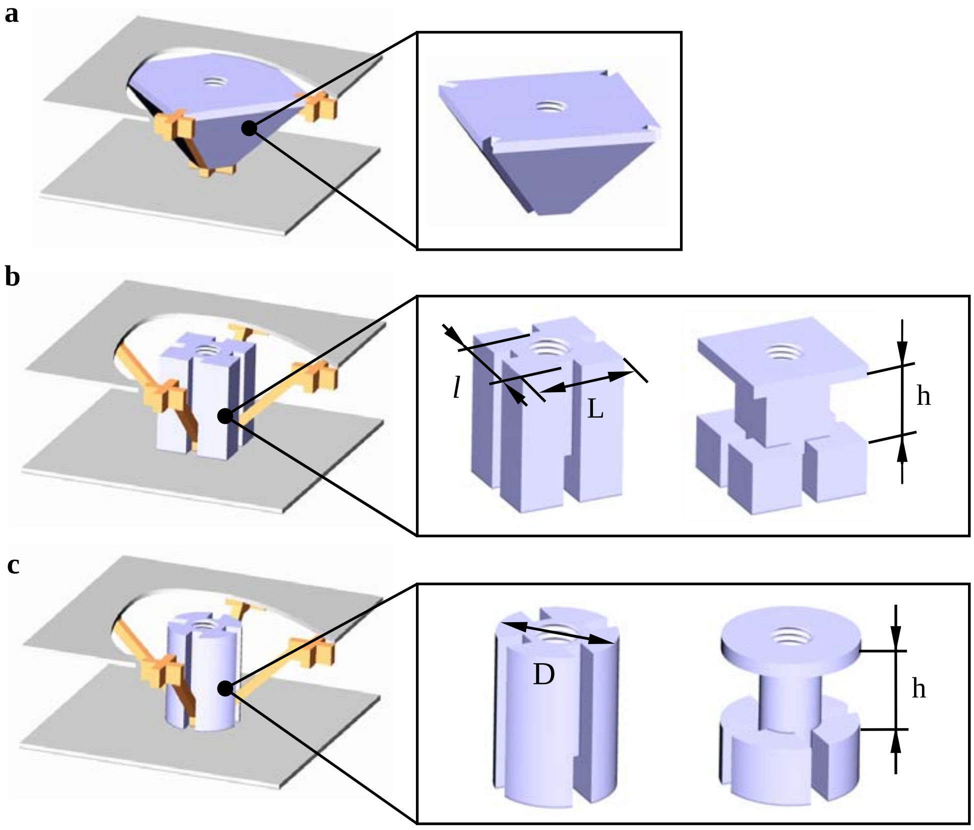


Figure 3. Schematics of honeycomb cells and a pyramidal truss cell.

All the inserts are designed to be bonded to the facesheets and truss bars, utilizing lightweight, thin, film adhesive, so when the density of the inserts if ρ, the diameter of clearance screw holes is d, the slot width is t and the height of the pyramidal truss cell as well as all the inserts is H, the weights are listed in Table 1, where W_1, W_2 are corresponding to the two design concepts in Fig. 3a and Fig. 3b sequentially, respectively.

Table 1. The weight of inserts for pyramidal truss core sandwich structures.

Insert Type	Pyramidal	Quadrangular	Cylinder
W_1	$\left(\frac{2}{3}H^2-\frac{\pi}{4}d^2\right)H\rho$	$\left[L^2-2(L-l)t-\frac{\pi}{4}d^2\right]H\rho$	$\left[\frac{D^2-d^2}{4}\pi-2(L-l)t\right]H\rho$
W_2	——	$\left[\frac{L^2(H-h)+l^2h}{H}-\frac{\pi}{4}d^2\right]H\rho$	$\left[\frac{D^2(H-h)+l^2h-d^2H}{4H}\pi\right]H\rho$

Because the inserts are placed while the cross slot is fitted to the truss bars in the procedure of fabrication, which contributes to localization and reinforcement, the dimensions of the pyramidal insert are determined by the pyramidal truss cell, while sizes of the other inserts change according to practice demands. Although the bonded area to the upper facesheet of the pyramidal insert is larger, little contact to lower facesheet prevents the stress concentration distribution to the whole sandwich

Excerpt from ISBN 978-3-00-053387-7

panel, which might result in node failure. The unique configuration and high demands of precision increase the manufacturing cost as well.

The design concepts of quadrangular inserts and cylinder inserts are similar, which utilizes simple and fast manufacturing process to achieve the insert bonding, without truss bars destroy. The surfaces glued to facesheets realize the transfer of localized loads, yet almost little constraint from the cores demands high stiffness of the facesheets. Spindly inserts via removing materials from the quadrangular or cylinder inserts facilitate weight reduction effectively, at the cost of more manpower and financial resources. The quadrangular and cylinder inserts (including the spindly form) would own a fine performance, and more evaluations of joining or joints characteristics require experimental investigation for further exploration.

4. Conclusions

Through analysis and comparison of honeycomb cells and pyramidal truss cells, three types of inserts (pyramidal, quadrangular, and cylinder) for pyramidal truss core sandwich panels are suggested. The weight of the inserts are calculated for preliminary assessment, and brief analysis based on the design concepts as well as manufacturing cost is conducted. The quadrangular and cylinder inserts (including the spindly form) would own good mechanical behavior and demands more investigation.

Acknowledgments

This present work was supported by National Science Foundation of China under grant.No.11172080 and 11222216.

References

[1] Gibson L J, Ashby M F, Solids C. Cellular Solids: Structure and Properties., Cambridge university press, Cambridge, UK, 1997.

[2] Ashby M F, Evans T, Fleck N A, Gibson L J. Metal Foams: A Design Guide. *Boston*, 2000.

[3] Evans AG, Hutchinson JW, Fleck NA, et al. The topological design of multifunctional cellular metals. *Progress in Materials Science*, 46:309–27, 2001.

[4] Sypeck D J. Wrought aluminum truss core sandwich structures. *Metallurgical and Materials Transactions B*, 36(1): 125-131, 2005.

[5] Deshpande V S, Ashby M F, Fleck N A. Foam topology: bending versus stretching dominated architectures. *Acta Materialia*, 49(6): 1035-1040, 2001.

[6] Hutchinson R G, Wicks N, Evans A G, et al. Kagome plate structures for actuation. *International Journal of solids and structures*, 40(25): 6969-6980, 2003.

[7] Zok F W, Waltner S A, Wei Z, et al. A protocol for characterizing the structural performance of metallic sandwich panels: application to pyramidal truss cores. *International Journal of Solids and Structures*, 41(22): 6249-6271, 2004.

[8] Lee Y H, Lee B K, Jeon I, et al. Wire-woven bulk Kagome truss cores. *Acta Materialia*, 55(18): 6084-6094, 2007.

[9] Zhang G, Wang B, Ma L, Xiong J and Wu LZ. Response of sandwich structures with pyramidal truss cores under the compression and impact loading. *Composite Structures*, 100: 451-463, 2013.

[10] Finnegan K, Kooistra G, Wadley H N G, et al. The compressive response of carbon fiber composite pyramidal truss sandwich cores. *International Journal of Materials Research*, 98(12): 1264-1272, 2007.

Excerpt from ISBN 978-3-00-053387-7

[11] Wang B, Wu L, Ma L, et al. Mechanical behavior of the sandwich structures with carbon fiber-reinforced pyramidal lattice truss core. *Materials & Design*, 31(5): 2659-2663, 2001.

[12] Yang JS, Xiong J, Ma L, et al. Vibration and damping characteristics of hybrid carbon fiber composite pyramidal truss sandwich panels with viscoelastic layers. *Composite Structures*, 106: 570-580, 2013.

[13] Thomsen OT, Rits W. Analysis and design of sandwich plates with inserts- a higher-order sandwich plate theory approach. *Composites Part B*, 29(6): 795–807, 1998.

[14] Smith B, Banerjee B. Reliability of inserts in sandwich composite panels. *Composite Structures,* 94(3): 820-829, 2012.

[15] Seemann R, Krause D. Virtual testing of Nomex honeycomb sandwich panel inserts. *Proceedings of the 20th International Conference on Composite Materials, Copenhagen*; 19-24 July 2015.

[16] Kim BJ, Lee DG. Characteristics of joining inserts for composite sandwich panels. *Composites Structures,* 86(1–3): 55–60, 2008.

[17] Song KI, Choi JY, Kweon JH, Choi JH, Kim KS. An experimental study of the insert joint strength of composite sandwich structures. *Composite Structures,* 86: 107–113, 2008.

[18] Raghu N, Battley M, Southward T. Strength variability of inserts in sandwich panels. *Proceedings of the 8th international conference on sandwich structures, Porto,* 6–8 May 2008. 558–69.

[19] Insert Design Handbook, ESA PSS-03-1202, European Space Agency, Paris, 1987.

Excerpt from ISBN 978-3-00-053387-7