EAN 2019
57th conference on experimental stress analysis

# Testing of honeycomb sandwich panel with potted insert

MANDYS Tomáš[1,a], LAŠ Vladislav[1], ZEMČÍK Robert[1] and KRYSTEK Jan[1]

[1] University of West Bohemia in Pilsen, NTIS – New Technologies for Information Society, Technická 8, 301 00 Pilsen, Czech Republic

[a]tmandys@kme.zcu.cz

**Keywords:** sandwich panel, honeycomb, insert, pull-out

## Abstract

This work is focused on the experimental and analytical determination of the load-carrying capability of the inserts potted in the sandwich structure with honeycomb core. The pull-out test of the sandwich structure specimens with two types of inserts were performed and load-carrying capability of inserts determined and compared with the results obtained via analytical solutions. The parametrical study of influence of the parameters describing the potting geometry on load-carrying capability was performed in case of analytical solution.

## Introduction

Sandwich panels with honeycomb core are widely used in different structural applications in lightweight transportation systems such as marine, aeronautic and astronautic industries because of their high specific strengths and stiffness.

A sandwich structure is made of two face sheets (skins) that are adhesively bonded to a lightweight core material. The combination of different bonded materials utilizes the properties of each separate component to the structural advantage of the whole assembly. The face sheets are usually fibre-reinforced composite laminates. Core material can be classified as being cellular, corrugated or honeycomb. Honeycomb cores are usually with hexagonal shaped cells made from aluminium or aramid. Honeycomb panel face skins are very thin which discourage direct mechanical attachment to other components. Therefore, the installation of special types of fasteners is required. Threaded inserts are universally employed to accept the attachment screws of various other components (brackets, holders, etc.).

The knowledge of the load capability of particular insert is important for the design of individual sandwich panels and for usage of particular type of inserts. The load capability is in case of insert not only dependent on the type and geometry of the insert, but also on the geometrical conditions associated with its installation (bonding) into the sandwich structure. The effect of the insert shape on the mechanical characteristics of composite sandwich panel and the load transfer characteristics are investigated experimentally in [1]. Besides the experimental investigation, the numerical simulation and the analytical calculation are other possibilities for determination of the load capability for particular insert in sandwich structure [2, 3, 4]. The theoretical background of the analytical solution of the load-carrying capability of the inserts is summarized in [2]. The comparison of the results of the numerical simulations and the performed experiments in case of pull-out loading is shown in [3, 4]. The parametric study investigating the effect of design variables such as core height and honeycomb core density and the face sheet thickness of the sandwich structure on the failure loads of the sandwich inserts is published in [5].

### Analytical solution of insert load capability

Failure of through-the-thickness type inserts of sandwich plates usually occurs in the honeycomb core next to the interface between honeycomb and the potting. In this place the core shear stress $\tau_C$ in the honeycomb reaches the maximum value $\tau_{C\max} = \tau_C(r = b_P)$. The failure occurs when $\tau_{C\max}$ reaches the core shear strength $\tau_{C\mathrm{crit}}$. Static load-carrying capability of through-the-thickness insert $P_{\mathrm{crit}}$ in a sandwich plate can be estimated by the formula [2]

$$P_{\mathrm{crit}} = 2\pi \cdot b_P \cdot d \cdot \tau_{C\mathrm{crit}}, \tag{1}$$

where $d$ is distance between the face sheet middle surfaces and $b_P$ effective potting radius. Distance $d$ is defined

$$d = \frac{t_{top}}{2} + c + \frac{t_{bot}}{2}, \tag{2}$$

where $c$ is the core height and $t_{top}$, $t_{bot}$ are thicknesses of top and bottom face sheets.

Effective potting radius $b_P$ is an analytical dimension describing the radial influence zone of the potting and it is defined as the average distance of the nearest single cell wall surrounding the potting from the center of the insert. The value of the effective potting radius $b_P$ depends on the combination of the insert radius $b_i$ and size of core cell (cell size) $S_C$ and on the certain position of the insert center within the hexagonal cell. The value of the effective potting radius $b_P$ can be determined by

$$b_P = \frac{1}{n}\sum b_n, \tag{3}$$

where $b_n$ is the radius of the corresponding effective potting geometry based on the position of double cell walls and failing single cell walls between hexagonal core and potted area. The effective potting geometry is red marked on Fig. 1, where is evident its meaning. The minimum $b_{P\min}$ and the average effective potting radius $b_{P\mathrm{avg}}$ can be given by the empirical formulae [2]

$$b_{P\min} = 0.93192 \cdot b_i + 0.874 \cdot S_C - 0.66151, \tag{4}$$

$$b_{P\mathrm{avg}} = 1.002064 \cdot b_i + 0.940375 \cdot S_C - 0.7113. \tag{5}$$

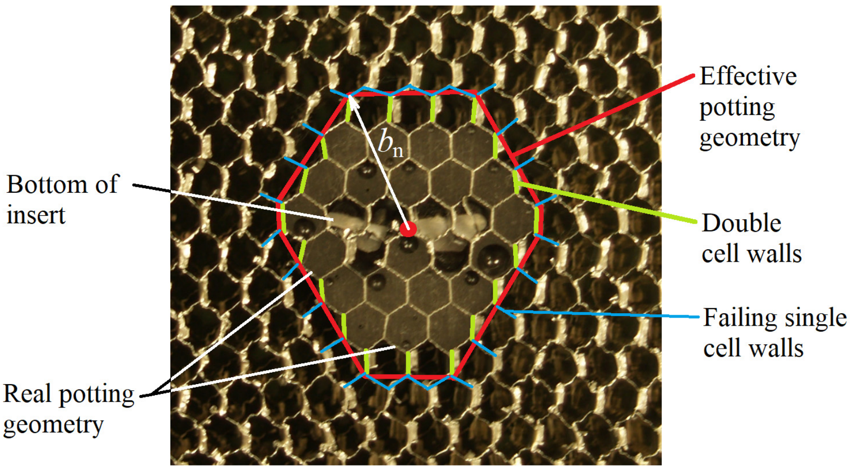


Fig. 1: Potting geometry of specimen with M8 insert

In case of potted type inserts (blind inserts) of sandwich plates the out of plane static load of potted insert $P_P$ can be divided into three parts

$$P_P = P_f + P_S + P_n, \tag{6}$$

where $P_f$ is load part carried by the upper face sheet, $P_S$ load part carried by shear stresses in the core around potting and $P_n$ load part carried by normal stresses in the honeycomb core underneath the potting material. Load part $P_S$ is limited by the core shear strength $\tau_{C\,\mathrm{crit}}$ and $P_n$ is limited by core strength $\sigma_{C\,\mathrm{crit}}$, that can be represented by tensile $\sigma^T_{C\,\mathrm{crit}}$ or compressive strength $\sigma^C_{C\,\mathrm{crit}}$, depending on the type of loading of partially potted insert. The shear rupture and tensile or compressive core rupture of honeycomb core in case of plane loading of insert occur usually simultaneously. The critical load $P_{P\,\mathrm{crit}}$, determining the load-carrying capability of potted insert in a sandwich plate, can be expressed in form [2]

$$P_{P\,\mathrm{crit}} = \frac{P_{\mathrm{crit}} - 2\pi \cdot b_P \cdot c \cdot \tau_{C\,\mathrm{crit}}}{2} + 2\pi \cdot b_P \cdot h_P \cdot \tau_{C\,\mathrm{crit}} + \pi \cdot b_P^2 \cdot \sigma_{C\,\mathrm{crit}} . \tag{7}$$

In Eq. (7) $h_P$ is the potting height that represents average depth to which the core cells are filled with potting resin. The average value of potting height $h_{P\,\mathrm{avg}}$ can be determined empirically in the form [2]

$$h_{P\,\mathrm{avg}} = h_{P\,\mathrm{min}} + A \tanh\left(\frac{c - h_{P\,\mathrm{min}}}{h_{P\,\mathrm{min}}}\right) , \tag{8}$$

where $h_{P\,\mathrm{min}}$ denoted the minimal allowable potting height in the core that depends on the insert height $h_i$ and the depth of the milled hole into sandwich structure (obviously 3-4 mm deeper than insert height). The meaning of the mentioned parameters is shown in Fig. 2. In Eq. (8) $A$ is the geometrical parameter dependent on cell size $S_C$ and that matches the size of one sixth of hexagonal cell circumference.

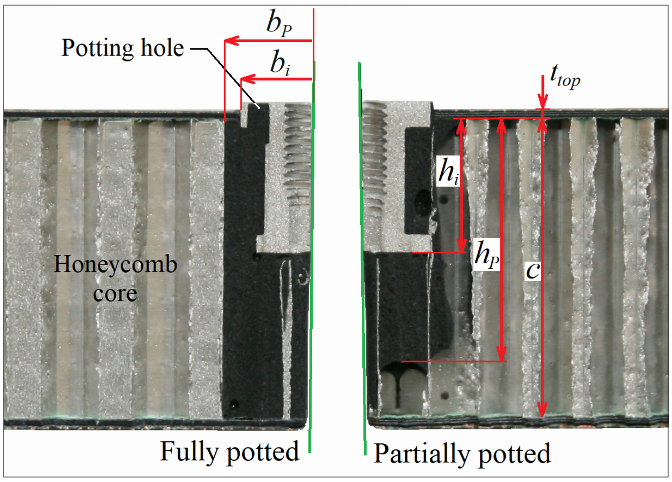


Fig. 2: Cross-section areas of specimens with fully and partially potted M5 inserts

## Experimental determination of insert load capability

The blind inserts with inner threads M5 and M8 installed (bonded) into sandwich structure were subjected to out-of-plane tensile pull-out tests. The sandwich specimens of the total dimension of 110 mm × 110 mm and the total thickness of 30 mm consisted of the face sheets made from 8 layers of unidirectional carbon prepregs with orientation [0/45/90/–45]s and total thickness of 0.74 mm and honeycomb hexagonal-type core made from 5056 aluminium alloy with cell size 3/16” and single wall thickness of 0.001”. The inserts were centrally located in selected face sheets of the specimens. The universal test machine Zwick-Roell Z050 was used. When the insert was loaded, the upper face sheet was pressed against the plate which has a central inner hole with diameter of 80 mm to ensure a sufficient free area around the insert. Six specimens for each insert type were tested. The loading speed was $v = 1.0$ mm/min. The testing setup is displayed in Fig. 3. The loading of specimens was carried out until visible damage. Force-displacement curves were the output from testing (see Fig. 4). Typical failure of the top and bottom face sheets of sandwich arising during the pull-out test is displayed on Fig. 5. Load capabilities were determined from aforementioned curves. In case of testing of specimens with M5 inserts, two failure modes of potted area (listed below) were observed depending on whether the inserts were only partially or fully potted. This fact is evident in the results of force-displacement curves, when the partially potted inserts reach the lower forces.

The occurrence of failure in case of partially potted M5 insert is underneath the potting material in the honeycomb core. This is the case of core strength $\sigma^{T}_{C\,\mathrm{crit}}$. The failure in case of fully potted M5 insert occurs at the interface of adhesive (potting) and bottom face sheet – corresponding strength $\sigma^{T}_{F\,\mathrm{crit}}$. The strength $\sigma^{T}_{F\,\mathrm{crit}}$ was additionally obtained from flatwise tension test of sandwich structure performed according to standard [6].

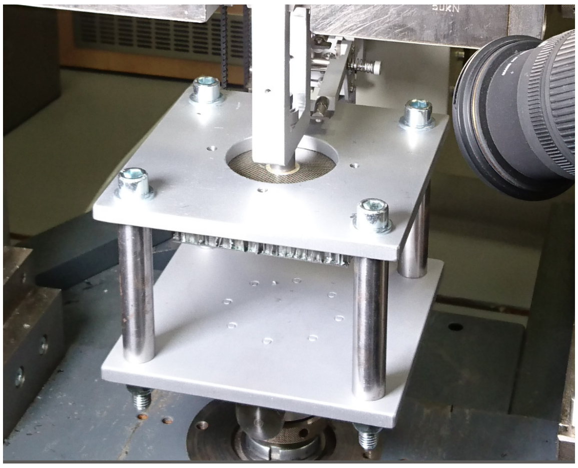

Fig. 3: Tensile pull-out fixture setup

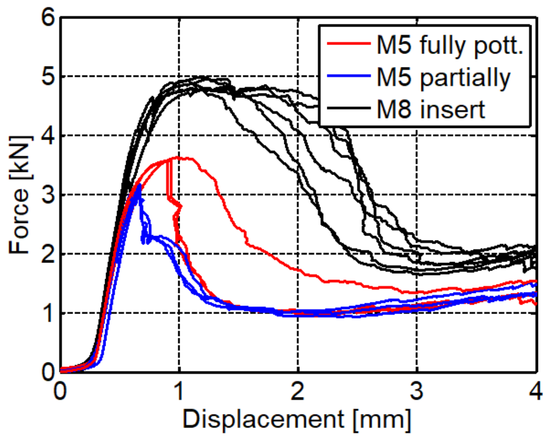


Fig. 4: Force-displacement dependencies

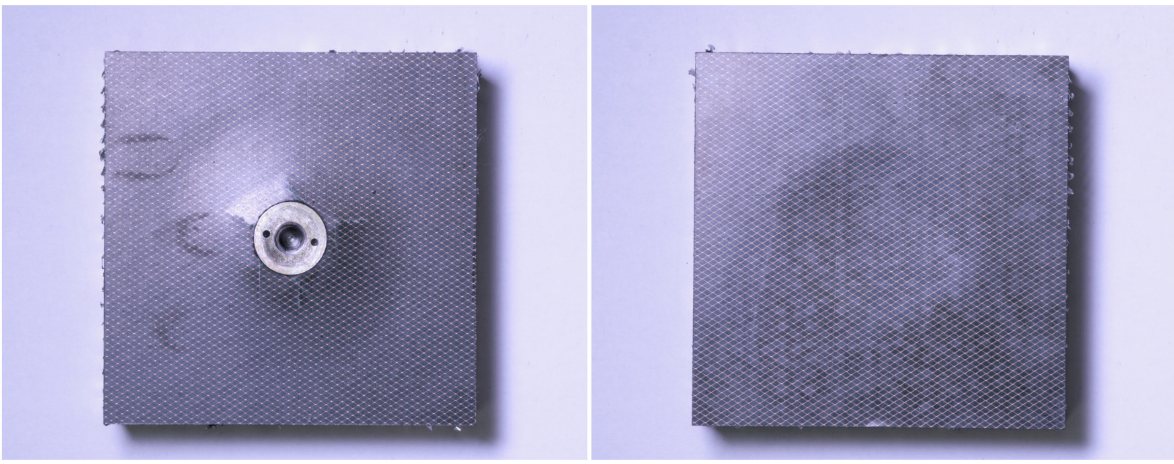

Fig. 5: Typical failure of tested specimens on top skin (left) and bottom skin (right), presented specimen with blind insert M8

**Comparison of experimental and analytical results**

The minimum and the average load capability of appropriated tested inserts in sandwich structure were analytically calculated according to the above equations. Analytical solution was used for both cases of potted area of M5 inserts detected during the experiment. The material and geometrical parameters needed for the calculation were obtained by the literacy [2, 7], by experiment and by the measuring of the specimens and are summarized in Table 1. In case of core strength were used two different values in dependence of type of failure caused due to occurrence of two different potting types (partially and fully potting) in case of M5 insert. The comparison of experimentally and analytically obtained load capabilities of inserts is performed in Table 2.

Table 1: Geometrical and material parameters

| Sandwich structure | | | |
|---|---|---|---|
| $t_{top}$, $t_{bot}$ = 0.738 mm, | $c$ = 28.52 mm, | $S_C$ = 4.763 mm, | $A$ = 5.0 mm |
| $\tau_{C\,\mathrm{crit}}$ = 1.07 MPa, | $\sigma^T_{C\,\mathrm{crit}}$ = 5.85 MPa, | $\sigma^T_{F\,\mathrm{crit}}$ = 2.52 MPa | |
| **Insert** | | | |
| M5: | $b_i$ = 7.15 mm, | $h_i$ = 12.60 mm | |
| M8: | $b_i$ = 10.70 mm, | $h_i$ = 19.60 mm | |

Table 2: The comparison of experimentally and analytically obtained load capabilities $P_P$

| Type of insert and installation | Experiment [N] | Analytical solution min/avg. value [N] |
|---|---|---|
| Blind M5 partially potted | 3099 | 3098 / 3913 |
| Blind M5 fully potted | 3589 | 3501 / 3831 |
| Blind M8 fully potted | 4889 | 4993 / 5486 |

The parametric study of influence of parameters describing the potting geometry, namely potting height $h_P$ and potting radius $b_P$, on load-carrying capability of insert was performed. The potting height $h_P$ was limited by the insert height $h_i$ and by core height $c$. The upper value of insert radius $b_i$ for calculation of potting radius $b_P$ was considered to be additional 50% of its dimension. In this case, height $h_i$ and radius $b_i$ are the dimensions of the milled hole for the insert installation that may not be the same as the inserts dimensions. The graphical representation of influence of resultant potting height $h_P$ and potting radius $b_P$ on the on load-carrying capability of M5 and M8 inserts is shown in Fig. 6. The influence of the widening of the insert radius $b_i$ on the load-carrying capability is summarized for case of fully potted inserts in Table 3.

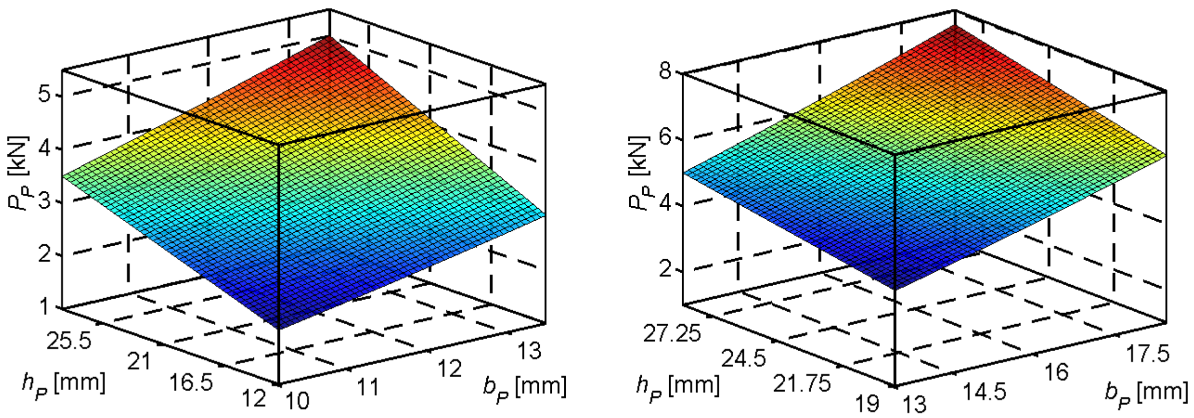


Fig. 6: Influence of the potting geometry on the load carrying capability of the blind insert with M5 thread (left) and M8 thread (right)

Table 3: The comparison of the dependency of insert radius on the load capability of the insert

| Type of insert and installation | $h_i$ [mm] | $b_i$ [mm] | $h_P$ [mm] | $b_P$ [mm] | $P_P$ [N] |
|---|---|---|---|---|---|
| Blind M5 fully potted | 28.52 | 7.15<br>10.72 | 28.52 | 10.16<br>13.50 | 3501<br>5004 |
| Blind M8 fully potted | 28.52 | 10.70<br>16.05 | 28.52 | 13.47<br>18.46 | 4993<br>7569 |

## Conclusions

The load capability of insert in sandwich structure was experimentally and analytically determined and the results were compared. The experimental data show a reasonable agreement with minimum values of load capabilities obtained from analytical solution. Based on this observation, a parametric study of influence of potting geometry on the load capability of insert was performed using analytical solution. This geometry depends on dimensions of the milled hole in form of radius and height for the insert installation in the sandwich core that may be different from the insert geometry. The load carrying capability of the inserts can be increased by the widening of the potting radius in the honeycomb core. The other possibility of increasing load carrying capability depends on the potting height and from this derived the partial or full potting, when the fully potted inserts have the higher load carrying capability than the partially.

## Acknowledgement

This publication was supported by the project LO1506 of the Czech Ministry of Education, Youth and Sports under the program NPU I and by project TRIO FV10400 “Development of processes applicable to development and production of components for the space industry” of Czech Ministry of Industry and Trade.

## References

[1] B.J. Kin, D.G. Lee, Characteristics of joining inserts for composite sandwich panels, Composite Structures, 86, pp. 55-60, 2008.

[2] Space Engineering – Insert design handbook, ECSS-E-HB-32-22A, ESA Requirements and Standards Division, Netherlands, 2011.

[3] R. Roy, K.H. Nguyen, Y.B. Park, J.H. Kweon, J.H. Choi, Testing and modelling of Nomex$^{TM}$ honeycomb sandwich panels with bolt insert, Composites: Part B, 56, pp. 762-799, 2014.

[4] S. Heimbs, M. Pein, Failure bahaviour of honeycomb sandwich corner joints and inserts, Composite Structures, 89, pp. 575-588, 2009.

[5] K.I. Song, J.Y. Choi, J.H. Kweon, J.H. Choi, K.S. Kim, An experimental study of the insert joint strength of composite sandwich structure, Composite Structures, 86, pp. 107-113, 2008.

[6] Standard ASTM C297, Test Method for Flatwise Tensile Strength of Sandwich Constructions.

[7] E.W. Kuenzi, Mechanical properties of aluminium honeycomb cores, Forest Products Laboratory, U.S. Department of Agriculture, Forest Services, 1962.