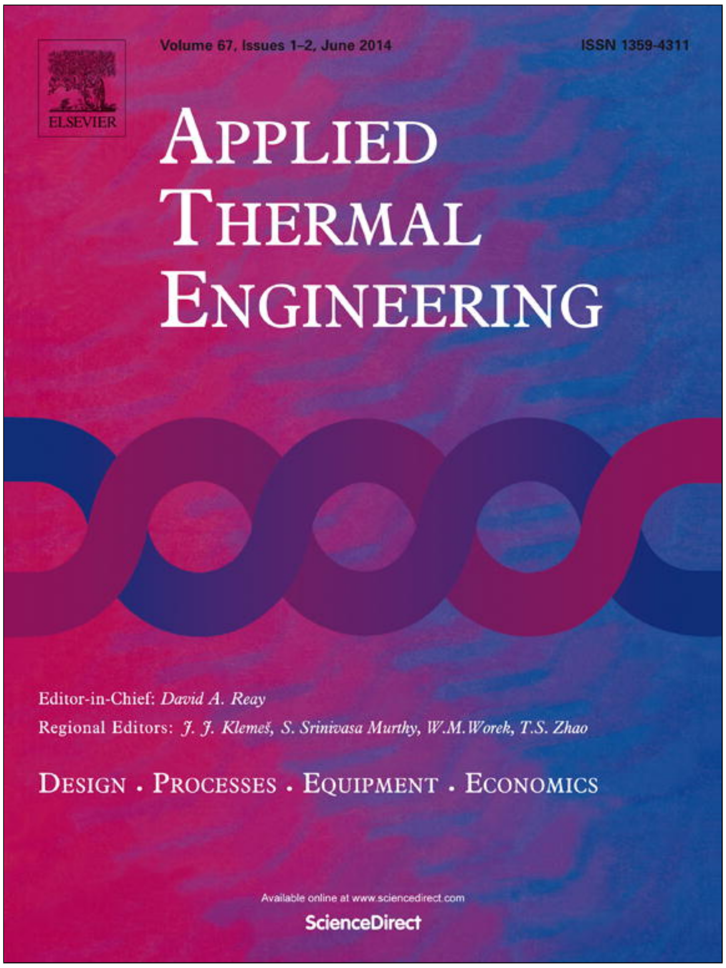
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Inserts thermal coupling analysis in hexagonal honeycomb plates used for satellite structural design

A. Boudjemai [a,*], A. Mankour [a], H. Salem [a], R. Amri [a], R. Hocine [b,1], B. Chouchaoui [c,2]

[a] Centre of Satellite Development (CDS), Space Technology Research Division, BP.: 4065 Ibn Rochd USTO, Oran, Algeria
[b] Department of Electronics Engineering, University of Sciences and Technology of Oran, BP 1505 EL M'Naour, Algeria
[c] Windsor Industrial Development Laboratory, Inc., 3310 Longfellow Avenue, Windsor, ON N9E 2L6, Canada

HIGHLIGHTS

- In this work we perform thermal analysis of honeycomb plates using finite element method.
- Detailed finite elements models for honeycomb panel are developed in this study including the insert joints.
- New approach of the adhesive joint is modelled.
- The adjacent inserts cause the thermal interference.
- We conclude that this work will help in the analysis and the design of complex satellite structures.

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ABSTRACT

Mechanical joints and fasteners are essential elements in joining structural components in mechanical systems. The thermal coupling effect between the adjacent inserts depends to a great extent on the thermal properties of the inserts and the clearance. In this paper the Finite-Element Method (FEM) has been employed to study the insert thermal coupling behaviour of the hexagonal honeycomb panel. Fully coupled thermal analysis was conducted in order to predict thermal coupling phenomena caused by the adjacent inserts under extreme thermal loading conditions. Detailed finite elements models for a honeycomb panel are developed in this study including the insert joints. New approach of the adhesive joint is modelled. Thermal simulations showed that the adjacent inserts cause thermal interference and the adjacent inserts are highly sensitive to the effect of high temperatures. The clearance and thermal interference between the adjacent inserts have an important influence on the satellite equipments (such as the electronics box), which can cause the satellite equipments failures. The results of the model presented in this analysis are significant in the preliminary satellites structural dimensioning which present an effective approach of development by reducing the cost and the time of analysis.

1. Introduction

Recently, honeycomb cellular materials have been an important research topic due to their outstanding potential in energy absorption, thermal isolation, dynamic and acoustic damper [1,2]. Periodic cellular metals are, in fact, highly porous structures with 20% or less of their interior volume occupied by metals [3,4,and 5]. Some, such as hexagonal honeycomb, have been widely used in the manufacture of the aerospace structures due to their lightweight, high specific bending stiffness and strength under distributed loads [2].

The first step in designing a sandwich structure is the choice of the different constituents, depending on the application: the face, the core and the adhesive joint to bond the faces to the core. Choice criteria are based, of course the mechanical properties of the constituents, but also on the processing and the price which can vary over several orders of magnitude.

A honeycomb sandwich structure consists of two thin face sheets attached to both sides of a lightweight core. Sandwich panel face sheets are commonly fabricated using aluminium or graphite/epoxy composite panels. The core is typically fabricated using a

* Corresponding author. Tel.: +213 41620324; fax: +213 41620320.
E-mail addresses: a_boudjemai@yahoo.fr (A. Boudjemai), M_Abdeldjalil@yahoo.fr (A. Mankour), ari090782@yahoo.com, amri_redha@yahoo.co.uk (R. Amri), rak_hocine@yahoo.fr (R. Hocine), bencho@widl.ca (B. Chouchaoui).
[1] Fax: +213 41 42 15 81.
[2] Tel.: +1 519 966 4479; fax: +1 519 966 7133.

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honeycomb or aluminium foam construction [6,7]. Typically the sandwich honeycomb plates are used widely in satellites structures on which the electronic equipment is mounted, the instrument unit and the propulsion part, and others. This is the case of the Algerian satellite Alsat-1 which is an earth observation satellite with a mass of 90 kg and was launched by a COSMOS 3M launch vehicle from the Plesetsk Cosmodrome in Russia on the 28th November 2002. The platform is measuring 640 × 640 × 680 mm. The spacecraft is cubical in shape with four body-mounted panels, with the remaining sides including the spacecraft launch adaptor, sensors, payload apertures and antennas [8] (see Fig. 1).

In sandwich structure applications, mechanically fastening panels with inserts is one of the most important parts of the design [9–21]. The sandwich honeycomb plates which are employed in the satellite structures require many inserts for assembly. Fig. 2 shows an example of an insert schematic. The insert is attached by an adhesive potting compound to a panel consisting of two face-sheets and a honeycomb or a foam core. While the insert shown in the figure is blind, through the thickness inserts are also common.

Local stress concentrations due to inserts are known to cause structural failures, and several studies [16] suggest that under several loading conditions, the initial failure event is a debond of the potting from the core, followed by buckling of the honeycomb and fracture/yield of the facesheets [22]. The potential failure modes are numerous (delamination, local fibre breaking, skin/core debonding, core crushing, core shear buckling, potting failure, etc.) [23]. Experiments demonstrated that, for the lower loads, the non-linearity and the hysteresis are mainly due to core shear buckling [23]. Nikhil Raghu et al. investigate sources of variability in the pull-out strength of metallic inserts in aramid honeycomb sandwich panels [24]. Sources of uncertainty in the sandwich-insert model include the geometry, the material properties, and the applied loads [22].

Several recent studies were related to the inserts in order to find the best configurations or at least to give sufficient design to fulfil the space environment requirements. Numerous works have been conducted in order to develop a sandwich panel with I-shaped inserts to allow them to bond the carbon fibre-aluminium honeycomb sandwich panels in a T-shape joint. The I-shaped insert was fixed inside the composite sandwich panel edge with a film adhesive [25]. H.K. Cho et al., performed their research to study the vibration in a satellite structure with a laminate composite hybrid sandwich panel which consists of a monocoque structure formed by joining several composite sandwich panels composed of an aluminium honeycomb core with carbon fibre reinforced laminate skins on both sides [26]. It must be noted that Bianchi Gabriel works were conducted on the structural performance of spacecraft honeycomb panels and also were focused on the inserts without involving the effect of temperature which is an important parameter of structural performance [24]. Other results show that while the insert joint failure loads for pull-out loading are affected by the core height and density, they are also greatly influenced by the face thickness [27].

Information on battery problems can be useful in guiding research to improve battery technology. Problems that are serious or reoccur are the obvious ones to concentrate on. Observed problems can be caused by more than one phenomenon. However the problem that was observed on the Alsat-1 battery module where some cells were damaged [28] and the damage was caused by extreme temperatures. This problem can be due the fact that the two different inserts (simple insert and hard insert) are very close which caused an increase in heat flux. The inserts used to support the battery in the honeycomb panel have a serious impact on the conduction from the solar panel to the battery pack (see Fig. 1), and so the temperature of the solar panel closer to the battery determines its temperature. For this reason the simulations were performed to observe carefully this phenomenon caused by the thermal coupling of the surrounding inserts and the important feedback from the results obtained in order to avoid design risk in the future on the Algerian satellites such as Alsat-1B.

In the present study we aim to investigate the presence of the thermal coupling between the adjacent inserts and the prediction of the temperature evolution caused by thermal effects as being a main factor in the correct design of the sandwich structures. The thermal analysis is carried out on a honeycomb plate with inserts and the study is focused on the thermal behaviour of the honeycomb adjacent inserts. In addition, the interaction of the structure, with the internal or external temperature and as well as the solar flux, leads to the presence of an important variation of the temperature gradient around the inserts. This is the case of satellites that carry equipments with very nearby bolted assembly; this temperature gradient around the inserts can cause electronics damages which can go to an equipment failure.

The 3-D finite element model of the honeycomb plate with the six inserts has been developed in Patran/Nastran. A new approach of the insert with an adhesive model was introduced into this study using finite element analysis.

The remainder of the paper is organized as follows: Section 2 describes the Thermal finite element model of a honeycomb plate. Following this description the simulation results are

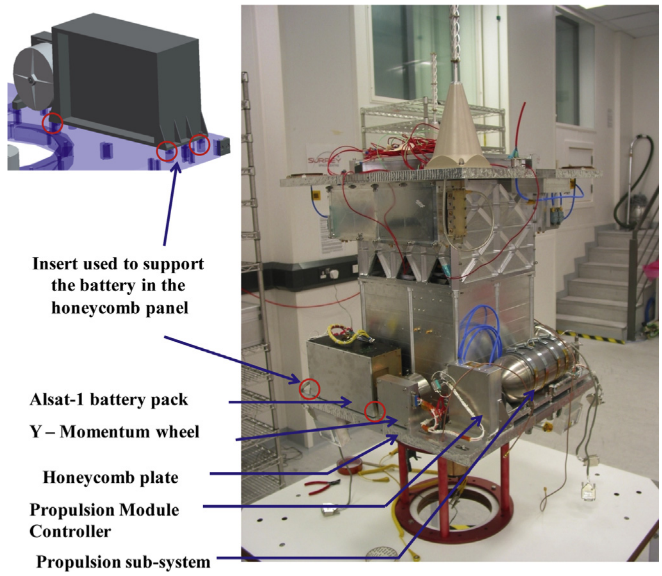

Fig. 1. Honeycomb sandwich applications in the first Algerian Microsatellite Alsat-1.

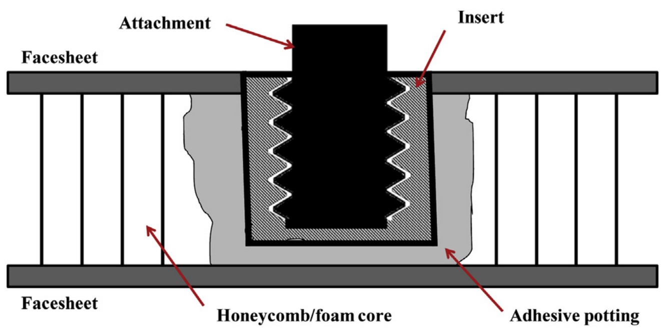

Fig. 2. An insert in a sandwich panel.

Table 1
Dimensions of the honeycomb plate.

Length (a)	Width (b)	Thickness of the skin (t)	Cell seize (l)	Cell thickness (t_{cell})	Core thickness (h)
320 mm	182 mm	1 mm	2 mm	0.2 mm	20 mm

Table 2
Honeycomb panel material properties.

Material property	Core (aluminium 6061-T6)	Face sheet (aluminium 6061-T6)	Insert (aluminium 6061-T6)	Adhesive (Acrylic)
Density ρ (kg/m^3)	2700	2700	2700	1400
Poisson ratio ν	0.33	0.33	0.33	–
Young's modulus E (pas)	7.31e + 10	7.31e + 10	7.31e + 10	–
Thermal conductivity (K) W/(m °C)	155.8	155.8	155.8	0.14
Heat capacity (C) J/(kg °C)	963	963	963	1000

presented in Section 3. Finally, the conclusion of this work is presented in Section 4.

2. Thermal finite element model

A finite element method (FEM) model of the sandwich plate with "fully potted" inserts is generated using the finite element package Msc. Patran/Nastran.

Dimensions of the plate are given in Table 1 according to Fig. 9.

Assuming linear elastic behaviour for the honeycomb plate, the materials used are given in Table 2.

Thermal and mechanical properties of the hexagonal honeycomb plate are taken as Aluminum (6061-T6) both for the skins and the core with the elastic modulus $E = 72$ GPa, the density $\rho = 2700$ kg/m^3, the Poisson ratio $\nu = 0.33$, the thermal conductivity $k = 155.8$ W/(m °C), and the heat capacity $C = 963$ J/(kg °C).

The filling material is required to provide a connection between the insert and the surrounding sandwich structure elements which was made of an Acrylic adhesive. The density $\rho_{adhesive} = 1400$ kg/m^3, the thermal conductivity $K_{adhesive} = 0.14$ W/(m °C), and the heat capacity $C_{adhesive} = 1000$ J/(kg °C).

2.1. Finite element model of a honeycomb sandwich plate

The finite element model of a honeycomb sandwich plate, have been established using Msc. Patran, shown in Fig. 3.

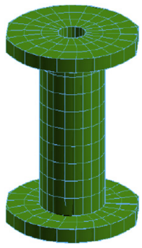

Fig. 4. Meshed finite element model of the insert.

The mesh of the skins and the core were made separately and the whole model of the honeycomb plate was assembled.

The elements employed in the finite element model are quad-4 element topology (four corner nodes) for honeycomb core and honeycomb faces.

2.2. The inserts model

The inserts were modelled with Hex8 hexahedron structural 3D solid element. Fig. 4 shows the finite element model of the insert.

2.3. The adhesive bonded joints model

There are two main problems in the classical FEM approach applied to bonded constructions. First we have to deal with the scale adherend joined by a very thin adhesive layer, which can cause mesh problems. In second case, if we do not consider the adhesive in the model, in this situation maybe can cause the influence on the results quality and also may make the singularities in the surrounding area of the insert.

An analysis was related to the insert with the adhesive one. To have a good contact between the insert, the adhesive one and the faces of the hexagonal cells thus the faces of the honeycomb, the preliminary analysis is carried on the reference joint geometry using hexagonal shape for the adherend and by conserving the real thickness of the adhesive layer and which have the same shape of the honeycomb cell. The main reason for this configuration was to give real contact approach, and once that model was working properly.

The Adhesive bonded joints model were modelled with Hex8 hexahedron structural 3D solid element.

The insert geometry for FEM analysis is simplified as shown in Fig. 5. The mechanical and geometric quantities of calculation of sandwich plate with insert are the same as those shown in Table 1.

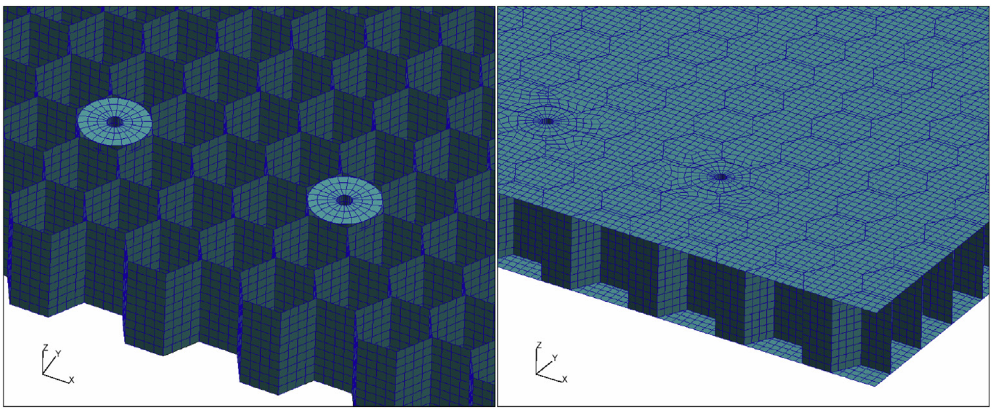

Fig. 3. FEM model of a honeycomb sandwich plate.

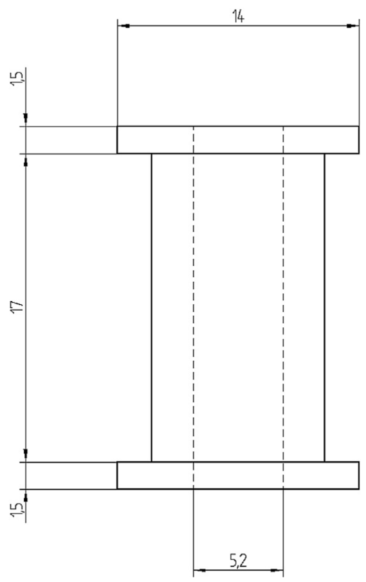

Fig. 5. Insert geometric dimension used in FEM analysis (All dimensions in mm).

In our purpose, we use the hexagonal shape for the adhesive bonded joint in the finite element model, which meets the above requirements (see Fig. 6(b)).

Fig. 6 shows the Insert and adhesive FEM model assembly.

2.4. Total model of a honeycomb plate

Total elements and nodes of the FEM models are 74904 elements and 77468 nodes for a complete honeycomb sandwich plate.

Fig. 7 shows the full FEM of the sandwich honeycomb panel, inserts position (all dimensions are in mm) and adhesive.

2.5. The boundary conditions

Multiple boundary conditions are used in this study. We apply each time either a gradient of temperature, or the solar density flux arriving at a surface of the honeycomb plate (see Fig. 8) so that to simulate the orbital condition. The different types of thermal loading used in this analysis are as follows:

- A fixed temperature (2 °C, 20 °C, 40 °C and 60 °C) on the top face of the honeycomb plate model.
- A 1378 W/m^2 direct radiation refers to the solar flux arriving at a surface of the honeycomb plate, and 5 W was applied on the honeycomb plate which represents the dissipated power in the Alsat-1 battery.

2.6. Heat transfer in honeycomb sandwich panels

A honeycomb plate has a different conductivity according to its three directions [29], namely the directions shown in Fig. 9:

- T, perpendicular to the plate, in the direction of the axes of the cells;
- S, the parallel to two branches of a cell;
- W, perpendicular to the two previous directions.

Heat transfer through honeycomb panels is non-isotropic and difficult to predict. If the effect of the cover faces is taken aside, and convection and radiation within the honeycomb cells can be neglected in comparison with conduction along the ribbons, heat transfer across each of the dimensions is [29]:

$$\dot{Q}_x = KK_L A_x \frac{\Delta T_x}{L_x} \quad (1)$$

$$\dot{Q}_y = KK_W A_y \frac{\Delta T_y}{L_y} \quad (2)$$

$$\dot{Q}_z = KK_T A_z \frac{\Delta T_z}{L_z} \quad (3)$$

With $K_L = 3\delta/2s$, $K_W = \delta/s$, $K_T = 8\delta/3s$

Where K_L, K_W, K_T are the factors modifying solid body conduction (the effective conductive area divided by the plate cross-section area), which are proportional to ribbon thickness, δ, divided by cell size, s (distance between opposite sides in the hexagonal cell), and depends on the direction considered (Fig. 9): L is along the ribbons (which are glued side by side), W is perpendicular to the sides, and T is perpendicular to the panel.

A_x, A_y, A_z = heat transfer areas (m^2)
K = thermal conductivity of the material (W/m °K)
ΔT = temperature difference across the honeycomb plate (°K)

3. Results and discussion

The thermal analysis is done on the honeycomb plate including the adhesive and inserts using Msc Patran/Msc Nastran softwares.

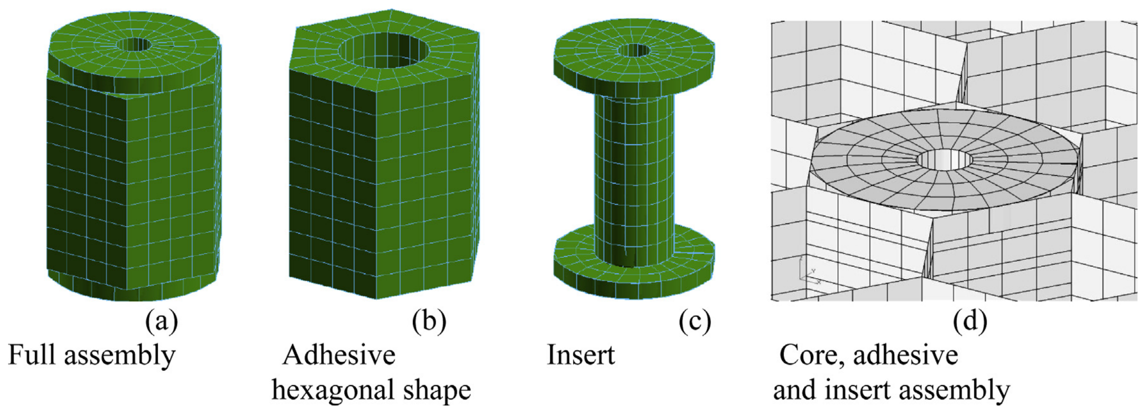

Fig. 6. Insert and adhesive FEM model assembly.

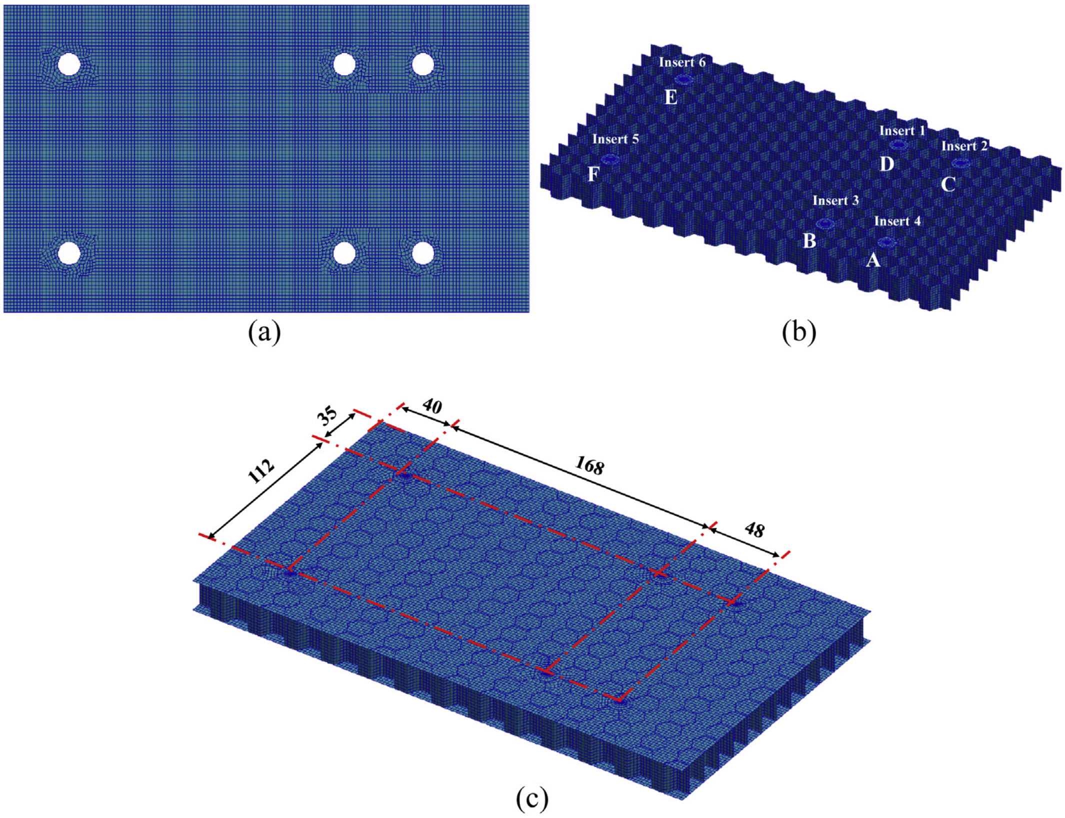

Fig. 7. Full FEM honeycomb plate. (a) FEM Honeycomb face, (b) FEM core with insert, (c) a complete FEM honeycomb model.

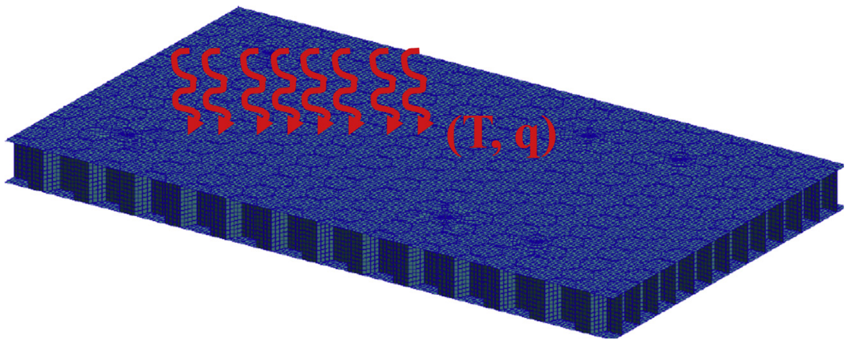

Fig. 8. Honeycomb sandwich plate subjected to heating T and heat source q over entire upper surface.

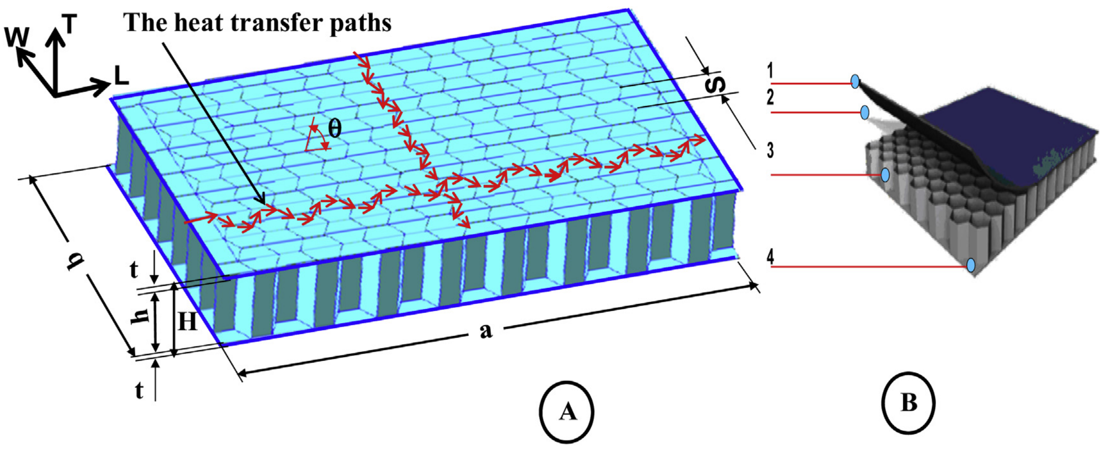

Fig. 9. Honeycomb sandwich structure. (A) Honeycomb sandwich plate geometry and heat transfer parameters. (B) 1. External Aluminium skin, 2. Adhesive, 3. Aluminium honeycomb core, 4. Internal Aluminium skin.

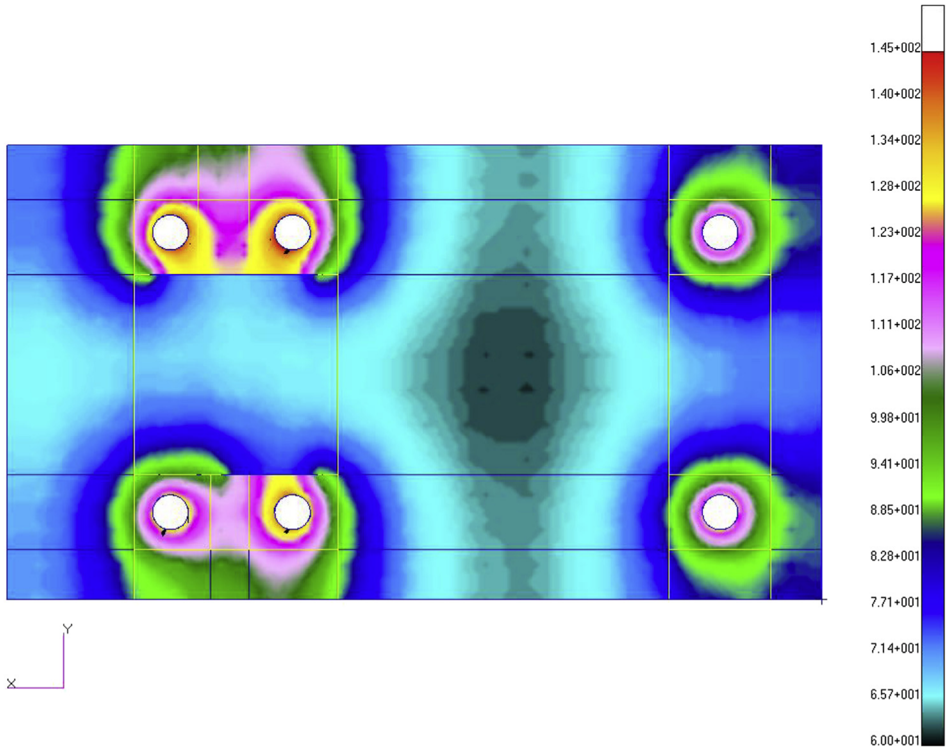

Fig. 10. Temperature Profile Distributions in °C (for Msc patran plot-boundary temperature $T = 60$ °C).

The mappings of thermal results onto a honeycomb plate model are given in this section.

The thermal temperature is a critical parameter in the mechanical design of space applications. However, the effects of the temperature on the electronic components carried by the honeycomb structures generally come from several sources. This is why these equipments are often heated significantly by the power dissipated within the devices (self heating)

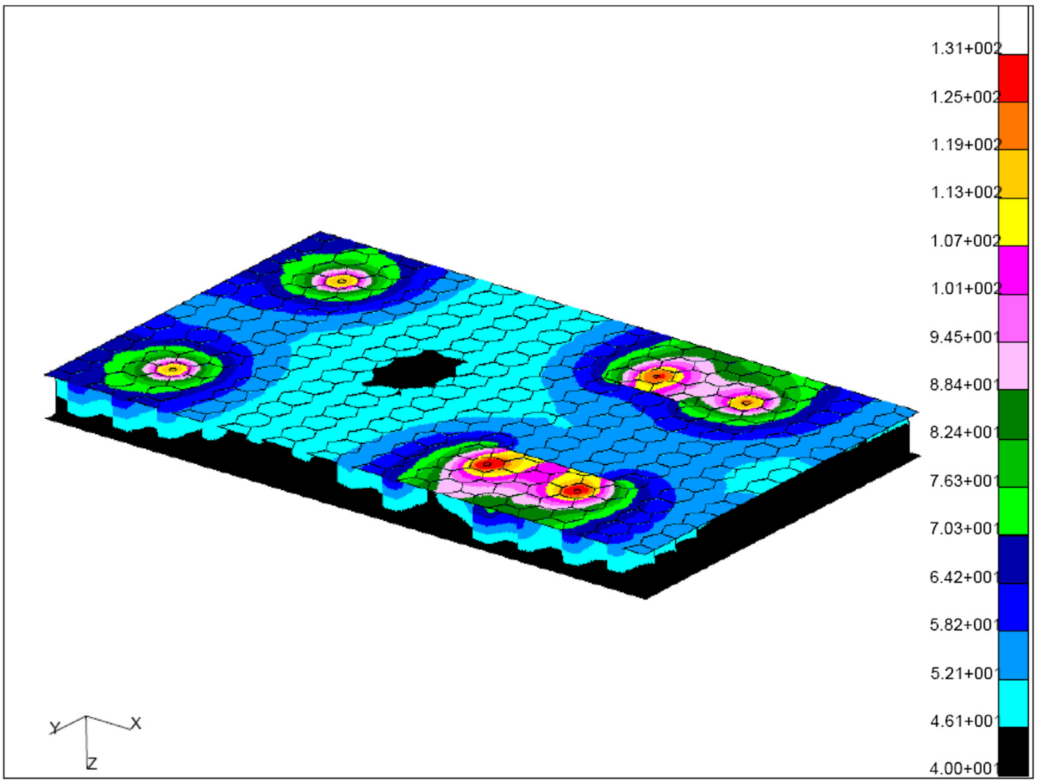

Fig. 11. Temperature Profile Distributions in °C (for Msc patran plot-boundary temperature $T = 40$ °C, $P = 1378$ W/m^2).

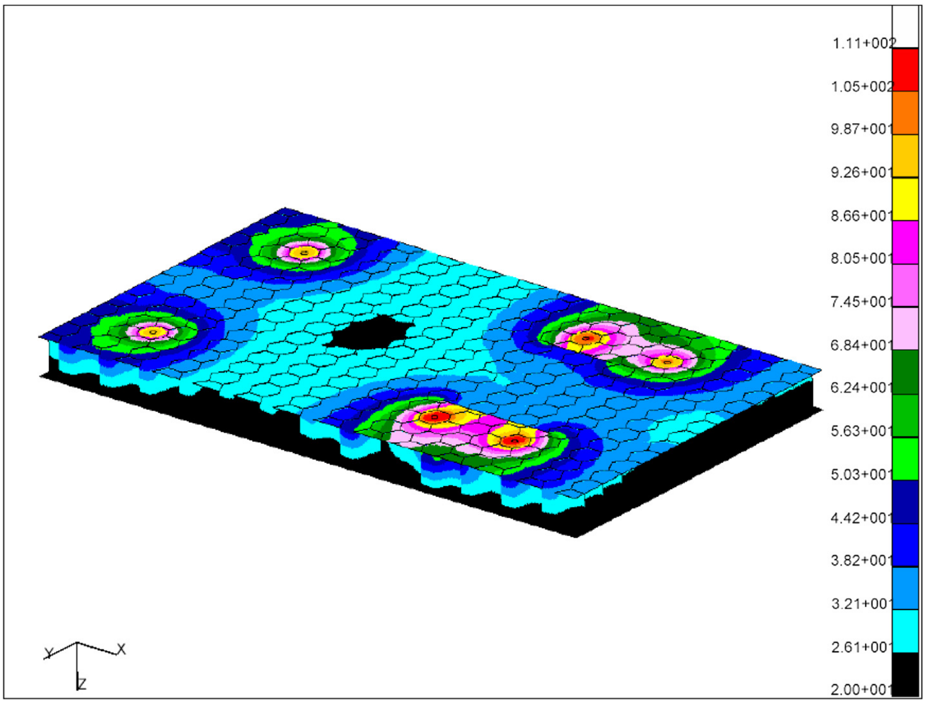

Fig. 12. Temperature Profile Distributions in °C (for Msc patran plot-boundary temperature $T = 20$ °C, $P = 1378$ W/m^2).

and by the power dissipated in adjacent inserts (thermal coupling).

All simulations were done according to Fig. 7(b), with A, B, C and D represents the adjacent inserts.

The results presented in Figs. 10 to 14 are those obtained with a honeycomb plate with six inserts and with two adjacent inserts. The analysis was carried out under the software Msc Patran and Msc Nastran.

Fig. 10 shows the results of the honeycomb plate subjected to thermal heating. The coloured fringes give the amplitude of the temperature vector describing the shape of each case. The red colour (in the web version) corresponds to maximum temperature.

Progressively with simulation, the effect of the heat transfer by conduction in the plate is noticeable. Indeed, the temperature on the level of the two adjacent inserts of the plate increases, causing a

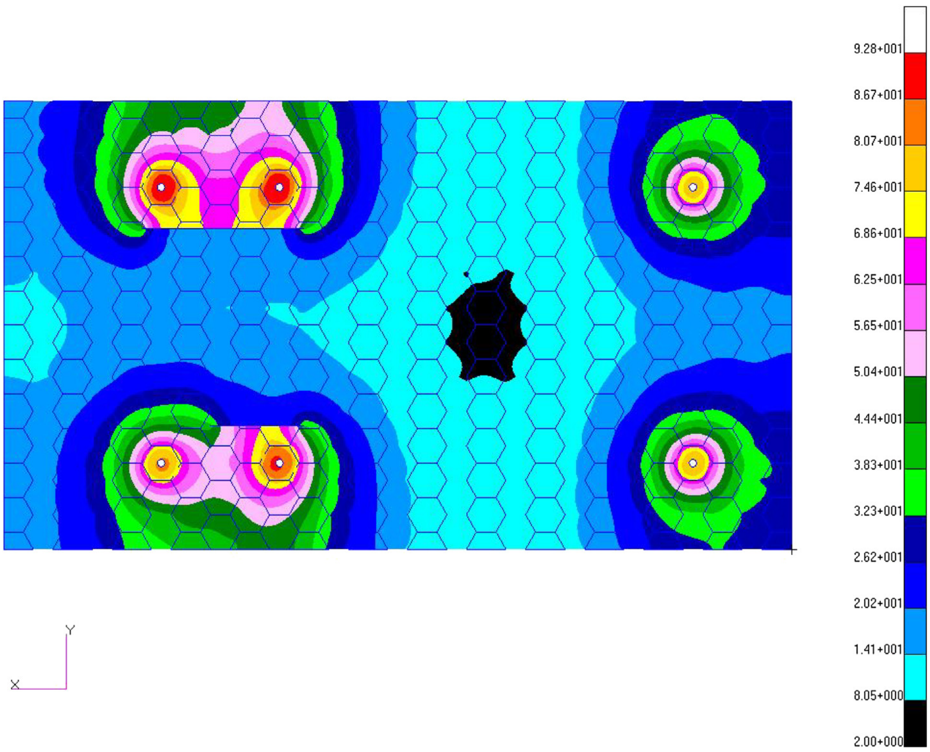

Fig. 13. Temperature Profile Distributions in °C (for Msc patran plot-boundary temperature $T = 2$ °C, $P = 1378$ W/m^2).

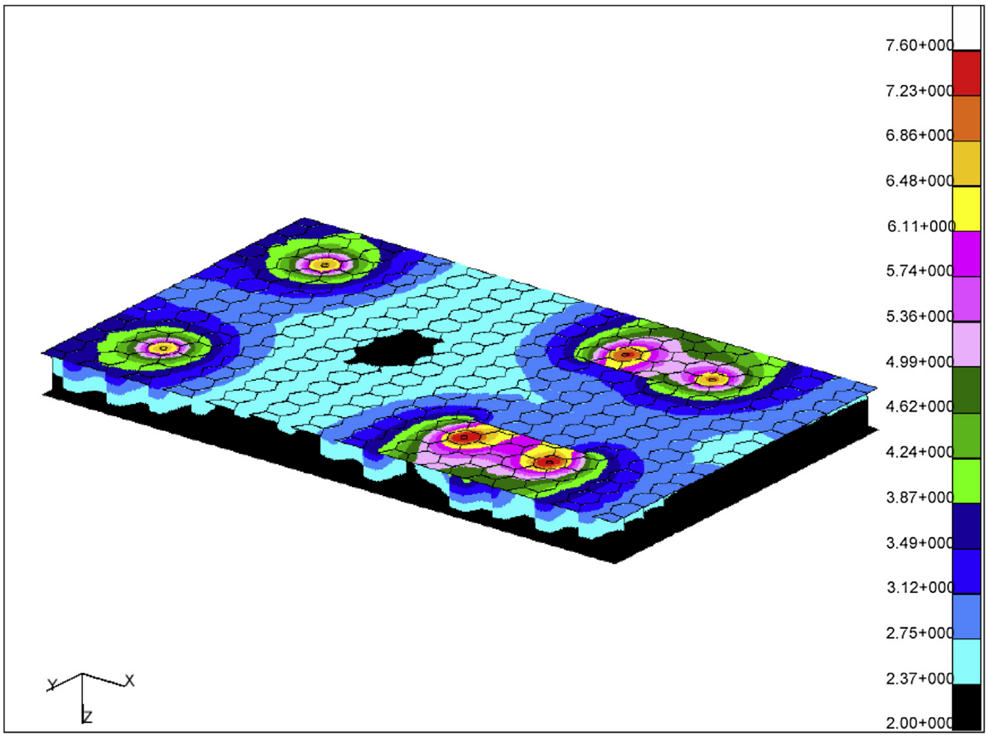

Fig. 14. Temperature Profile Distributions in °C (for Msc patran plot-boundary temperature condition, $T = 2$ °C, $P = 5$ w).

transfer of heat which comes to heat the electronics components carried by the panel.

Note that a strong coupling was observed in the inserts (D) and (C) as well as in the inserts B and A. However, we have found that the weak coupling is observable in the case of inserts E and F.

The choice of the type of adhesive affects the coupling region. On the other hand, the temperature variation has an effect on the performance of the adhesive. Therefore, the need of reliable highly material properties for adhesive joints is very important in spacecraft design.

We notice that the increase or decrease of temperature depends on the temperature imposed in the boundary conditions. This is due to the existence of temperature variations on the satellite orbit.

We also note that the distance between the inserts plays an important part in increasing the heat transfer in the coupling region. Another issue is when heat travels through the core, most of it is conducted through the walls of the cells, which furthermore contribute to increasing the heat transfer in the coupling region.

The presence of a large amount of heat in the coupling area is also due to the dissipated power by the equipments carried by the honeycomb plate.

A specific thermal control of the alsat-1b battery is a necessary process for removing excessive heat from inside battery pack in order to keep the battery components within a safe operating temperature.

Fig. 15 shows the temperature profiles along cross head inserts along X-directions. According to the results, the lateral heat distribution effect causes the thermal coupling between the inserts.

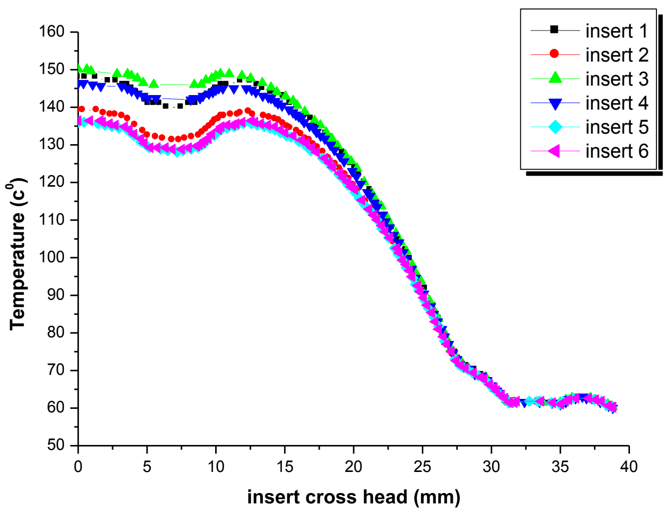

Fig. 15. The temperature variations in insert cross head (for Msc patran plot-boundary temperature $T = 80$ °C).

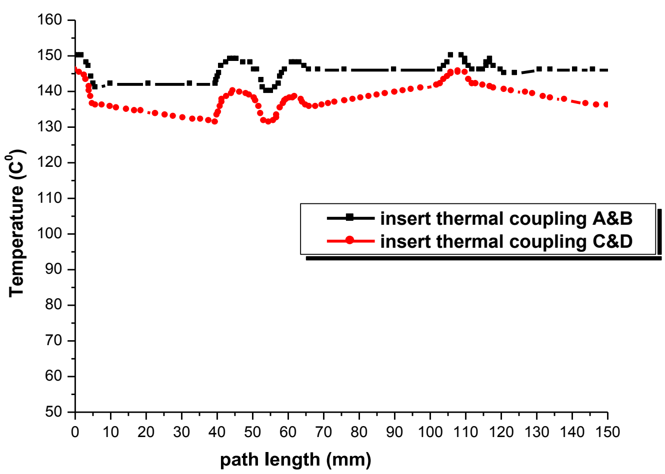

Fig. 16. Temperature profiles along path length of the honeycomb plate (for Msc patran plot-boundary temperature $T = 80$ °C).

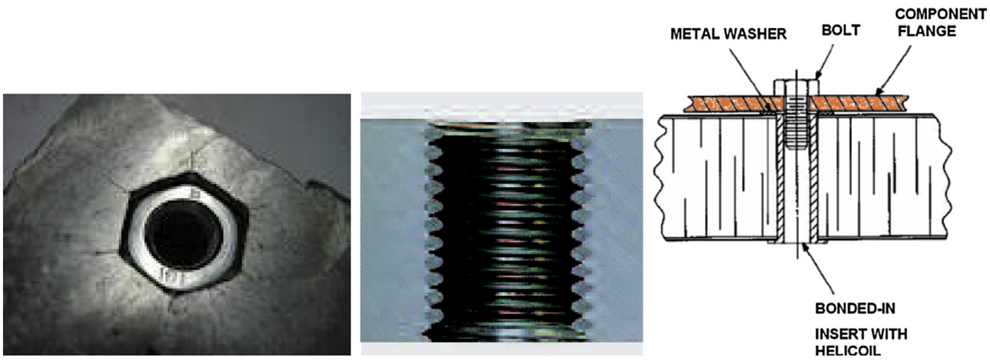

Fig. 17. Helicoils assembly.

Fig. 16 shows the temperature profiles along path length of the honeycomb plate. It is noticed that the variation in temperature involves the increase in the temperature of neighbouring inserts, which creates a thermal coupling.

The temperature distribution pattern in a heated structural insert joint of a given geometry was found to change considerably due to the closed insert. The degree of such change depends on the value of interface thermal conductivity.

In this situation the exposure of the honeycomb panel to extreme temperatures, the structural adhesives are expected to undergo a thermal degradation.

It is noticed that the position of the inserts and the assembly of the equipment in the honeycomb plate are very significant in order to avoid any risk failure. To avoid this, multiple activities may be approved during the preliminary satellite design phase. Current uses consist in the assembly to add helicoils in order to ensure a significant braking which is opposed at any risk of inopportune unscrewing of the screw (thermal or vibratory shocks) as shown on Fig. 17.

For space designers, a selection of space materials play a vital role in heat transfer management in a honeycomb plate with fully-potted inserts used for spacecraft design. The success of any particular design with regard to thermal management materials will depend on the thoroughness of the research, the quality of the material and its proper dependence of temperature.

4. Conclusion

In light of this study, the thermal coupling problem between two adjacent inserts of a honeycomb plate was analysed.

The clearance and thermal interference between the adjacent inserts has an important influence on the satellite equipments (such as the electronics box), which can cause the satellite equipments failures.

The representation of adhesive model using finite elements analysis in this study proved to be a good approach and improves the quality of the results.

From the results obtained in this paper, the position of the inserts and the assembly of the equipment into the honeycomb plate are very significant in order to avoid any risk failure.

This study will help to guide the designers and manufacturing specialists in choosing the most effective parameters for improving the robustness of bonded joints using inserts and thus to improve its design by selecting optimum joint configurations.

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References

[1] T. Bitzer, Honeycomb Technology, Chapman & Hall, London, 1997.
[2] A. Boudjemai, R. Amri, A. Mankour, H. Salem, M.H. Bouanane, D. Boutchicha, Modal analysis and testing of hexagonal honeycomb plates used for satellite structural design, Mater. Des. 35 (March 2012) 266–275.
[3] A.G. Evans, J.W. Hutchinson, N.A. Fleck, M.F. Ashby, H.N.G. Wadley, The topological design of multifunctional cellular metals, Prog. Mater. Sci. 46 (2001) 309–327, http://dx.doi.org/10.1016/S0079-6425(00)00016-5.
[4] H.N.G. Wadley, N.A. Fleck, A.G. Evans, Fabrication and structural performance of periodic cellular metal sandwich structures, Comp. Sci. Technol. 63 (2003) 2331–2343, http://dx.doi.org/10.1016/S0266-3538(03)00266-5.
[5] A.G. Evans, J.W. Hutchinson, M.F. Ashby, Multifunctional of cellular metal systems, Prog. Mater. Sci. 43 (1999) 171–221, http://dx.doi.org/10.1016/S0079-6425(98)00004-8.
[6] A. Boudjemai, M. Bekhti, M.H. Bouanane, A.M. Si Mohammed, G. Cooper, G. Richardson, Small satellite computer-aided design and manufacturing, SP-581, in: Proceedings of the European Conference on Spacecraft Structures, Materials & Mechanical Testing, 10–12 May 2005, August 2005, pp. 181–188. ISSN: 1609-042X.
[7] A. Boudjemai, M.H. Bouanane, L. Merad, M.A. Si Mohammed, in: Small Satellite Structural Optimisation Using Genetic Algorithm Approach, 3rd International Conference on Recent Advances in Space Technologies, RAST '07, 2007, pp. 398–406. Istanbul, Turkey, ISBN: 1-4244-1057-6, © IEEE.
[8] R. Amri, D. Gibbon, In orbit performance of butane propulsion system, Adv. Space Res. 49 (2012) 648–654.
[9] F. Noirot, J.-F. Ferrero, J.-J. Barrau, B. Castanié, M. Sudre, Analyse d'inserts pour les structures sandwich composites, Mec. Ind. 1 (2000) 241–249.
[10] Insert Design Handbook, 1987. ESA PSS 03-1202.
[11] O.T. Thomsen, Sandwich plates with 'through-the-thickness' and 'fully-potted' insert: evolution of differences in structural performance, Compos. Struct. 40 (2) (1998) 159–174.
[12] www.shur-lok.com/product_dls/Design_Manual.pdf.
[13] www.shur-lok.com/product_dls/Sandwich_Structure.pdf.
[14] http://www.wittenco.com/WittenCo-Catalog.pdf.
[15] Sebastian Heimbs, Marc Pein, Failure behaviour of honeycomb sandwich corner joints and inserts, Compos. Struct. 89 (2009) 575–588.
[16] Bryan Smith, Biswajit Banerjee, Reliability of inserts in sandwich composite panels, Compos. Struct. 94 (3) (February 2012) 820–829.
[17] Song-Jeng Huang, Hwa-Long Lin, Hsiao-Wei Liu, Electronic speckle pattern interferometry applied to the displacement measurement of sandwich plates with two 'fully potted' inserts, Compos. Struct. 79 (2007) 157–162.
[18] Elena Bozhevolnaya, Anders Lyckegaard, Structurally graded core inserts in sandwich panels, Compos. Struct. 68 (2005) 23–29.
[19] P. Bunyawanichakul, B. Castanié, J.-J. Barrau, Non-linear finite element analysis of inserts in composite sandwich structures, Compos. Part B 39 (2008) 1077–1092.
[20] Byoung Jung Kim, Dai Gil Lee, Characteristics of joining inserts for composite sandwich panels, Compos. Struct. 86 (2008) 55–60.
[21] G. Bianchi, G.S. Aglietti, G. Richardson, Optimization of bolted joints connecting honeycomb panels, in: 1st CEAS, 10th European Conference on Spacecraft Structures, Materials and Mechanical Testing, Berlin, Germany, 10–13 Sep 2007, 2007.
[22] P. Bunyawanichakul, B. Castanie, J.-J. Barrau, Experimental and numerical analysis of inserts in sandwich structures, Appl. Compos. Mater. 12 (2005) 177–191.
[23] N. Raghu, M. Battley, T. Southward, Strength variability of inserts in sandwich panels, J. Sandw. Struct. Mater. 11 (6) (2009) 501.

[24] G. Bianchi, G.S. Aglietti, G. Richardson, Static performance of hot bonded and cold bonded inserts in honeycomb panels, J. Sandw. Struct. Mater. (2010), http://dx.doi.org/10.1177/1099636209359840.
[25] Byoung Jung Kim, Dai Gil Lee, Development of a satellite structure with the sandwich T-joint, Compos. Struct. 92 (2010) 460–468.
[26] H.K. Cho, J. Rhee, Vibration in a satellite structure with a laminate composite hybrid sandwich panel, Compos. Struct. 93 (2011) 2566–2574.
[27] Keun-Il Song, Ji-Young Choi, Jin-Hwe Kweon, Jin-Ho Choi, Kwang-Soo Kim, An experimental study of the insert joint strength of composite sandwich structures, Compos. Struct. 86 (2008) 107–113.
[28] M. Bekhti, M.N. Sweeting, High Temperature Effects on the Performances of the Alsat-1 Power Subsystem, vol. 1–2, RIGEL, January 2011, pp. 48–56.
[29] Gilmore G. David, Spacecraft Thermal Control Handbook, in: Fundamental Technologies, vol. I, The Aerospace Corporation, EL Segundo, California, 2002.