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

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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

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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 facesheets 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 nonlinearity 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

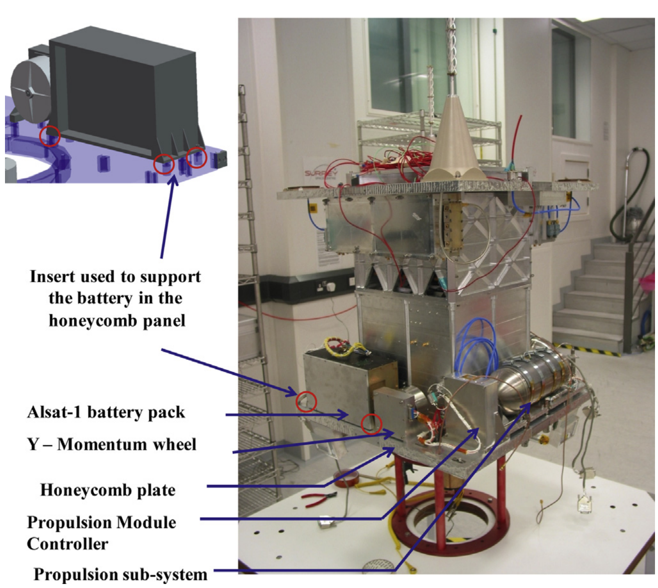

Fig. 1. Honeycomb sandwich applications in the first Algerian Microsatellite Alsat-1.

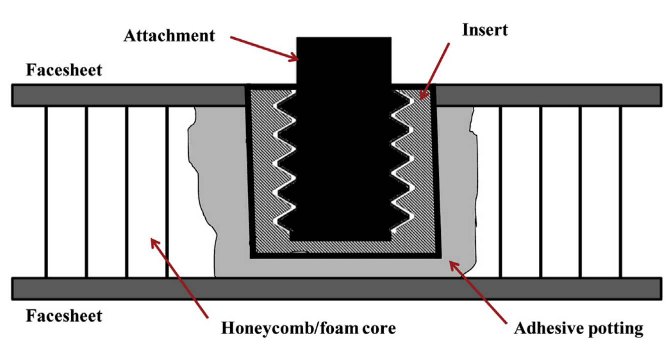

Fig. 2. An insert in a sandwich panel.