THERMOSTRUCTURAL ANALYSIS OF HONEYCOMB SANDWICH PANELS

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Abstract

The thermal analysis is performed on a heated Inconel 617 honeycomb-core sandwich panel. Sandwich panel is supported at its four edges with spar-like sub-structures that acted as heat sinks, which are generally not considered in the classical analysis. One side of the panel is subjected to a heat flux on the surface. Two types of surface heating were considered: (1) hexagonal honeycomb sandwich panels, and (2) square honeycomb sandwich panel, which approximates the actual surface temperature distribution associated with the existence of edge heat sinks. The finite-element method is used to find the thermal stress distributions in the face sheets and core of the sandwich panel. The detailed thermal stress distributions in the sandwich panel are presented. This technical report presents comprehensive, 3D graphical displays of thermal stress distributions in every part of a Inconel 617 honeycomb-core sandwich panel and also shows the comparison of effective heat transfer rate between hexagonal and square honey comb sandwich panels.

This Paper is to perform geometrical analysis of different candidate honeycomb cells that have the same effective density but different geometrical shapes. heat-transfer analysis of TPSs with different honeycomb cell geometry and thermal bending analysis of TPS panels subjected to one-sided heating and under different support conditions.

Key words: *High Temperature Material, Honey comb Structure, Ansys.*

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1. INTRODUCTION

A sandwich-structured composite is a special class of composite materials that is fabricated by attaching two thin but stiff skins to a lightweight but thick core. The core material is normally low strength material, but its higher thickness provides the sandwich composite with high bending stiffness with overall low density.

Sandwich panels are used for design and construction of lightweight transportation systems such as satellites, aircraft, missiles, high speed trains. Structural weight saving is the major consideration and the sandwich construction is frequently used instead of increasing material thickness. This type of construction consists of thin two facing layers separated by a core material. Potential materials for sandwich facings are aluminum alloys, high tensile steels, titanium and composites depending on the specific mission requirement. Several types of core shapes and core material have been applied to the construction of sandwich structures. Among them, the honeycomb core that consists of very thin foils in the form of hexagonal cells perpendicular to the facings is the most popular.

A sandwich construction provides excellent structural efficiency, i.e., with high ratio of strength to weight. Other advantages offered by sandwich construction are elimination of welding, superior insulating qualities and design versatility. Even if the concept of sandwich construction is not very new, it has primarily been adopted for non-strength part of structures in the last decade. This is because there are a variety of problem areas to be overcome when the sandwich construction is applied to design of dynamically loaded structures. To enhance the attractiveness of sandwich construction, it is thus essential to better understand the local strength characteristic of individual sandwich panel/beam members.

The conventional single skin structure, which is of single plates reinforced with main frames and stiffeners normally necessitates a fair amount of welding, and has a considerable length of weld seams. Further, the lighter but thinner plates employed tend to increase weld distortions that may in some cases require more fabrication work to rectify. More weld seams also mean a greater number of fatigue initiation locations as well. Honeycomb sandwich construction, with a honeycomb core is sandwiched by two outer facing skins is better able to cope with such difficulties.

Sandwich panels also provide added structural weight savings in the structure. It is for these reasons that the sandwich construction has been widely adopted for large weight critical structures. Honeycomb-cored sandwich panels have been used as strength members of satellites or aircraft, thus efficiently reducing their structural weight. In the railroad industry, passenger coaches of high-speed trains have been designed and fabricated using aluminum honeycomb sandwich panels. Recently, attempts to use aluminum sandwich panels as strength members of high-speed vessel hulls have also been made.

Honeycomb is predominately used as a core in sandwiched structures to meet design requirements for highly stressed structural components. When sandwiched between layers of carbon fiber, honeycomb exhibits extreme resistance to shear stresses. As a structural core material, it is used in all types of aerospace vehicles and supporting equipment where sandwich structure offers rigid panels of minimum weight, aerodynamic smooth surfaces, and high fatigue resistance. The same structural properties are also used for commercial applications such as tools, snow and water skis, bulkheads, and floors. Honeycomb is also used where designs need a means of directional air/fluid flow control and/or energy absorption.

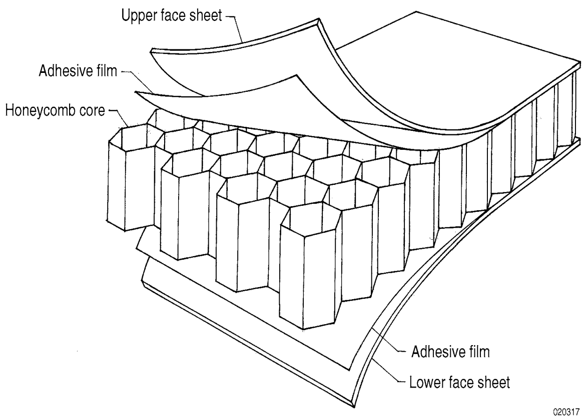

Fig-1: Exploded view of honeycomb core sandwich panel.

Goodrich fabricates titanium and Inconel honeycomb structures where light weight, stiffness, and elevated temperature durability are required. The titanium honeycomb structures utilize the patented Liquid Interface Diffusion (LID) bonding process, resulting in near-parent material properties for the honeycomb-to-skin joint.

Goodrich also offers a unique technology called Super plastic Forming (SPF) of large structures in a vacuum furnace which require no post-SPF chem-milling. This process is ideal for circular structures such as nozzle components.

2. ANALYSIS

Thermal analysis calculates the temperature distribution and related thermal quantities in the system or component .Typical thermal quantities are:

- The temperature distribution
- The amount of heat lost or gain.
- Thermal gradients.
- Thermal fluxes

Thermal analysis plays a very important role in the design of many engineering applications, including internal combustion engines ,turbines, heat exchangers, piping systems and electronic components. In many cases , engineers follow a thermal analysis with a stress analysis to calculate thermal stress.

3. MATERIAL PROPERTIES OF THE INCONEL617

- Heat flux =10W/m^{2}k.
- Young’s Modulus=27.50e6 N/mm^2
- Poissons ratio=0.27
- Thermal Expansion=7.5e10-6 /°C
- Density=0.301 Kg/mm^3

4. HEAT TRANSFER ANALYSIS

Heat transfer is a science that studies the energy transfer between two bodies due to temperature difference. conductive heat transfer analysis on honey comb sandwich panels and the tiny volume inside each honeycomb cell, convection heat transfer of the interior air mass were neglected. This section studies the effect of honeycomb cell geometry on the heat-shielding performance of the TPS panel. Before doing analysis to mesh the model so that the effectively find the change in temperature at each and every point. As it is difficult to regenerate all cells, Heat transfer analysis only on one cell by symmetry and calculate heat transfer in all cells. Performing heat transfer analysis under transient state condition.

5. TRANSIENT THERMAL ANALYSIS

Transient Thermal Analysis determines temperatures and other thermal quantities that vary over time. Engineers commonly use temperatures that a transient thermal analysis calculates as input to structural analysis for thermal stress evaluations.

A transient thermal analysis follows basically the same procedures as a steady –state thermal analysis. The main difference is that most applied loads in a transient thermal analysis are functions of time .To specify time-dependent loads, use both the Function Tool to define an equation or function describing the curve and then apply the function as a boundary conditions or divide the load –versus –time load into load steps.

6. MODELLING AND ASSEMBLY

The honeycomb-core structure is fabricated using multiple layers of thin strips of metallic (or nonmetallic) foils joined together and properly deformed. The thin strips are bonded together first at equally spaced parallel zones. The equally spaced bonding zones on one side of each thin strip are staggered with respect to those on the opposite side. The bonded multiple sheet assembly then is pulled apart in the thickness direction through bending of the bonded and free junctures to form a final honeycomb structure. By modifying the width of the interfacial bonding belt zones and their spacing, and by pulling apart the multiple layers through bending deformations to a desired level, a family of different honeycomb cell geometry could be generated. Figure.1 shows the exploded view of the construction of a sandwich panel with upper and lower face sheets to be bonded to the honeycomb core through the brazing process.

Figure shows two types of honeycomb cell geometry to be analyzed. The honeycomb cell wall thickness for the first three types is t(c). The first type is a right hexagonal cell with identical side lengths of b1. The second type is a square cell with side lengths of b2, which is modified from the right hexagonal cell by reducing the bonding interface length to a minimum of √2 tc. The size, d(i) (i=1,2) of each type of honeycomb cell is defined as the maximum diagonal of the cell cross section.

6.1 Cell Dimmensions

The size of honeycomb cells types 1, 2, are adjusted to have the same effective density (that is, ρ1= ρ2). By equating equations, the cell sizes d1 and d2 are determined as

$$d_1 = \frac{10\sqrt{3}}{3\sqrt{2}(\sqrt{2}+3)} d_3$$

$$d_2 = \frac{15}{4(\sqrt{2}+3)} d_3$$

Where . *l:* side length of honeycomb-core sandwich Panel

a: depth of honeycomb core

t_c : honeycomb cell wall thickness

t_s : sandwich face sheet thickness

b_i : length of free side of type I honeycomb cell cross section

b^1: length of bonded double side of TPS cell cross section

d_i : size of type i honeycomb cell (maximum diagonal of the cell cross section)

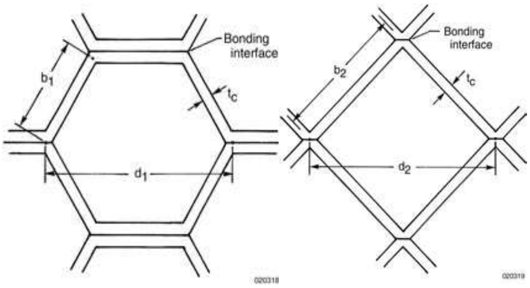

Fig- 2: (a) Right hexagonal cell. (b) Square cell

6.2 Numerical Input Values

A typical candidate TPS panels has the following dimensions are given:
a = 0.488 in., d3 = 6.35mm. l = 424.18mm. ts = 1.524mm. tc = 0.0381mm.

Cell type	b(*i*),mm.	b'.mm	d(*i*),mm	t(*c*),mm.
Hexagonal	2.93624	2.93624	5.87248	0.0381
Square	3.81508	0	5.39496	0.0381

Table-1: Dimensions Of Hexagonal & Square Honey Comb Sandwich Panels

Modeling of Hexagonal Honey Comb Face Plate

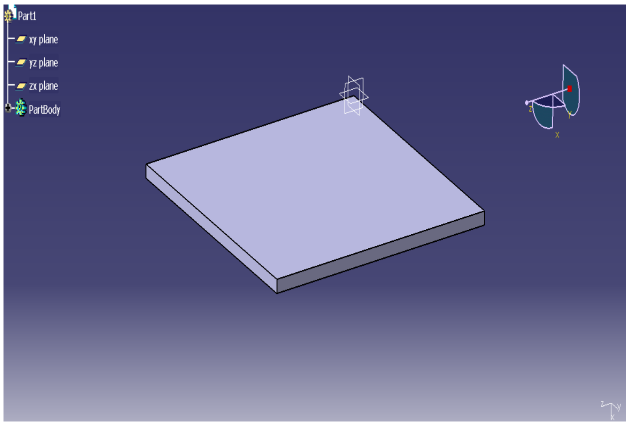

Fig- 3: Modelling Of Honey Comb Face Plate

Modelling of Hexagonal Honey Comb Cells

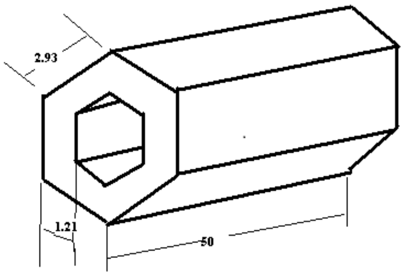

Fig- 4: Geometry Of Hexagonal Honey Comb Cell

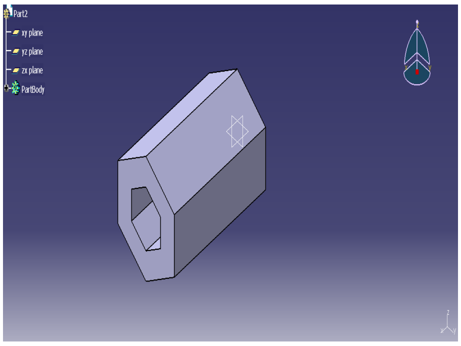

Fig- 5: Hexagonal Honeycomb Model

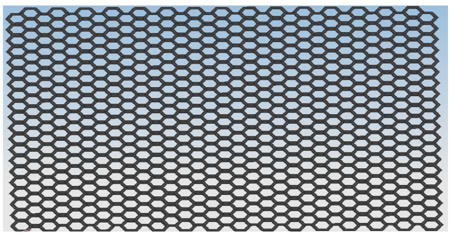

Fig -6: Pattern Of Hexagonal Honeycomb Cells

ASSEMBLY

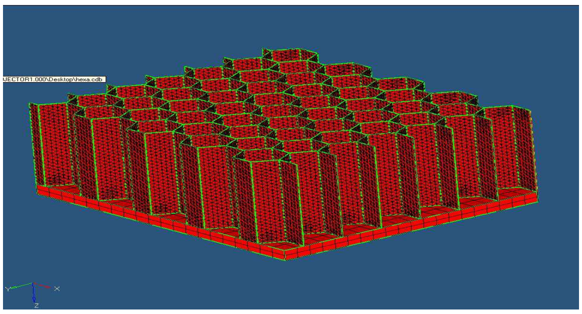

Fig-7: Hexagonal Cells Placed On Face Plates

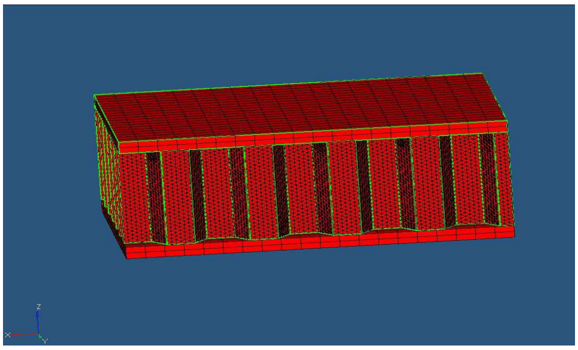

Fig-8: Modelling of Square Honey Comb Cells

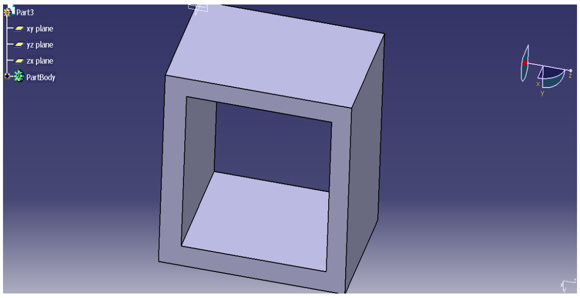

Fig-9: Square Honey Comb Model

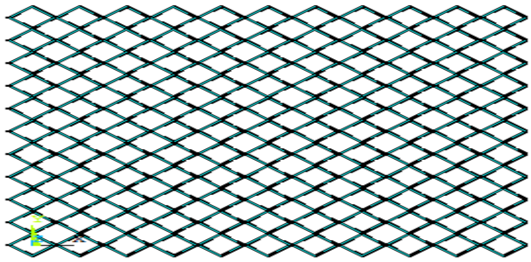

Fig-10: Pattern Of Square Honey Comb Cells

ASSEMBLY

Fig-11: Square Cells Placed On Face Plate

S.NO	TIME(SEC)	TEMPERATURE
1	50	420
2	100	380
3	150	365
4	200	330
5	250	305

Table- 2: Temperature vs Time for Hexagonal structure

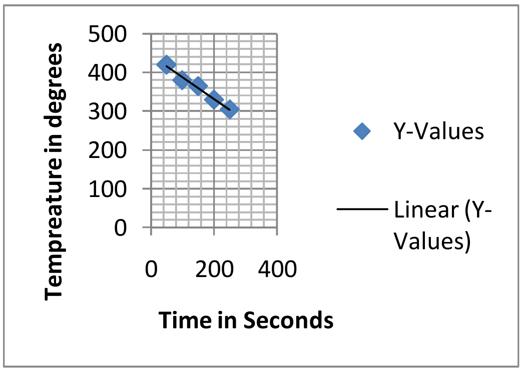

Fig-12: Temperature vs Time graph

S.NO	TIME(sec)	TEMPERATURE
1	50	450
2	100	402
3	150	360
4	200	318
5	250	290

Table-3: Temperature vs Time For Square structure

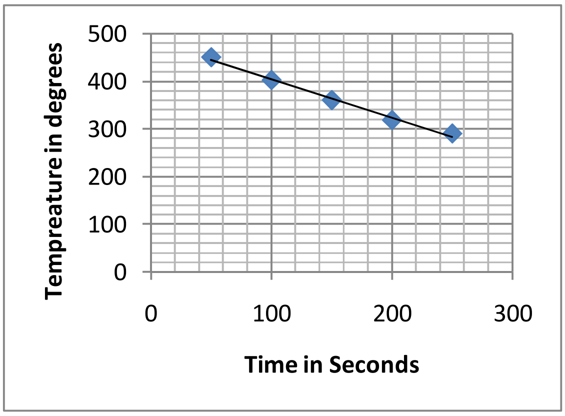

Fig-13: Temp Vs Time Graph

7. THERMAL BENDING ANALYSIS

A particular method is employed for the analysis of bending behavior for the present sandwich panel specimen. A simply supported fixed edges and fixed supported fixed edges panel is subjected to a thermal load at its mid-span is considered. If the thickness t_f of facing plates is small, the variation of bending stress through plate thickness direction may be ignored.

Figure shows a finite-element model generated for the honeycomb TPS panel for thermal bending analysis. Because of symmetry with respect to the in-plane x- and y-axes, only few cells of the TPS panel were modeled.

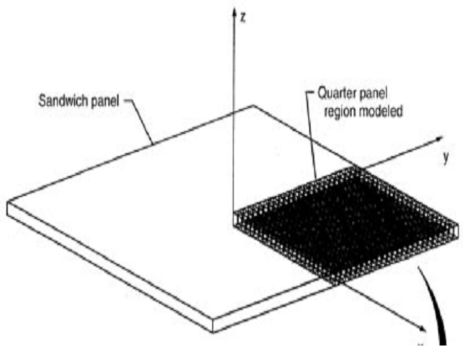

Fig-14: Finite-element model generated for the honeycomb TPS panel for thermal bending analysis

Each face sheet is modeled with one layer of quadrilateral combined membrane and bending 4 node Solid 285 element type, and the honeycomb core with a single layer of tetrahedral structural solid with nodal pressures S81 elements connecting the upper and lower face sheet 4 node Solid 285 elements.

In the thermal bending analysis, the extensional and bending stiffness of the sandwich panel is assumed to be carried by the two face sheets, and the transverse shear stiffness by the honeycomb core. The TPS panel will be supported under the following different boundary conditions for comparing different degrees of thermal deformations and thermal stress fields induced in the TPS panel:

1.Fixed simply supported edges : Four edges of the middle plane are simply supported and fixed.
2. Free simply supported edges : Four edges of the middle plane are simply supported, but are allowed to move freely in the x and y directions.

This method of simply supporting a sandwich panel is slightly different from simply supporting a solid flat plate. To simulate the fixed or free simply supported condition for the sandwich panel, pin-ended rigid rods were attached vertically to the panel edges (or corners) to connect the two face sheets .

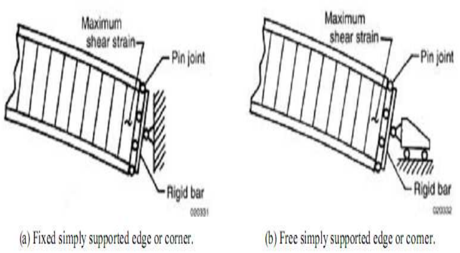

Fig-15: Different support conditions at edges or corners of honeycomb sandwich TPS panel

Because the honeycomb core does not carry extensional or bending stiffness, edge support points cannot be attached to the honeycomb core. The midpoint of each rigid rod was pin-joined to a point (fixed or movable in the x-y plane) lying in the hypothetical panel middle plane. Each pin-ended rigid rod was modeled with two identical E22 elements (beam elements for which the intrinsic stiffness matrixes are given). To simulate the rigidity of the rods, the extensional and the transverse shear stiffness of the E22 elements were made very large. The pin-joint condition at the face sheet edges was simulated by assigning zero values to the rotational spring constants in the stiffness matrix for the E22 elements. To simulate the pin-joint condition at the hypothetical middle plane, the three rotational constraints were eliminated. One node of each E22 element was connected to the associated node of E43 element, and the other node was connected to the hypothetical middle-plane point. For the fixed or free simply supported edges, only one pair of E22 elements was attached to one corner of the model. For the fixed or free clamped edges , the panel edges (or corners) were constrained to have zero transverse rotations.

Support Condition	E22	E43
Simply supported, Clamped edges	98	1152
Simply supported, clamped corners	2	1152

Table-4: Sizes of quarter-Panel finite-element models for honeycomb TPS panel

The upper face sheet will be heated uniformly to temperature, *T(u)*, of 800 °F and the lower sheet to temperature, *T(l)*, of 450 °F. These temperature levels are similar to the temperatures across the TPS depth giving the maximum temperature gradient at a certain body point during a new STS mission.

This section examines the panel deflections and the levels of the induced thermal stresses in the TPS panel under different support conditions.

We are performing coupled field analysis on the TPs panel. Coupled field includes both thermal and structural analysis. Before the analysis, we need to mesh the model so that we would be effective to find out the stress distribution at each and every point.

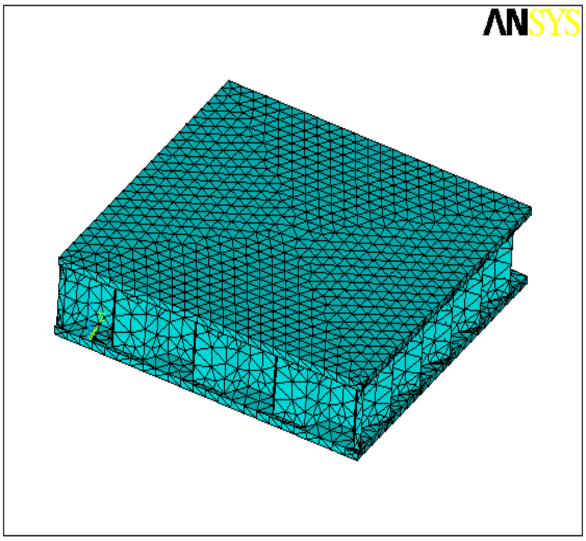

Fig-16: Meshing Of Hexagonal Honey Comb Sandwich Panel

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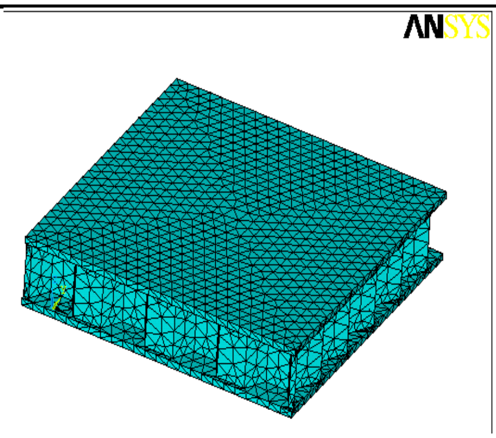

Fig-17: Meshing Of Square Honey Comb Sandwich Panel

CASE 1 : FIXED SIMPLY SUPPORTED EDGES

Thermal Bending Analysis Of Hexagonal Structure

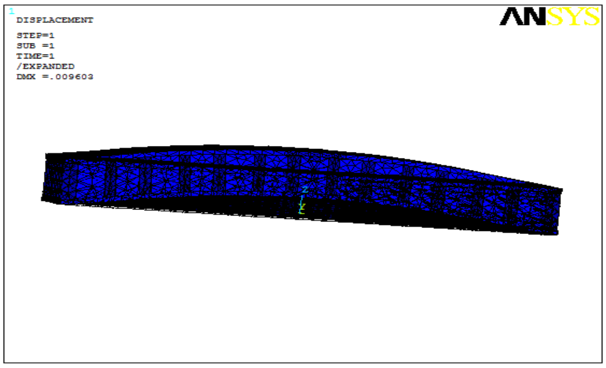

Fig- 18: Maximum Deflection for Hexagonal Cell Structure

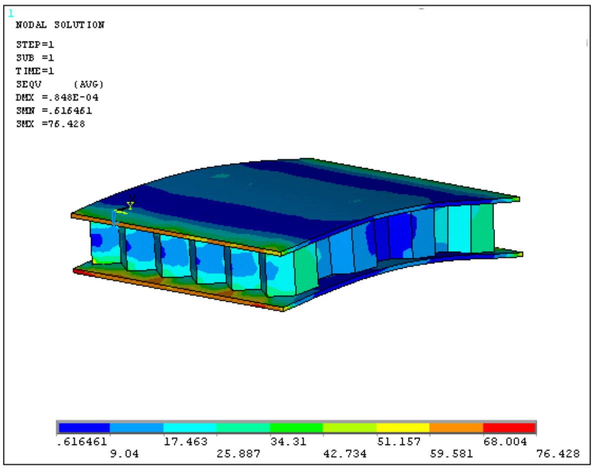

Fig-19: Stress Distribution for Hexagonal cell Structure

THERMAL BENDING ANALYSIS OF SQUARE CELL STRUCTURE

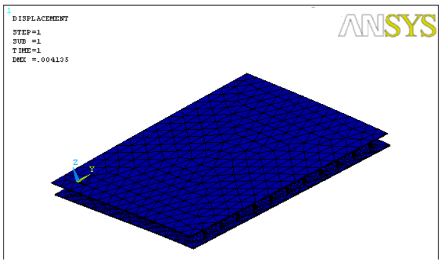

Fig-20: Maximum Deflection for Square Cell Structure

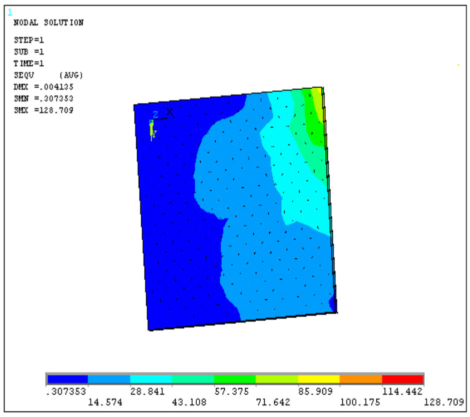

Fig-21: Stress Distribution for Square Cell Structure

CASE 2 : FREE SIMPLY SUPPORTED EDGES

Thermal Bending Analysis of Hexagonal Structure

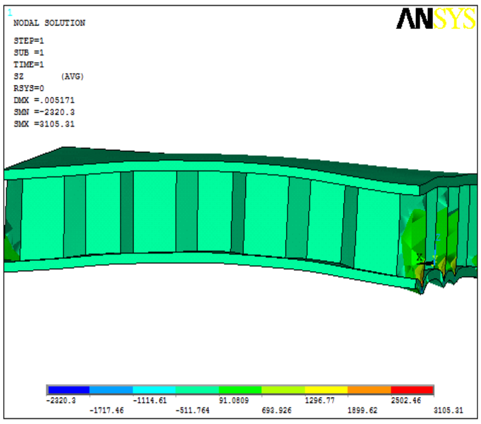

Fig-22: Stress Distribution for Hexagonal cell Structure

Thermal Bending Analysis Of Square Cell Structure

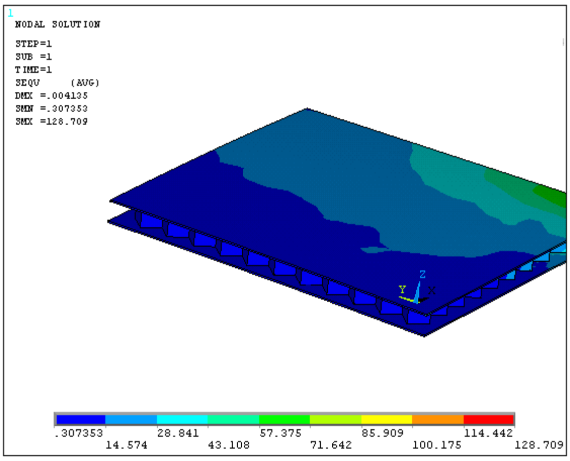

Fig-23: Stress Distribution for Square cell Structure

The effect of TPS honeycomb cell geometry has been investigated. The result of thermal bending analysis of superalloy honeycomb TPS panels are as follows :

The above figures show typical deformed shapes of honeycomb TPS panel subjected to thermal bending (Tu=800 °F; Tl=450 °F) for case with simply supported fixed edges and free supported fixed edges.

Boundary conditions	Panel center W(*max*)	Upper center σ(*x*) *max*
1.Fixed simply supported Edges		
(a)Hexagonal panel	0.009603	76.488
(b)Square panel	0.004135	128.708
2. Free simply supported Edges		
(a)Hexagonal panel	0.005171	3105.31
(b)Square panel	0.003215	128.709

Table-5: Panel deflections and thermal stresses induced in the face sheets of superalloy honeycomb TPS under different support conditions

Table shows a summary of the deflections at the sandwich panel center, W (*max*) and stresses {σ(*x*)*max* } induced at the center of the upper face sheets.

When the panel is under "fixed simply supported corners" and "free simply supported corners", it results in outward bulging of the panel, hence to eliminate the outward bulging condition, we are considering "edges" condition instead of "corners". However the fixed edges conditions causes high stresses on the face sheets that could cause the entire TPS panel to buckle.

8. CONCLUSION

This paper deals with modelling of honeycomb structure performing thermal analysis using ANSYS 12 software and comparing the heat transfer rate in different sandwich panels . As hexagonal area is greater than square honeycomb sandwich panel area, it requires more time to transfer heat from top surface to bottom surface. Thermal bending analysis was performed on a super alloy thermal protection system(TPS) honeycomb sandwich panel. The deflections and thermal stresses are obtained under different support conditions by the deflection and stress distribution values.

So we can find out the heat transfer rate is effective in hexagonal honeycomb sandwich panels when compared to square honeycomb sandwich panels and the hexagonal cells have less stress distribution and have good stiffness than the square cells.

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