

## Heat Insulation Analysis of an Aluminium Honeycomb Sandwich Structure

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### Abstract

Heat-transfer has been performed on a sandwich thermal protection system (TPS) for future flight vehicles. The sandwich structures are built from thin walled metal sheets. These structures as a part of the airframe outer cover provide thermal protection to the interior parts mounted inside the vehicle. The temperature protection materials used for sandwich structures should have high strength even at the elevated temperatures. It is easier to simulate the 150<sup>0</sup> C (after 150<sup>0</sup> C material properties are changed) temperature on the Aluminium sandwich structures and find the temperature gradient across the sandwich depth. Though the experiment was done on hexagonal cells honeycomb, the ANSYS analyses have been done for both square cell's sandwich panel and hexagonal honeycomb panel for comparison. Experiments are done on using Al alloy honeycomb sandwich panels and the validations of experimental work using ANSYS analysis have been performed. ANSYS modelling, analysis has been done for both, the square and hexagonal honeycomb sandwich panels of the Al alloy. This paper focuses on the heat transfer analysis and in exploring the ways to reduce the heat transfer effect with the methods mentioned above, which could be effectively used for flight vehicle applications.

### I. INTRODUCTION

Sandwich panels are used for the design and construction of lightweight transportation systems such as satellites, aircraft, and missiles. Structural weight saving is the major consideration and the sandwich construction is frequently used instead of increasing material thickness, honeycomb is made of very thin material. They reduce the weight, while providing the structural rigidity. This type of sandwich construction consists of two thin facing layers separated by a core material. Potential materials for sandwich facings are aluminium alloys, high tensile steels, titanium, inconel-617 and composites with honeycomb cores and a suitable matrix depending on the specific mission requirement. Several types of core shapes and core materials 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. Honeycomb sandwich structure as shown in Fig 1 are currently being used in the construction of high performance aircraft and missiles and are also being proposed for construction of future high speed vehicles. The design of a vehicle for high speed flight must be supported by structural temperature predictions and the amount of heat

transferred through the exterior panels during flight. In order to predict these quantities, it is necessary to have knowledge of the heat transfer characteristics of the honeycomb panel. The core of a sandwich structure can be almost any material or architecture, but in general they are classified into four types, foam or solid core, web core, corrugated or truss core and honeycomb core, the exploded view of the honeycomb core sandwich structure is shown in Fig 2. The adhesion of face sheets and core is another important criterion for the load transfer and for the functioning of the sandwich structure as a whole

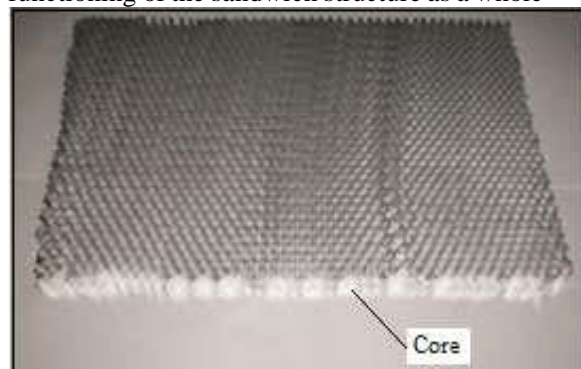


Fig 1 Honeycomb sandwich structure

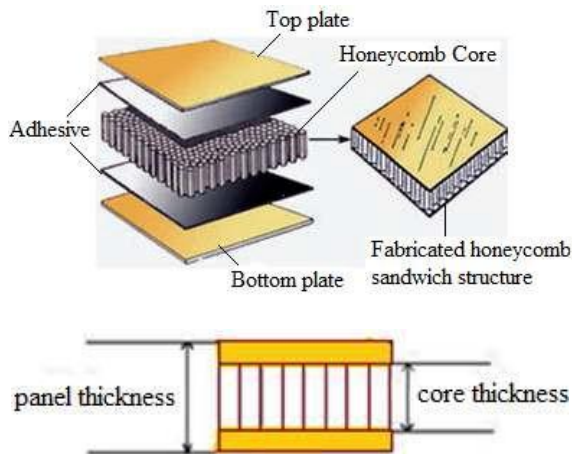


Fig 2 Exploded view of honeycomb core sandwich structure

### 1.1 Honeycomb Core

The purpose of the core is to increase the flexural stiffness of the panel. The honeycomb core as shown in Fig 3, in general, has low density in order to add as little as possible to the total weight of the sandwich construction. The core must be stiff enough in shear and perpendicular to the faces to ensure that face sheets are at a constant distance apart to prevent their detachment..

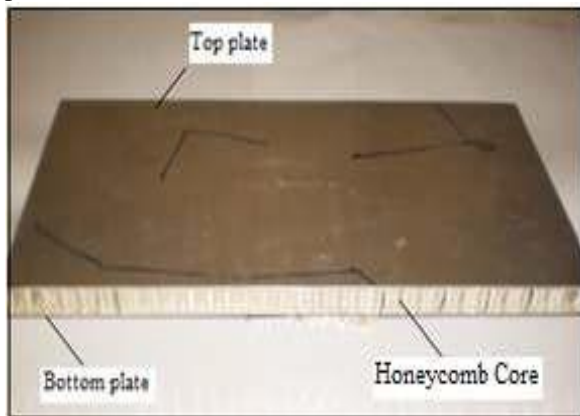


Fig 3 Honeycomb core

### 1.2 High Temperature Adhesives

High Temperature Adhesives find their application mainly in aerospace industries. A number of adhesives available can operate at high temperatures than epoxies and phenolics. These adhesives are really expensive and require high cure temperatures, and sometimes complicated cure schedules.

### 1.3 Application Areas of Sandwich Structures

The use of honeycomb sandwich structures in aeronautical and aerospace, applications are getting wider as these structures have excellent

stiffness to weight ratios that leads to weight reduction. In aerospace applications various honeycomb cored sandwich structures were used for space shuttle constructions. They are also used for both military and commercial aircraft.

## II. NOMENCLATURE

$L$ =Length of a Rectangular Plate (mm),  $w$ =Width of a Rectangular Plate (mm),  $\alpha$  = Depth of the Honeycomb Core, (mm),  $A$ =Surface area, (Square meters)

$K$ =Thermal Conductivity, (w/m-k)

$H$ =Heat transfer Coefficient, (w/m<sup>2</sup>-k),  $t$ = Time (sec)

$C_p$ =Specific Heat (j/kg-k),

$T_{\infty}$ =Ambient Temperature ( $^{\circ}C$ )

$T$ =Temperature to be measured at time  $t$  ( $^{\circ}C$ ),

$T_i$ =Inner face sheet temperature ( $^{\circ}C$ )

$T_o$ =Outer face sheet temperature ( $^{\circ}C$ )

$\Delta T$ =Difference between outer and inner face sheet temperature ( $^{\circ}C$ )

$T_c$ =Honeycomb cell wall thickness (mm),

$t_s$ =Sandwich face sheet thickness, (mm)

$b_1$ =Length of bonded side of hexagonal cell, (mm)

$d_1$ = Size of diagonal of hexagonal cell, mm

$b_2$ = Length of bonded side of square cell,

$d_2$ = Size of diagonal of square cell,

## III. MATERIAL PROPERTIES

The honeycomb panel material was modelled as a sandwich structure with three layers through the thickness. For Aluminium honeycomb panel (upper & lower parts) material is Al-2024 and core material is Al-3003. These properties are summarized in Table-1.

Table- 1 Honeycomb Panel Material Properties

S.No	Properties	Al-2024	Al-3003
1	Thermal Conductivity W/(m <sup>o</sup> C),	121	162
2	Heat Transfer Coefficient (W/m <sup>2</sup> -K)	25	25
3	Poisson ratio	0.33	0.33
4	Density (Kg/m <sup>3</sup> )	2780	2730
5	Specific Heat J/(kg K)	875	893
6	Thermal Expansion (m/m- $^{\circ}C$ )	$22.9 \times 10^{-6}$	$23.1 \times 10^{-6}$

#### IV. HONEYCOMB CELL GEOMETRY

Fig 4 shows two types of honeycomb cell geometry to be analysed. The honeycomb cell wall thickness for the first two types is  $t(c)$ . The first type is a right, hexagonal cell with identical side lengths of  $b_1$ . The second type is a square cell with side lengths of  $b_2$ , which is modified from the right, hexagonal cell by reducing the bonding interface length to a minimum of  $\sqrt{2} t_c$ . The size,  $d$  ( $i=1,2$ ) of each type of honeycomb cell is defined as the maximum diagonal of the cell cross section. The size of honeycomb cells types 1, 2, are adjusted to have the same effective density (that is,  $\rho_1 = \rho_2$ ). Honeycomb structures are composed of plates or sheets that form the edges of unit cells.

##### 2.1 Two-dimension model of Honeycomb Sandwich Structure

In this model, the aluminium honeycomb core was 3003 material and upper & lower plates was 2024 materials, with reduced mass density. Otherwise, the general structure of the sandwich material remained the same, with an aluminium core, trapped between two aluminium plates, with adhesive layers between the two species. Temperature independent values were taken for the conductivity and capacity of the honeycomb- equivalent material, while the properties of the other materials were the same. Fig 5 is a cartoon representing the 2D model implemented in this paper.

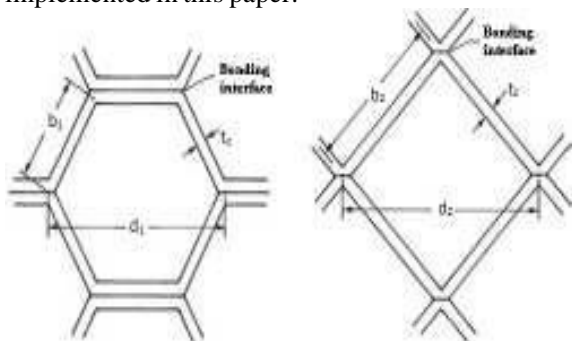


Fig 4 (a) Right hexagonal cell. (b) Square cell

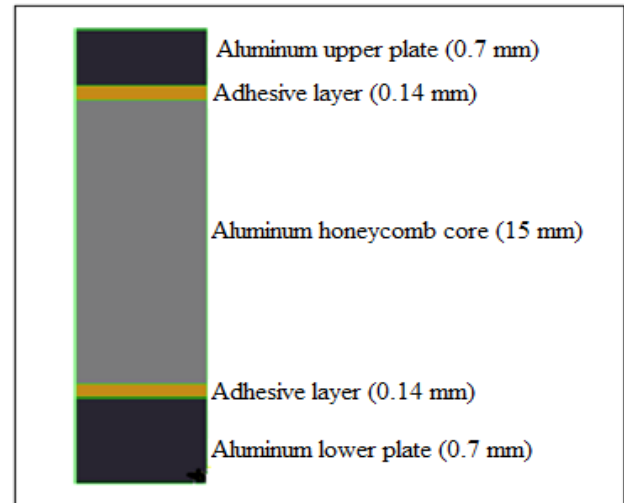


Fig 5 Two-dimensional model of Honeycomb Sandwich Structure

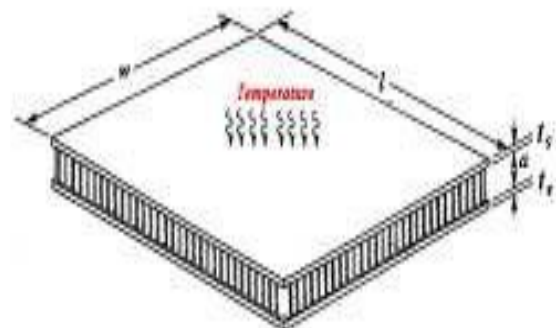


Fig 6 Honeycomb sandwich thermal protection system (TPS) subjected to overheating entire upper surface.

Fig 6 shows a honeycomb-core sandwich thermal protection system panel subjected to transient surface temperature, over its entire outer surface. The thermal protection system panel is rectangular with a side length  $l$  and width  $w$ , and is fabricated with two identical face sheets with a thickness of  $t_s$  and honeycomb core with a depth of  $a$ . For a given material, the overall heat-insulation performances of the honeycomb thermal protection system panel depend on the thickness of the face sheets, depth of the honeycomb core, thickness of the honeycomb cell walls, and size and shape of the honeycomb cells,

##### 4.2 Numerical Input Values

A typical candidate honeycomb sandwich structures has the following dimensions:  
 $l = 115$  mm,  $w = 85$  mm,  $d_1 = 7$  mm,  $d_2 = 7.42$  mm,  $b_1 = 3.5$  mm,  $b_2 = 5.25$  mm,  $t_s = 0.7$  mm,  $a = 15$  mm,  $t_c = 0.005$  mm

### 4.3 Modelling Details

Design is done in ANSYS by Modelling.  
Type of Mesh is Tet-Free  
Mesh Size is 0.001 ; Time step is 90 seconds (i.e  
1.3 degree C per second)

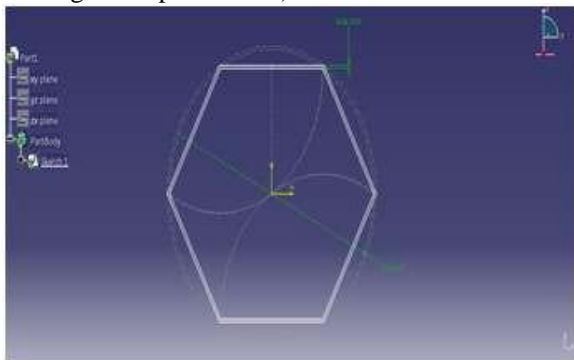


Fig 7 Geometry of Hexagonal Honeycomb Cell

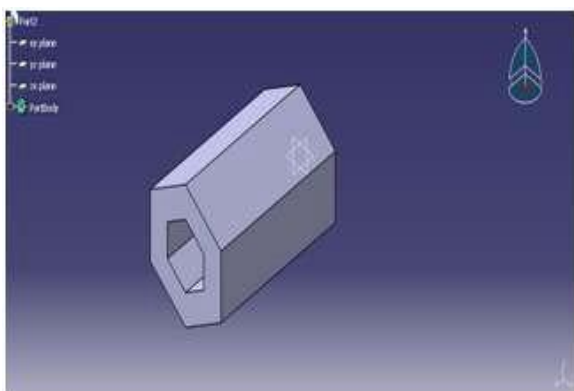


Fig 8 Modelling of Hexagonal Honeycomb Cell

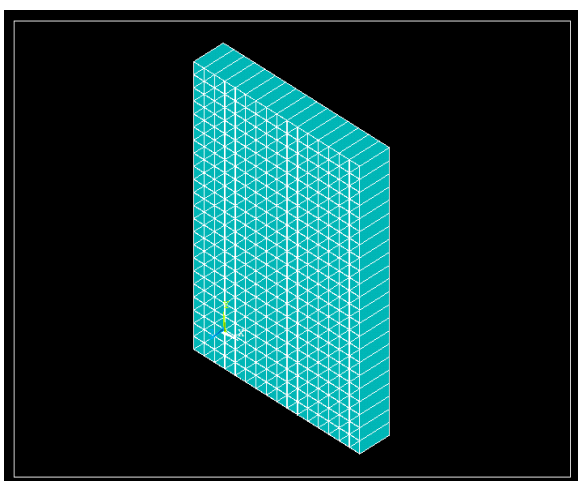


Fig 9 Pattern of Hexagonal Honeycomb Cells

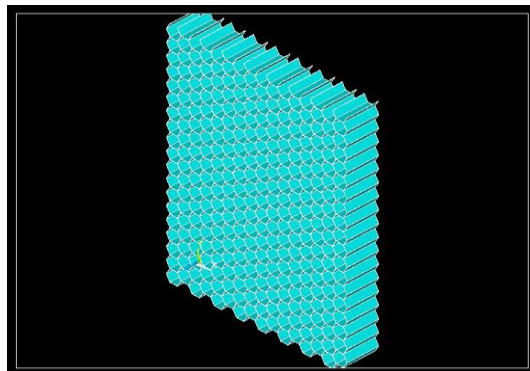


Fig 10 Assembly of Hexagonal Honeycomb cells with structure

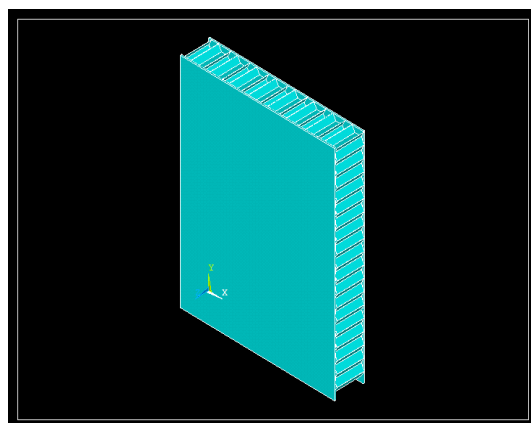


Fig 11 Geometry of Square Sandwich Cell

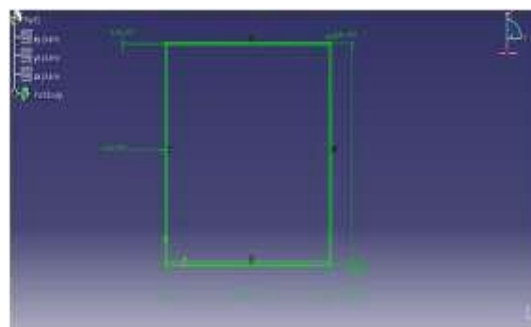


Fig 12 Modelling 3D- Square Honeycomb Cell

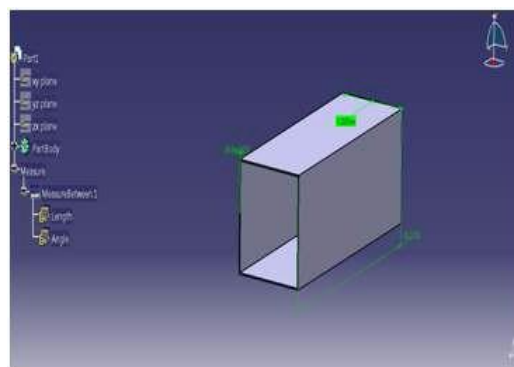


Fig 13 Assembly of square cell

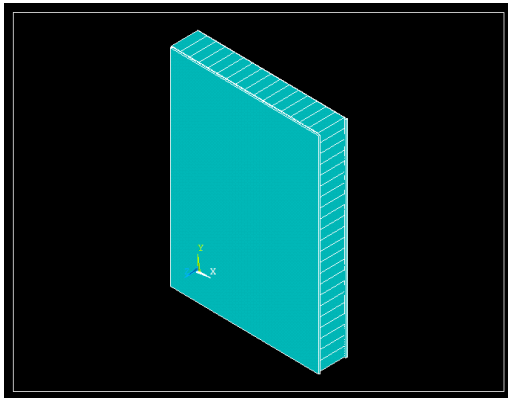


Fig 14 Assembly of square Structure with panels

## V. ANALYSIS OF HONEYCOMB SANDWICH STRUCTURE

Heat transfer analysis plays a very important role in the design of many engineering applications. Heat transfer analysis calculates the temperature distribution and related thermal quantities in the system or component. In general, the heat transfer in honeycomb sandwich panels is as a result of (1) conduction of heat in the cell walls, (2) radiation interchange within the cell, and (3) convection of heat through the air at the back side of the panel. However, this paper is concerned with sandwich panels in which the primary modes of heat transfer are due to conduction in the cell walls and radiation exchange within the cell. For most honeycomb cores used in the fabrication of sandwich panels, it can be shown that they heat exchange by convection and conduction within the air contained in the cell is negligible compared to conduction in the cell walls and radiation within the cell.

### 5.1 To simplify the analysis, the following assumptions are introduced.

First, honeycomb cells have the same effective density, but different geometrical shapes are considered (i.e., hexagon & square shapes).

Second, the effect of internal radiation turned out to be much smaller than that of conduction for the present TPS core geometry, hence radiation can be negligible.

Third, the thermal properties of the materials used do not change with the temperature.

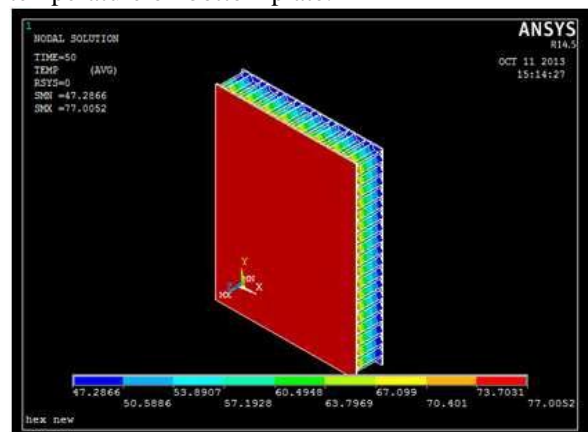
Fourth, there is no convection heat transfer inside the panel, as the experiment will take place inside a still environment. Convection heat transfer is considered for backside of the panel.

### 5.2 Heat Transfer Analysis

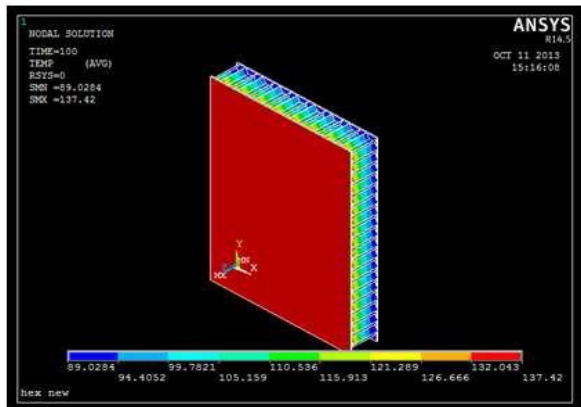
Heat transfer is a science that studies the energy transfer between two bodies due to temperature difference. Conductive heat transfer analysis on honeycomb sandwich panels and the tiny volume inside each honeycomb cell, convection heat transfer of the interior air mass were neglected. This section studies the effect of honeycomb cell geometry on the heat-insulating 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. Perform heat transfer analysis under transient state condition.

### 5.3 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 evaluations. A transient thermal analysis follows basically the same procedures as a steady-state thermal analysis. The main difference is that 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 condition or divide the load-versus-time load into load steps. Shown in Figs 15 (a) & (b) analysis of aluminium hexagonal honeycomb sandwich structure with different times. Fig 16 was plotted time vs temperature of bottom plate. Shown in Figs 17 (a) & (b) analysis of aluminium hexagonal honeycomb sandwich structure with different times. Fig 18 was plotted time vs temperature of bottom plate.

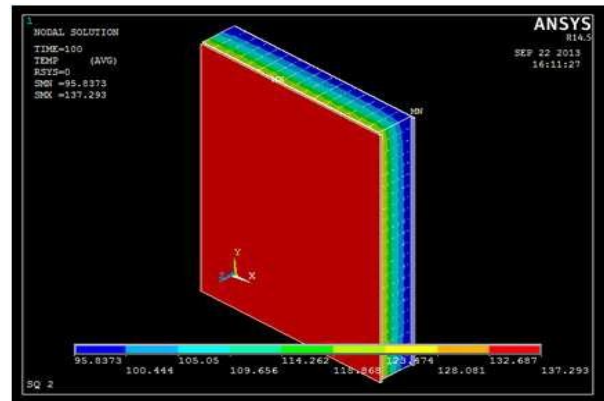


50 sec



100sec (c)

Fig 15 Temperature distribution with respect to time



(b) 100 sec

Fig 17 Temperature distribution with respect to time

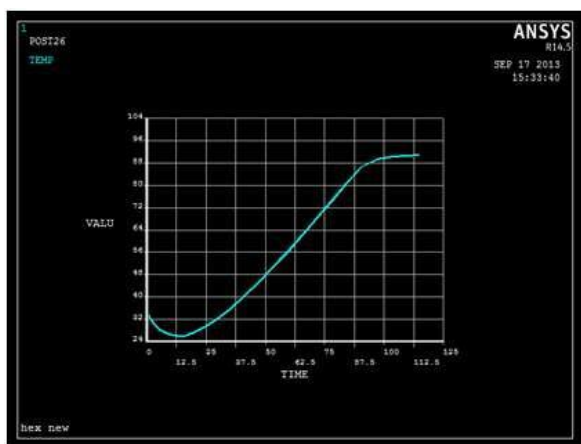


Fig 16 Time vs Temperature for bottom plate of aluminium hexagonal structure

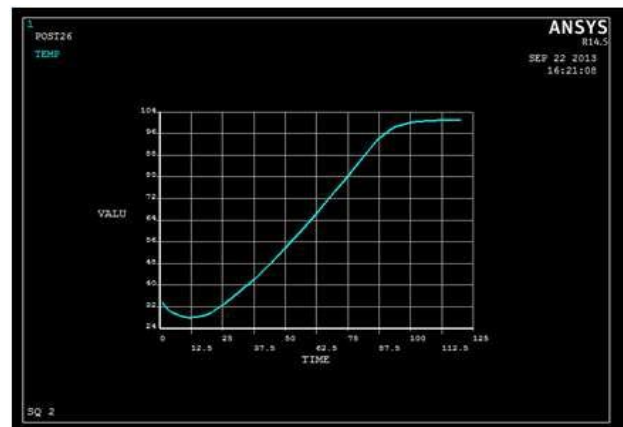
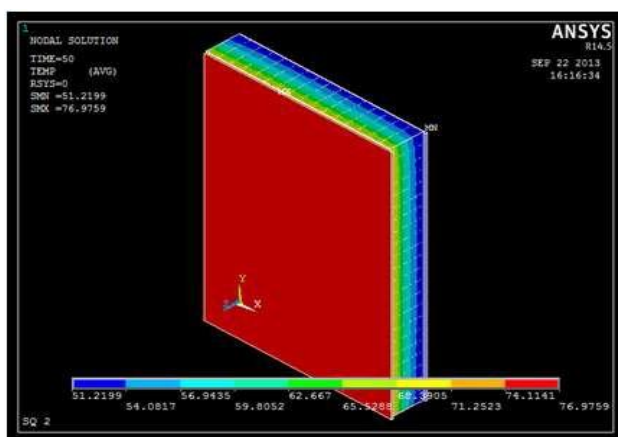


Fig 18 Time vs Temperature for bottom plate of aluminium square structure



(a) 50 sec

## VI. RESULTS AND DISCUSSION

The effect of honeycomb cell geometry on the heat-insulating performance of an aluminium alloy TPS has been analysed. The results of heat-transfer, of aluminium alloy honeycomb TPS panels are presented in Table-2 and Table-3. Fig 26 and Fig 27 shows the difference between the top plate and the bottom plate temperatures,  $\Delta T$  is a measure of the heat-insulating performance of the TPS. The larger the  $\Delta T$  values of the better the heat-insulating performance. It was observed that hexagonal cell geometry reaches a maximum in 86.36 sec of  $50.58^{\circ}\text{C}$  and square cell geometry reaches a maximum of  $87.13$  seconds at  $39.91^{\circ}\text{C}$  then it decreases slightly with the increasing time,  $t$ . Aluminium hexagonal honeycomb structure for heat insulating is better than square honeycomb structure. The effect of internal radiation turned out to be much smaller than that of conduction for the present TPS core geometry.

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