Investigation of Heat Insulation Performance of Aluminium Honeycomb Sandwich Panel With and Without Composite Material for Square and Hexagonal Shape with Different Thickness

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Abstract: *Heat-transfer analysis has been performed on sandwich thermal protection system (TPS) for future vehicles. The structures are fabricated from thin walled metal sheets. These fabricated structures are part of the air frame outer cover provide thermal protection to the interior parts mounted inside the vehicle. The temp protection system materials used for sandwich structures should have high strength even at elevated temperatures. It is easier to simulate the 1500 C temperature on the Aluminum sandwich structures and find out the temperature gradient across the sandwich depth. Experiment was done on hexagonal structure honeycomb cell, the ANSYS analyses have been done for both square cell panel and hexagonal honeycomb panel for comparison. Experiments we conducted on Aluminum alloy honeycomb sandwich panels and the validations of experimental work using ANSYS analysis have been performed. The ANSYS modeling done for both, the square and hexagonal honeycomb sandwich panels of the Aluminum alloy. This paper focus the heat transfer analysis and in exploring the ways to reduce the heat transfer effect with the methods mentioned above, which would be effectively used for flight vehicle applications.*

Keyword — *Hexagonal core cell, Square core cell, aluminium panel, Adhesive, FEA.*

I. INTRODUCTION

Honeycomb Structures

In honeycomb structural sandwiches cell, face sheets are mostly identical in material and thickness, structures cell are called symmetric sandwich structures. However, in some special cases face sheets thickness or material may be vary because of different loading conditions or working environment. In general the sandwich structures are symmetric; the variety of sandwich constructions basically depend on the configuration and size of the core. The honeycomb core consists of very thin foils in the form of hexagonal cells perpendicular to the facings. (K. Kantha Rao, et al, 2014) 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 sandwich structure can be classified in to four types, foam or solid core, web core, corrugated or truss core and honeycomb core.

Fig 2 shows the 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 Core

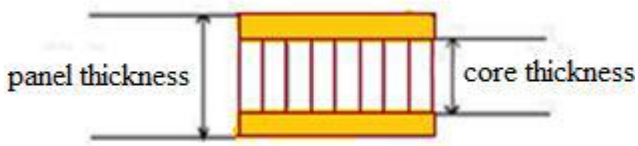

Fig – 2 Honeycomb Sandwich Structure

The function of the core is to increase the flexural stiffness of the panel. The honeycomb core as shown in fig.3, in general the core has low density in order to add as little as possible to the total weigh of the sandwich construction. The core must be strong enough in shear and perpendicular to the faces to ensure that face sheets are constant distance apart to present their detachment.

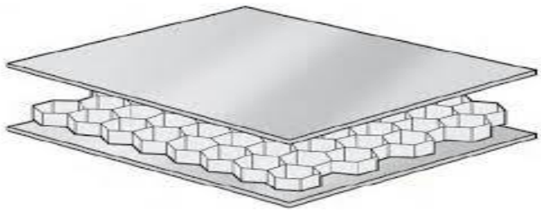

Fig – 3 Honeycomb Sandwich Panel

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

II. OBJECTIVE

I. To analyze the heat transfer performance using ANSYS and experimental validation of Aluminium Honeycomb Sandwich Panel.

II. To compare and find out optimum thickness configuration amongst with and without composite hexagonal honeycomb structure and square honeycomb structure with different thickness i.e.15mm, 20 mm, and 25mm.

III. To investigate heat transfer effect in, with and without composite hexagonal honeycomb structure and square honeycomb structure with different thickness i.e.15mm, 20 mm, and 25mm.

III. LITERATURE REVIEW

A. Gopichand [1] In this paper a stainless steel is chosen a face sheet and copper as a core material. The defining characteristic of these Honeycombs is a very high porosity; typically 75-95% of the volume consists of void spaces. Static three-point bending tests were carried out in order to investigate load and deflection variations. The theoretical load and defections in copper honey comb sandwich panel values is adapted and compared with experimental and simulation results. Based on the results it is found that the gradient of deflection curve is high for lower core height and stress is low for higher value of core height. These results can be used as input when designing sandwich panels.

K.Kantha Rao et al [2] This paper focus the heat transfer analysis and in exploring the ways to reduce the heat transfer effect. ANSYS analyses have been done for both square cell 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 modeling analysis have been done for both, the square and hexagonal honeycomb sandwich panels of the Al alloy. The geometrical (shape) analysis of different candidate honeycomb cells that have the same effective density but different cell geometrical shapes. Heat-transfer, analysis are performed on a aluminum alloy thermal protection system (TPS) for future vehicles. Effect of honeycomb cell geometry on the heat-insulating performance, are fin out. Infra-red experiment was conducted to investigate the response of several areas of the shield during the flight. The Aluminum alloy specimen researches its temperature limits in 90 seconds. For aerospace use, it is desirable to use the material which can attain its temperature limit after the elapse of more time. The heat-insulating performance of a honeycomb TPS is insensitive to the shape of the honeycomb cell under the same effective core density, but improves with the core depth

K. Jayathirtha Rao et al [3] 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. So it was concluded that 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.

Pratap Reddy et al [4] Heat-transfer has been performed on a sandwich thermal protection system (TPS) for future flight vehicles. The effect of honeycomb cell geometry on the heat-insulating performance of an aluminum alloy TPS has been analyzed. The difference between the top plate and the bottom plate temperatures, ΔT is a measure of the heat- insulating performance of the TPS. The larger the ΔT values of the better the heat-insulating performance.

IV. MATERIAL PROPERTIES

For Aluminum 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/(mo C),	121	162
2	Heat Transfer Coefficient (W/m2-K)	25	25
3	Poisson ratio	0.33	0.33

4	Density (Kg/m3)	2780	2730
5	Specific Heat J/(kg K)	875	893
6	Thermal Expansion (m/ m- °C)	22.9×10-6	23.1×10

V. HONEYCOMB CELL GEOMETRY

Below figure shows two types of honeycomb cell geometry to be analysis. The thickness of honeycomb cell for the first two 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. The honeycomb size cell are types 1, 2, are adjusted to have the same effective density (that is, ρ1= ρ2). Honeycomb structures are composed of plates or sheets that form the edges of unit cells. (K. Kantha Rao, et al, 2014). These can be arranged to create, square and hexagonal as shown in fig.4.

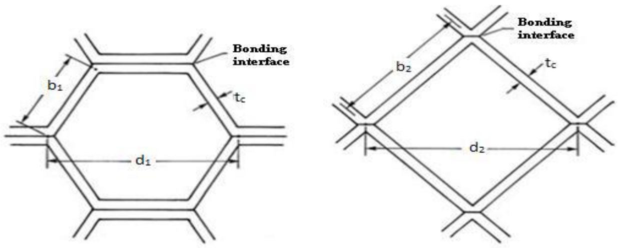

Fig – 4 (A) Hexagonal Honeycomb Cell (B) Square Honeycomb Cell

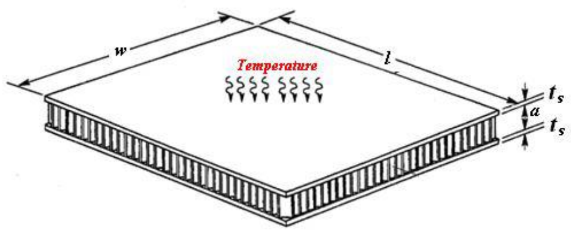

Fig - 5 Honeycomb sandwich (TPS) subjected to overheating entire upper surface.

Above fig 5 shows Honeycomb sandwich thermal protection system (TPS) subjected to heating over entire upper surface. Honeycomb-core sandwich thermal protection system is entirely subjected to transient surface temperature, over its entire outer surface. The thermal protection system panel is rectangular with a side length – l & width-w, and is constructed with two identical face sheets with a thickness of ts and honeycomb core with a depth of. The performances of heat-insulation of honeycomb thermal protection system depends 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. (K. Kantha Rao, et al, 2014)

5.1 Geometry of Hexagonal Honeycomb Cell of thickness 15mm, 20mm, 25mm

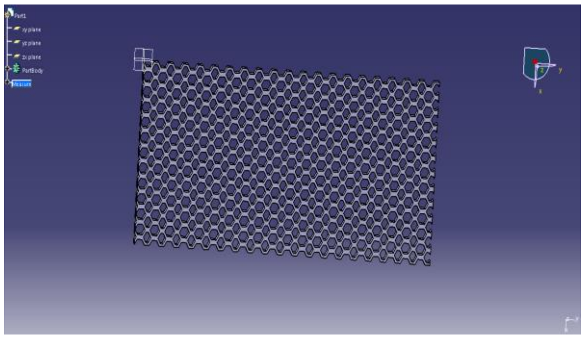

Fig - 6 Honeycomb_Hexagonal Core Structure

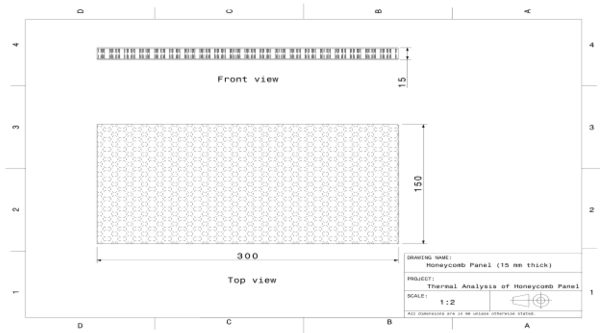

Fig- 7 Honeycomb Hexagonal Structure T-15 mm

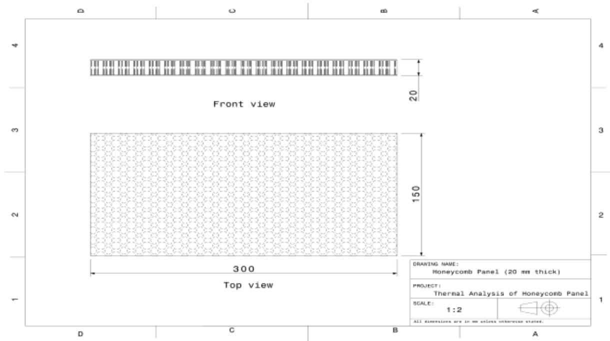

Fig – 8 Honeycomb Hexagonal Structure T-20 mm

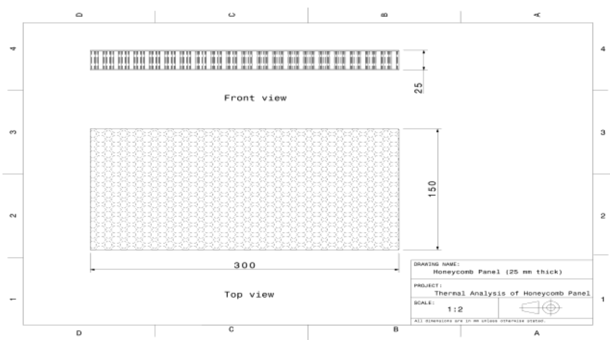

Fig – 9 Honeycomb Hexagonal Structure T-25 mm

VI. FINITE ELEMENT 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 negligible. Now in this section studies the effect of honeycomb cell geometry on the heat shielding performance of the TPS panel. Before starting 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.

6.1 Analysis of Honeycomb Sandwich Structure:

Heat transfer analysis plays a very important role in the design of many engineering applications. Heat transfer analysis find out the temperature distribution and related thermal quantities in the system or component. In general, the heat transfer in honeycomb sandwich panel cell is a result of

(1) Conduction of heat transfer in the cell walls,
(2) Radiation interchange within the cell, and
(3) Convection of heat transfer through the air contained back side of the panel.

However, this paper 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 honeycomb cell. For number of honeycomb cores used in the fabrication of sandwich panels, it can be shown that the heat exchange by convection and conduction within the air contained in the cell is smaller compared to conduction in the cell walls and radiation within the cell.

6.2 Heat Transfer Analysis:

Heat transfer analysis is a science that studies the energy transfer between two bodies due to temperature difference. For honey comb sandwich panels conductive heat transfer analysis 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 Thermal Protection System panel. Before analysis starting to mesh model we can effectively find out the change in temperature at each and every point. We perform heat transfer analysis under transient state condition. (K. Jayathirtha Rao, et al, 2012)

6.3 Transient Thermal Analysis:

Transient Thermal Analysis find out 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 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, us e both the f unction 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. Aluminum Hexagonal Honeycomb Sandwich Structure. (K. Jayathirtha Rao, et al, 2012)

6.4 Comparative Ansys Analysis for 15 mm Thickness Honeycomb Sandwich Panel

Table 2 : Time and Temperature Readings for 15 mm Thickness Honeycomb Panel

Time	Top Plate Temp °C	Square 15 mm Thick.	Hexagonal 15mm Thick.	Composite Square 15 mm Thick.	Composite Hexagonal 15 mm Thick.
0	24.66	22.068	22.098	21.924	21.887
1	25.25	22.213	22.286	21.816	21.718
1	25.839	22.443	22.56	21.701	21.531
2	27.608	23.552	23.75	21.536	21.165
4	32.916	28.072	28.306	22.433	21.734
7	39.516	34.309	34.597	23.923	22.566
10	46.116	40.839	41.145	26.433	23.521
13	52.716	47.415	47.727	29.855	25.043
16	59.316	54.065	54.375	34.029	27.149
19	65.916	60.685	60.993	38.796	29.819
22	72.516	67.349	67.653	44.021	33.009
25	79.116	73.974	74.275	49.594	36.667
28	85.716	80.638	80.935	55.431	40.738
30	90	84.944	85.376	59.267	43.414

6.5 Experimental Set up Block Diagram

A Schematic block diagram of the Experimental model as shown in fig 4.1 The size of hexagonal sandwich panel is 150x300 sq.mm and the height of the core is 15 mm and the thickness of the top & bottom plate is 0.7mm. Face sheets are bonded with epoxy adhesive.

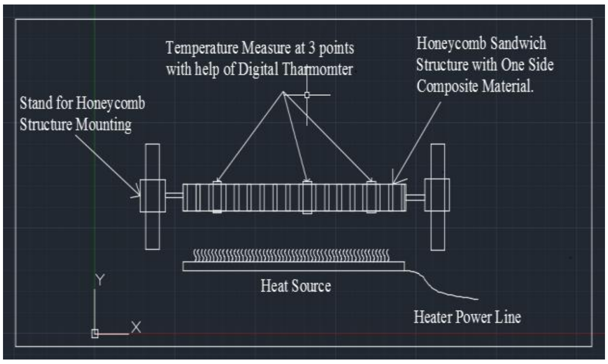

Fig -10 Schematic Block Diagram of Experimental model of Honeycomb Sandwich Panel

Heat Source used to heat the specimen plate up to 90˚C. The rate of heating is controllable. The infrared thermometer records the temperature levels on the specimen. The rate of heating is chosen such that the limiting temperature is reached in the time of a couple of minutes, to simulate the aerospace flight environment at high speeds.

6.6 Actual Experimental Set Up

Fig-11 Actual Experimental Set Up for 15 mm Composite Hexagonal Honeycomb Panel

6.7 Comparative Experimental Analysis for 15 mm Thickness Honeycomb Sandwich Panel

Table- 3 Experimental Time and Temperature Readings for 15 mm Thickness Honeycomb Panel

Time in Sec	Top Plate Temp ˚C	Square 15 mm Thick	Hexagonal 15mm Thick	Composite Square 15 mm Thick	Composite Hexagonal 15 mm Thick
0	23.5	23.5	24.1	24.1	23.4
15	25.2	23.7	24.3	24.3	23.6
30	27.5	24.8	25.4	25.1	23.9
45	32.8	28.8	29.8	25.8	24.2
60	40.3	35.1	33.1	27.1	24.5
75	46.3	41.9	38.2	28.8	24.7
90	52.8	47.8	44.1	31.7	25.1
105	58.2	53.4	50.8	35.2	26.8
120	62.8	57.6	56.4	37.9	28.2
135	66	61.1	60.1	41.1	29.8
150	71.1	66.7	64.1	43.9	32.1
165	74.8	69.7	68.8	46.6	34.2
180	79.5	74.1	72.9	49.1	36.2
195	83	77.6	75.4	52.8	38.4
210	84.9	79.6	79.1	54.9	40.8
225	87.8	82.1	81.1	57.6	42.3
240	89.6	83.8	84.1	60.1	43.1
260	91	85.4	84.6	61.2	43.8

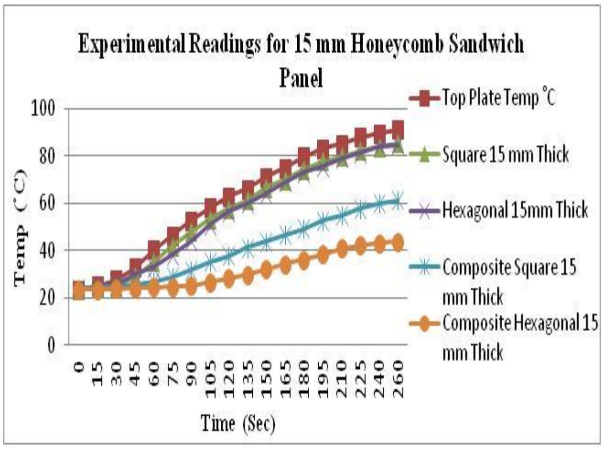

Fig-12 Comparative Temperature (0C) V/S Time (s) Graph for 15 mm Thickness Honeycomb Panel

From above fig 12, it is observed that minimum temp observed in square and hexagonal honeycomb is 85.4˚C and 84.6˚C respectively when temp applied up to 90˚C. And for composite material its observed 61.2˚C and 43.8˚C for square & hexagonal honeycomb sandwich panel

6.8 Comparative Experimental Heat Flux Plot for 15 mm Thickness Honeycomb Sandwich Panel

Table-4 Experimental Heat Flux Readings for 15 mm Thickness Honeycomb Sandwich Panel

Time in Sec	Q/A for Square 15 mm Thick	Q/A for Hexagonal 15 mm Thick	Q/A for Composite Square 15 mm Thick	Q/A Composite Hexagonal 15 mm Thick
0	0.0	0.0	43.1	43.1
15	21500.0	10033.3	690.3	388.3
30	38700.0	24366.7	1553.2	1035.5
45	44433.3	30100.0	3710.5	3020.2
60	48733.3	34400.0	6817.0	5695.2
75	54466.7	41566.7	9319.4	7550.5
90	60200.0	45866.7	11951.3	9103.7
105	63066.7	54466.7	13547.7	9923.4
120	65933.3	61633.3	14928.3	10743.2
135	67366.7	65933.3	15618.6	10743.2
150	68800.0	73100.0	16826.7	11735.6
165	73100.0	81700.0	17517.0	12167.0
180	77400.0	84566.7	18682.0	13116.2
195	77400.0	86000.0	19242.9	13029.9
210	78833.3	87433.3	19027.1	12943.6
225	81700.0	88866.7	19631.2	13029.9
240	83133.3	90300.0	20062.6	12727.9
260	83133.3	90300.0	20364.6	12857.3

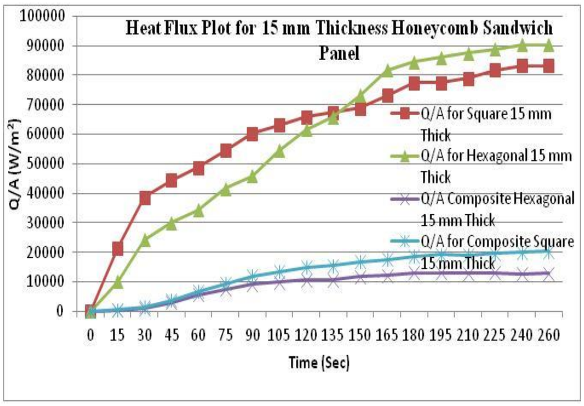

Fig -13 Heat Flux Plot For 15 mm Honeycomb Sandwich Panel

From the above fig 13, it is observed that maximum heat flux can be obtained in Hexagonal honeycomb sandwich panel up to 90300 W/m². In case of composite hexagonal honeycomb sandwich panel, maximum heat flux can be obtained up to 12857.33 W/m². It is also observed that for composite hexagonal honeycomb sandwich panel gives minimum heat flux as compaired to square, hexagonal and composite square honeycomb sandwich panel.

Comparative Experimental and ANSYS Analysis for 15 mm Composite Hexagonal Honeycomb Sandwich Panel

Table-5 Experimental and ANSYS Time and Temperature Readings for 15 mm Thickness Composite Hexagonal Honeycomb Sandwich Panel

Time	Top Plate Temp By ANSYS °C	Bottom Plate Temp By ANSYS °C	Top Plate Temp By Experimental °C	Bottom Plate Temp By Experimental °C
0	24.7	21.9	23.4	23.4
1	25.3	21.7	25.1	23.6
1	25.9	21.5	27.2	23.9
2	27.7	21.2	33.2	24.2
4	33.1	21.7	40.3	24.5
7	39.7	22.6	46.2	24.7
10	46.3	23.5	53.5	25.1
13	52.9	25.0	58.1	26.8
16	59.5	27.1	62.4	28.2
19	66.1	29.8	66.3	29.8
22	72.9	33.0	70.7	31.1
25	79.7	36.7	74.8	33
28	86.4	40.7	79.6	36.2
30	90.6	43.4	82	39.4
---	---	---	85.1	40.8
---	---	---	87.8	42.3
---	---	---	89.9	43.1
---	---	---	91	43.8

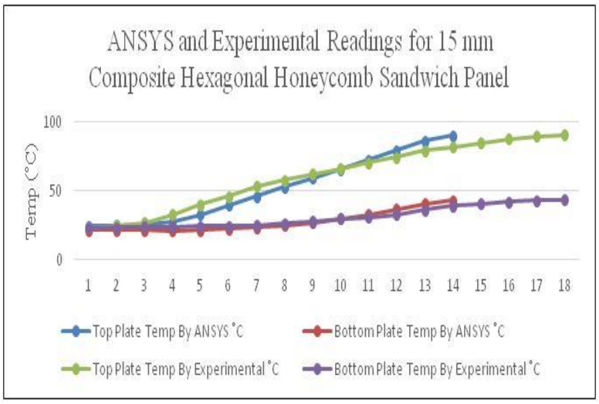

Fig -14 Experimental and ANSYS Time and Temperature Readings for 15 mm Thickness Composite Hexagonal Honeycomb Sandwich Panel

From the above fig 14, experimental validation and results through finite element method it has been observed that experimental readings validate with ANSYS readings for 15 mm thickness composite hexagonal honeycomb sandwich panel.

Experimental and ANSYS Temperature Readings for 15 mm Honeycomb Sandwich Panel

Table-6 Experimental and ANSYS Temperature Readings for 15 mm Honeycomb Sandwich Panel

Size	Square Minimum Temp °C	Hexagonal Minimum Temp °C	Composite Square Minimum Temp °C	Composite Hexagonal Minimum Temp °C
15mm ANSYS	84.94	85.376	59.267	43.414
15 mm Experimental	85.4	84.6	61.2	43.8

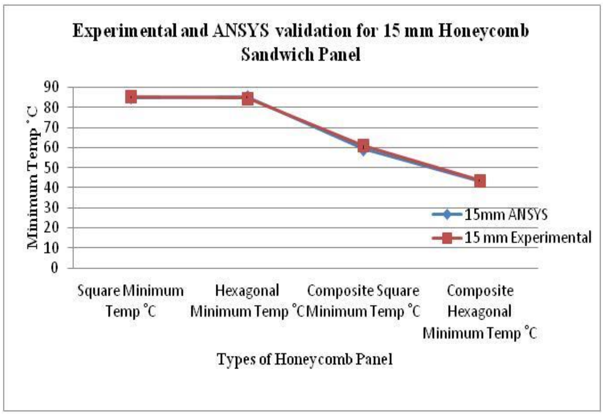

Fig -15 Experimental and ANSYS validation for 15 mm Honeycomb Sandwich Panel

From the above fig 15, the experimental validation and results through finite element method it has been observed that out of two different with and without composite honeycomb cross sections with different thickness, the hexagonal honeycomb with Composite material for 15 mm thickness is most preferable one because the heat transfer rate is minimum as compared to other simple and composite cross section combinations.

VII. RESULTS AND DISCUSSION

Comparing Square section structure with varying thickness i.e. 15mm, 20mm, 25mm to hexagonal section with varying thickness i.e. 15mm, 20mm, 25mm above graph shows that 15 mm thickness with hexagonal section give best result for temperature distribution. The heat insulating performance of honeycomb shape of the honeycomb cell under the same core density, but improves the core depth. Aluminium hexagonal honeycomb structure for heat insulating is better than square honeycomb structure.

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