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Design and Analysis of Sandwich Honey Comb Structures

Y. Kiran Kumar Reddy[1], N. Venkatramana Reddy[2]
[1]*PG Student, Dept. of Mechanical Engg., Sir Vishveshwaraiah Inst. of Science and Tech., Madanapalle, India*
[2]*Assistant Prof., Dept. of Mechanical Engg., Sir Vishveshwaraiah Inst. of Science and Tech., Madanapalle, India*

***Abstract*: Honeycomb structures offer high strength to weight ratio and act as energy absorbers in impact analysis. In this work, different types of honeycomb structures are studied. The honeycomb structures are studied under various types of loading and boundary conditions. Initially, three different shapes of honeycomb structures are studied. These are considered as reference models. According to the results of initially built models, the hexagonal cell model has been considered as the best model. After that two types of hexagonal honeycomb structures are modeled, one is isotropic model and the other, orthotropic model. The isotropic material properties are taken from literature. Equivalent orthotropic material properties are calculated based on various available models in literature. Both models are analyzed under same loading and boundary conditions. Primary goal is to develop an equivalent model by replacing the actual model with orthotropic model. ANSYS programming is used for the analysis. The results are compared to find out the best performing equivalent model.**

***Keywords*: Honey Comb Structures**

1. Introduction

Sandwich composites have high strength to weight ratio (which results in increase of payload, provides greater range and/or reduced fuel consumption), extended operational life, lower maintenance cost (due to less corrosion).Composite sandwich structures have been widely used in aerospace structures, ship building, infrastructure, etc. due to their light weight and high strength to weight ratio. Traditionally, light-weight core materials such as foam core, truss core, honeycomb core, aluminum core have been used in fabricating sandwich structures. A typical sandwich structure consists of honeycomb core material covered by face sheets on both sides.

Composite materials are widely used in today's modern world. With the advent of new materials, production techniques and new application areas, etc., composite materials have become one of the most attractive areas in engineering. As in many areas of engineering, generic applications are based on analytical methods and with the increasing complexity of the geometries, boundary conditions and material, in almost every case, the use of analytical methods become very tedious if not impossible. At this point, the use of computational methods comes into picture. With the help of computational methods, namely finite element method (FEM) for structural analyses, highly complicated problems can be handled with great accuracy. The disadvantage of using computational methods is that, in order to get accurate results, too much computational time is needed, and this increase when the problem becomes more complex. In addition, FEM models require a detailed study before the model is sent to the solver. Shell structures are widely used in engineering applications for their high strength to weight ratio and energy absorption in axial compression. In vehicle crash tests, moving or stationary deformable barriers made of aluminum honeycombs are used. During the compression of cellular structures, the kinematic energy of a moving mass transforms into the energy of plastic deformation. This energy is absorbed through the large compressive stroke, therefore buckles in a progressive mode. The energy absorption and crushing strength characteristic of these structures are influenced by the mechanical properties, the thickness, the geometric configuration and also the mass of the cell walls.

2. Literature survey

Aydincak [1] investigated design and analysis of honeycomb structures. He develop an equivalent orthotropic material model that is a good substitute for the actual honeycomb core. By replacing the actual honeycomb structure with the orthotropic model, during the finite element analyses, substantial advantages can bebtained with regard to ease of modeling and model modification, solution time and hardware resources. He figure out the best equivalent model among the approximate analytical models. A comparison is made. First sandwich beams with four different honeycomb cores are modeled in detail and these are accepted as reference models. Then a set of equivalent models with the same dimensions is generated. The material properties of the equivalent models are taken from different studies performed in the literature. Both models are analyzed under the same loading and the boundary conditions. In finite element analyses, ANSYS finite element program is used. The results are compared to find out the best performing equivalent model. After three major analyses loops, decision on the equivalent model is made. The differences between the total reaction forces calculated.

Schwingshackl et al. [2] examines several available analytic and experimental methods to determine the orthotropic material properties of honeycomb. Fifteen published sets of simple equations for the material properties were reviewed and their values calculated for a specific honeycomb aluminum core and tested the same core with ASTM standard methods and the agreement between the theoretical material properties and the experimental results was considered. To reduce the time and cost for the experimental determination, also introduced a simple technique for measuring the main dynamic material properties of honeycomb. A good agreement was found between the major theoretical out-of-plane material properties of honeycomb, the experimental ASTM methods, and the presented dynamic approach. Muhammad Yousuf Ayub [3] investigated the behavior of a prototype aluminum honey comb satellite Structure. Under various kinds of mechanical loadings. It describes the static and dynamic analyses of prototype satellite structure that were carried out in Ansys Workbench V12.0. The structure is composed of aluminum honeycomb sandwich panels. Izaz et al. [4] developed the effective elastic properties of sandwich structures. This methodology is based on strain energy based criteria. Sandwich structures contain core material and face sheet. Earlier work in this domain contains the homogenization of core material and determining its equivalent orthotropic properties.

They developed equivalent properties for core material then modeled along with face sheet for final analysis. They modeled core material and face sheets together to determine the equivalent orthotropic properties of sandwich structure. Coanda et al.[5] presented an analysis of honeycomb structures mechanical properties. They developed the honeycomb sandwich construction is one of the structural engineering and used in aerospace industry. The honeycomb sandwich structures provide the benefits over conventional materials: very low weight, high stiffness, durability and production cost savings. The finite element method is applied for the determination of the elastic characteristics of the sandwich structure with honeycomb core, in terms of constraints, loads and displacements. R. A. Pasha et al. [6] determined the modulus of elasticity by analytical and numerical means and correlated with experimental results for Nomex paper hexagonal honeycombs. The analytical methods included continuum formulations and models based on strength of materials including a variety of beam theories. Thomas G. Carne et al.[7] developed a constitutive model for the elastic response of an aluminum honeycomb material using virtual testing from cell-level computational simulations. The derived constitutive model treats the honeycomb as a continuous material rather than a shell-like structure.

The orthotropic constitutive model for honeycomb requires nine distinct parameters that were determined from cell-level computational simulations using the nominal honeycomb geometric definition. Jasrobin Singh Grewal [8] analyzed dynamic properties of sandwich beam-type structure using finite element method based on a nonlinear model for displacement field in the viscoelastic core layer of the beam structure. Results obtained for the nonlinear and linear models are compared to the test data available in literature. Whitty et al.[9] used the finite element (FE) method to study the mechanical and thermal properties of both conventional and re-entrant (i.e. negative Poisson's ratio) honeycombs, which may be used as the cores of sandwich panel composites. Developed the analysis of the mechanical properties of the core materials for sandwich panels. In this work, the core is firstly a honeycomb and secondly tubular structure. This kind of core materials are extensively used, notably in automotive construction (structural components, load floors).

3. Methodology

In this thesis, 3 initial honeycomb models are considered, hexagonal, circular and octagonal also introduced a simple technique for measuring the main dynamic material properties of honeycomb. The models are developed such that the surface area of all the shapes is the same. The initial dimensions of the hexagonal cell (as considered from [1] are:

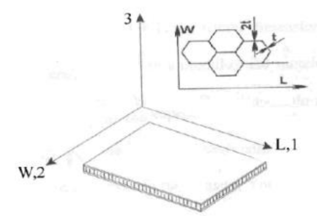

Fig. 1. Axis direction of the honeycomb structures

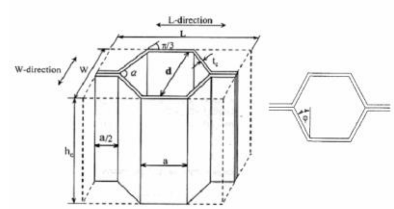

Fig. 2. Dimensions of the honeycomb cell

A. Hexagonal cell

Step 1: The hexagonal cell is drawn according to the dimensions

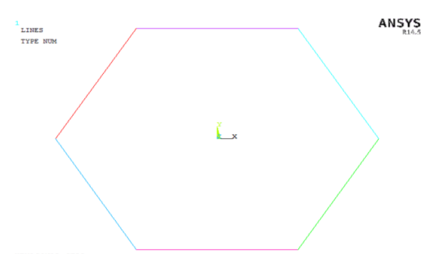

Fig. 3. First step towards final modeling

Step 2:

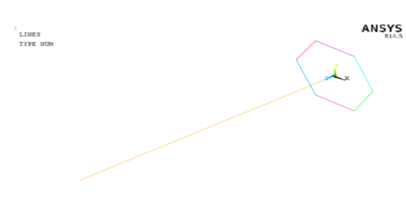

Fig. 4. Second step towards final modeling

A line is drawn from the center of the hexagon in the z-direction this line is used to extrude the area of the hexagon.

Step 3: To achieve the shell model hexagon extruded with a height of 15.875

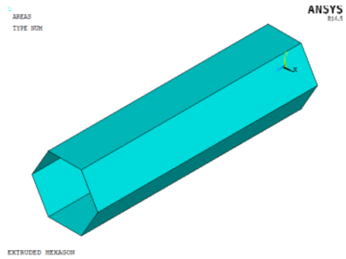

Fig. 5. Third step towards final modeling

Step 4: Horizontal array is created for the above hexagonal model

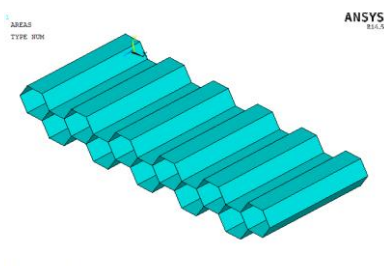

Fig. 6. Fourth step towards final modeling

Step 5: Vertical array also created for the hexagonal cell

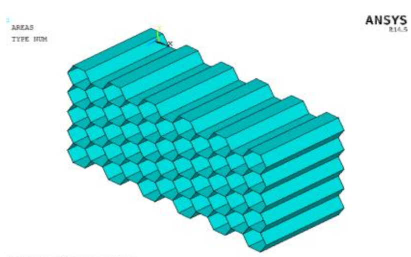

Fig. 7. Fifth step towards final modeling

Step 6: The above model is meshed

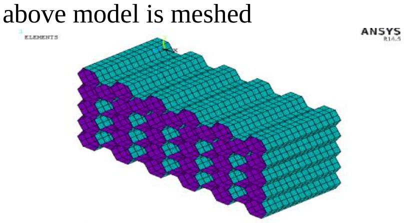

Fig. 8. For the fifth model boundary conditions are applied

One end is fixed at all degrees of freedom and other end is subjected to the displacement. These are identical in all the direction, invariant with respect to the direction.

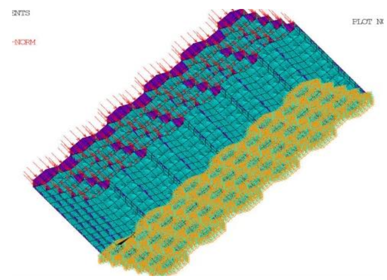

Fig. 9. Figure configuration in isometric view

B. *Octagonal cell*

The design procedure for an octagonal cell is same as above procedure, first designed a single shell type honeycomb cell after that created an array of 6*5.

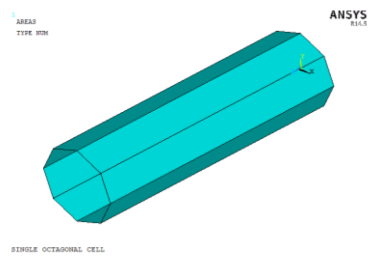

Fig. 10. Single shell type honeycomb octagonal cell

Meshed the total honeycomb structure and the loads and boundary conditions applied.

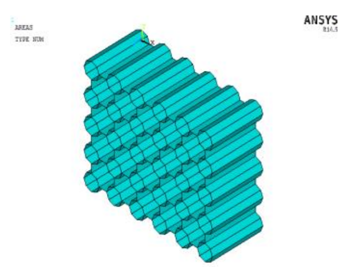

Fig. 11. Multi shell type honeycomb octagonal cell

C. *Circular cell*

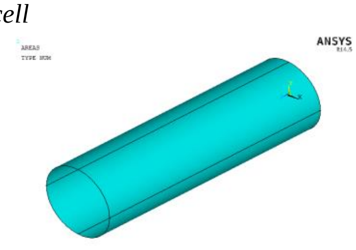

Fig. 12. Single shell type honeycomb circular cell

The design procedure for an circular cell is same as above procedure, first designed a single shell type honeycomb cell after that created an array of 4*4. Meshed the total honeycomb structure and the loads and boundary conditions are applied.

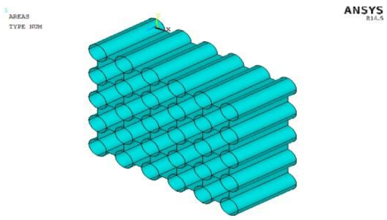

Fig. 13. Multi shell type honeycomb octagonal cell.

1) Material contact models

Two types of material models are used in this thesis. Isotropic model is used for the honeycomb structure and orthotropic model was used for equivalent modeling.

2) Isotropic model

An isotropic material, in contrast, has the same properties in every direction. It can be proved that a material having two planes of symmetry must have a third one. Isotropic materials have an infinite number of planes of symmetry. Isotropic model is a model which possessing uniform physical properties in all directions. Having physical properties as elasticity that is same in measurement along all axis or direction. These are identical in all the direction, invariant with respect to the direction. A good agreement was found between the major theoretical out-of-plane material properties

3) Glue model

In this glue model is carried out by two types one is shell model and another one is solid model. In shell model the face sheets are considered as shell elements, and in solid model the face sheets are considered as solid elements. In this model the contact between hexagonal cell and face sheet is given by glue command in Ansys modeling.

D. Boundary conditions

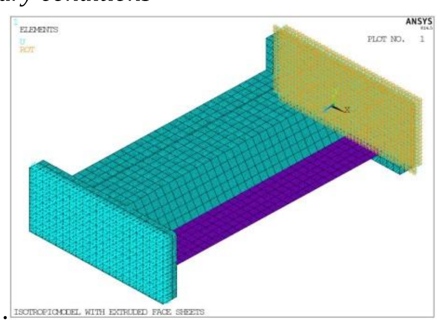

Fig. 14. Outcome honeycomb structures by Ansys

Boundary conditions applied on the hexagonal honeycomb structure is, fixing the one end of the face heet so that we can apply the force on the other end of face sheet in such a way that the hexagonal honeycomb cell subjected to the compression.

E. Glue model

By using rectangle command two face sheets are attached to the hexagonal honeycomb cell by using glue command in Ansys modeling.

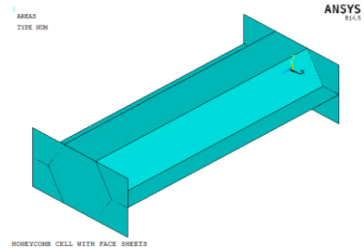

Fig. 15. Honeycomb cell with face sheet

The above model is meshed and then subjected to the given boundary conditions

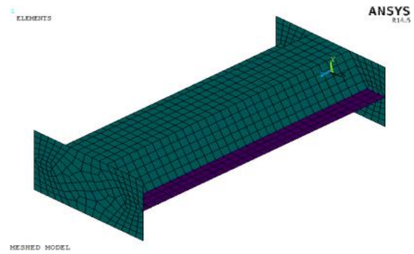

Fig. 16. Meshing of Honeycomb cell with face sheet

F. Solid model

In this solid model the face sheets are considered as solid elements. The above model is

Step 1: The face sheets of meshed model is extruded to foil length. This is subjected to solid element.

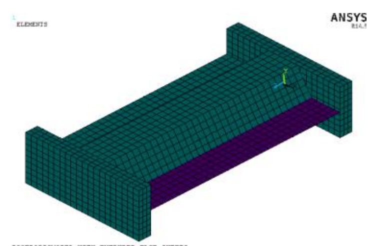

Fig. 17. Isotrpoic model with extruded face sheet

Step 2: The boundary and loading conditions are applied to the solid model

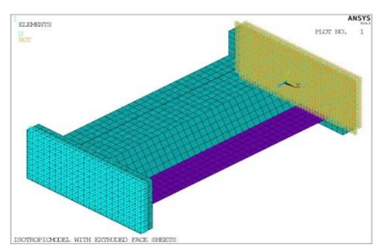

Fig. 18. B.C on Isotrpoic model with extruded face sheet

1) Contact model

The honeycomb cell is modeled same as the above procedure the only difference is that the contact is given by creating contact between hexagonal cell to the face sheet.

2) Shell model and solid model

The contact is given to the shell model and solid model as same but only the difference is that shell model created with shell element and solid model is created with solid elements.

The contact between hexagonal honeycomb cell and the face sheet as shown below.

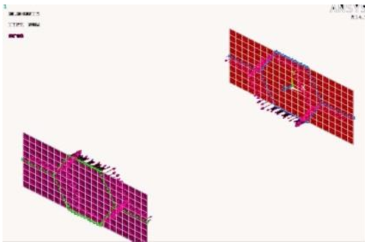

Fig. 19. Contact between hexagonal honeycomb cell and the face sheet

G. *Equivalent Model*

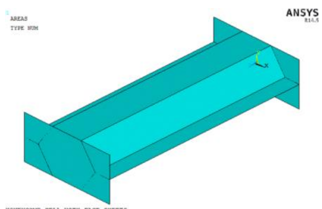

Fig. 20. Honeycomb cell with face sheet

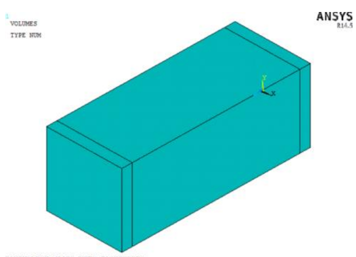

Fig. 21. Equivalent model with face sheet

H. *Procedure of orthotropic model*

1) Contact model

The contact is given by creating contact between solid body to the face sheet. In contact model the contact between the 3 volumes are given by creating contact in between them as shown below.

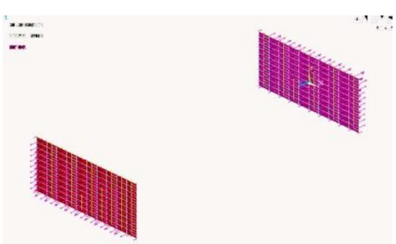

Fig. 22. Contact between solid body to the face sheet

Step 1: The equivalent model is drawn according to given dimensions.

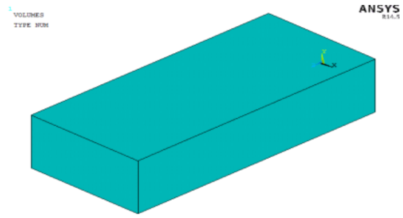

Fig. 23. Equivalent model by given dimension

Step 2: The face sheets with given dimensions and properties are drawn and attached to the equivalent model using GLUE command.

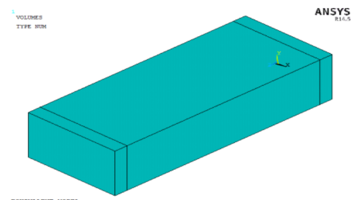

Fig. 24. Equivalent model by given dimensions

Step 3: The above model is meshed by giving the element size

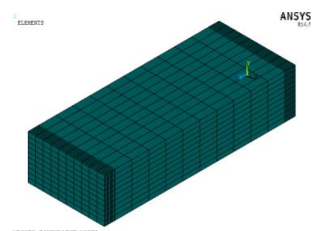

Fig. 25. Meshed equivalent model

Step 4: Boundary and load conditions are applied to the equivalent model

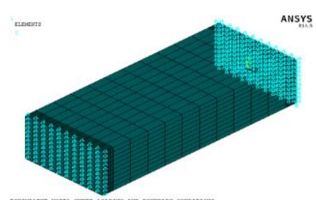

Fig. 26. Meshed Equivalents model under loading and B.C conditions

4. Results and discussions

A. *Hexagonal shape*

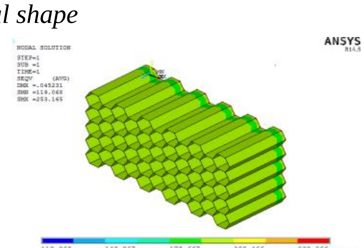

Fig. 27. Developed von-mises stress at the centre for hexagonal honeycomb

The pressure of 100 MPa is applied on one end of the honeycomb structure. From the figure it was understood that the von-mises stress developed at the center of the hexagonal honeycomb is 178.667 MPa

B. *Circular shape*

The pressure of 100 MPa is applied on one end of the honeycomb structure. From the figure it was understood that the von-mises stress developed at the center of the circular honeycomb is 257.657 MPa

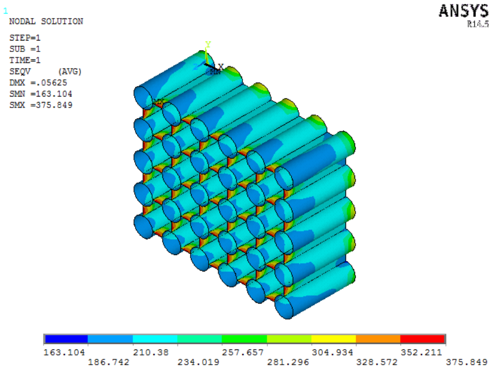

Fig. 28. Developed von-mises stress at the centre for circular honeycomb

C. *Octagonal shape*

The pressure of 100 MPa is applied on one end of the honeycomb structure. From the figure it was understood that the von-mises stress developed at the center of the octagonal honeycomb is 219.164 MPa.

Table 1
Comparison various model shapes result values

S. no	Shape	Mass (kg)	Deflection (mm)	W/δ (N/mm)
1	Octagonal	0.0180	0.058	3044.48
2	Hexagonal	0.0120	0.058	2029.65
3	Circular	0.0121	0.056	2119.66

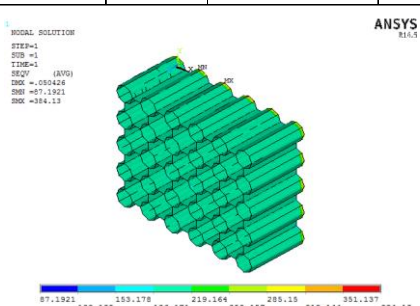

Fig. 29. Developed von-mises stress at the centre for octagonal honeycomb

D. *Comparison*

By comparing all the results hexagonal shape considered as best model. It gives the less weight per unit deflection. And it resist high stress compared to the octagonal and circular shape honeycomb models. The pressure of 100 MPa is applied on one end of the honeycomb structure.

E. *Comparing graphs*

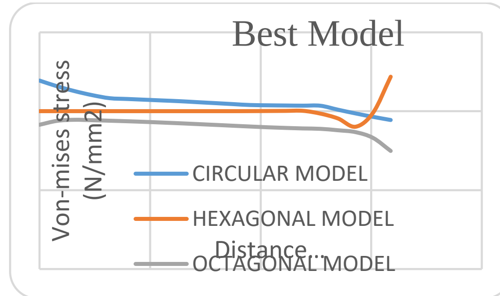

Fig. 30. Comparison of hexagonal model

F. *Isotropic model*

1) *Glue model*

By applying the loading and boundary conditions, the result obtained that the von – mises stress of isotropic glue model is 3.6186 for both shell model and solid models.

G. *Shell mode*

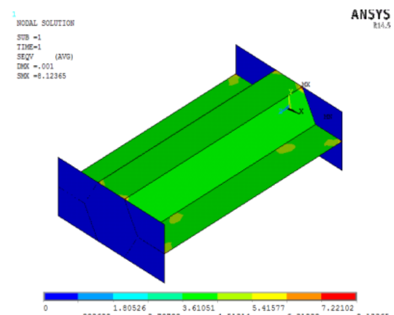

Fig. 31. Developed von-mises stress of Isotropic glue shell model

H. *Solid mode*

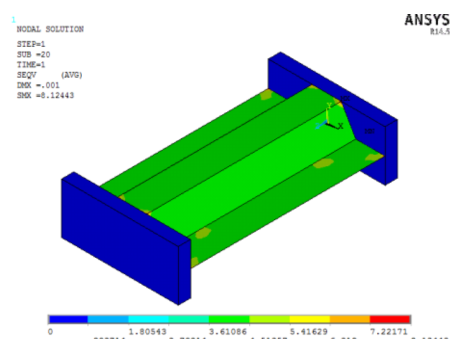

Fig. 32. Developed von-mises stress of Isotropic glue solid model

I. *Contact model*

By applying the loading and boundary conditions, the result obtained that the von – mises stress for isotropic contact model is 3.68 for both the shell model and solid model. Boundary conditions applied on the hexagonal honeycomb structure is, fixing the one end of the face heat.

J. Shell model

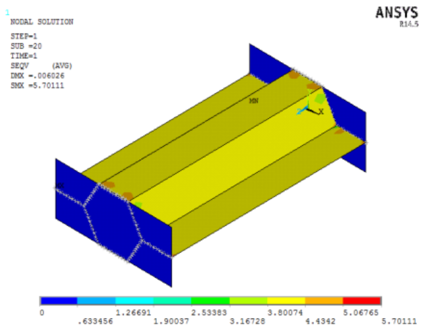

Fig. 33. Developed von-mises stress of Isotropic contact shell model

K. Solid model

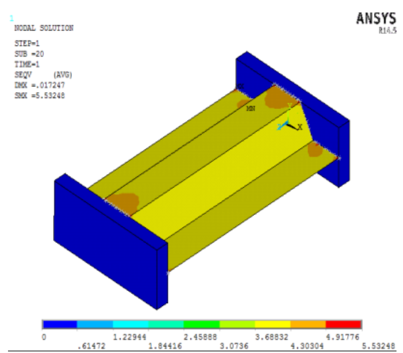

Fig. 34. Developed von-mises stress of Isotropic contact solid model

L. Isotropic model graphs

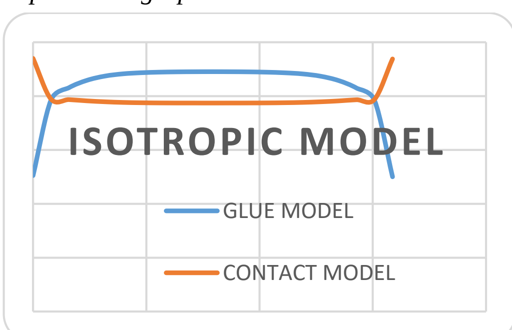

Fig. 35. Comparison of isometric model

M. Orthotropic model

1) Contact model

By applying the loading and boundary conditions, the result obtained that the von–mises stress for orthotropic contact model is 3.733.

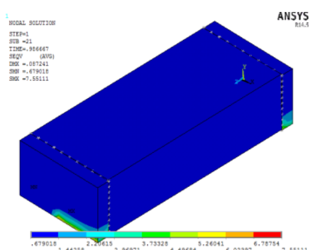

Fig. 36. Developed von-mises stress of Orthotropic contact model

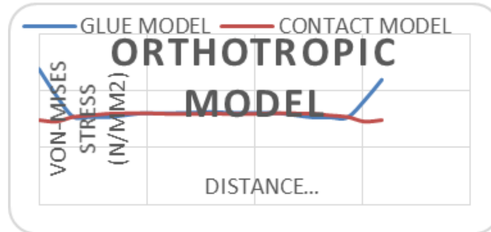

Fig. 37. Comparison of isometric model

Initially Von-mises stresses are very different from the isotropic model. Hence, the given equivalent model is not sufficient. By trial and error method the property of E1 magnified at a value of 10^5 given comparable result.

Table 2
Comparison various view model shapes result values

model	type of contact	element	displacement (mm)	von-mises stress (N/mm^2)
Isotropic	contact	Shell	0.001	3.68
		Solid	0.001	3.68
	Glue	Shell	0.001	3.61
		Solid	0.001	3.61
Orthotropic	contact	Solid	0.001	3.73

N. Orthotropic graphs

Fig. 37, Comparison of orthotropic model

5. Conclusion and future scope

When isotropic properties used in honeycomb models, the hexagonal shape gave best results among hexagon, octagon, circular shapes. The deformation as well as stresses are minimized for hexagonal shape. The weight per unit deflection of the hexagonal shape is 2029 N/mm is less than that of octagonal and circular shapes. In ansys modelling glue and contact models gave similar results and hence either can be used. Modeling of the face sheets using shell elements and solid elements gave similar results. However shell requires lower computational time. When equivalent model was built with the orthotropic properties calculated formulas available in literature, very different results are obtained.

By trial and error method, the orthotropic property E1 had to be magnified by a value of 10^5 to obtain comparative results.

Table 3
Comparison various model shapes result values

Shape	Mass (kg)	Deflection (mm)	W/δ (n/mm)
Octagonal	0.0180	0.058	3044.48
Hexagonal	0.0120	0.058	2029.65
Circular	0.0121	0.056	2119.66

Table 4
Comparison various view model shapes result values

model	type of contact	element	displacement (mm)	von-mises stress (N/mm^2)
Isotropic	contact	Shell	0.001	3.68
		Solid	0.001	3.68
	Glue	Shell	0.001	3.61
		Solid	0.001	3.61
Orthotropic	contact	Solid	0.001	3.73

A. Scope for future work

A different orthotropic model needs to be developed in order to achieve an equivalent model. Use of the composite materials has to be studied. The arrangement of laminates in the shell may yield higher results.

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