

**ANALYSIS OF PVC FOAM-FILLED HONEYCOMB HYBRID
CORE SANDWICH WALL PANELS WITH ALUMINIUM
FACE SHEET**

PROJECT REPORT

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CERTIFICATE

Certified that this report entitled '**ANALYSIS OF PVC FOAM-FILLED HONEYCOMB HYBRID CORE SANDWICH WALL PANELS WITH ALUMINIUM FACE SHEET**' is the report of the project presented by **UMAROHINI S R**, Roll No.: **TKM20CESC16** during **2021-2022** in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Structural Engineering & Construction Management of the A P J Abdul Kalam Technological University.

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ABSTRACT

Rapid development in the construction industry necessitates the use of new technologies and construction materials. Sandwich panels are a newly emerging structural member because of the advantages of lightweight and high strength and stiffness of the sandwich core composite structure. Sandwich panels are lightweight structures with a high strength-to-weight ratio. They are composed of two face sheets and a core. The face sheet will be of high stiffness. The core will be of low density. Mainly used in aerospace, automotive, marine, and construction industries.

In this present work, the sandwich panel is analyzed by using commercial finite element software, ANSYS Workbench22. An aluminium-skinned PVC foam-filled aluminium honeycomb hybrid cored sandwich panel of 500 x 1000 mm size is selected for the analytical study. The total deformation, skin stresses, and core shear stress were calculated. The result is compared with a bare honeycomb sandwich panel. The effect of the change in core thickness, change in the face sheet thickness, and the honeycomb cell size in the behaviour of the sandwich wall panel is also included in the present study.

Keywords: *Sandwich panels, Honeycomb core, green materials, hybrid core, ANSYS Workbench*

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

A structural sandwich is a specific type of laminated composite made up of a combination of various materials that are bonded to one another in order to take advantage of the structural advantages of each individual component. Three main components make up a sandwich, as shown in Fig. 1.1. A thick, light core lies between two thin, stiff, and strong faces. To achieve a load transfer between the components, the faces are adhesively connected to the core.

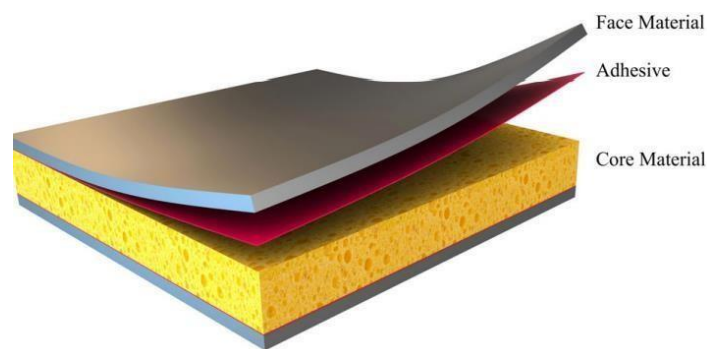


Fig 1.1: sandwich structure (Khan et al.,2020)

Sandwich panels is comparable to an I-beam. The faces in a sandwich are used in place of the flanges, and the core is used in place of the web. The core of a sandwich is made of a different material than the faces, and instead of being concentrated in a narrow web, it is spread out to provide continuous support for the faces. Together, the faces will work to create an effective stress couple or resisting moment that will balance out the external bending moment. The core prevents the faces from buckling or wrinkled and resists shear. The shear and tensile stresses that are placed between the faces and the core must be able to withstand the link between them. Thus, the glue that secures the faces to the core is crucial. The assembly's extremely high stiffness-to-weight ratio, high bending strength-to-weight ratio, great impact resistance, etc. are its most obvious benefits.

1.2 SANDWICH PANELS

The basic components of a sandwich panel are face, core and adhesive film.

(a) **Face:** Face ought to be thin, stiff, and strong. Depending on the requirements of the construction and manufacturing method, both faces may be made of the same material or from

separate materials. Steel, stainless steel, aluminium alloys, plywood, reinforced plastics, fibre composites, and other materials are more frequently employed.

(b) Core: The core should be light, thicker, and weaker. To minimise the weight of the construction as a whole, the core material should have a low density. Since shear is the main force acting on the core, it should have a shear modulus high enough to provide the necessary shear stiffness. Young's modulus perpendicular to the face should be high because although while the transverse forces causing normal stress in the core are typically minimal, even a minor decrease in core thickness could result in a significant reduction in flexural rigidity. The core material and its thickness have a significant impact on some sandwich functions, including thermal and acoustical insulation. The most widely used core materials include end grain balsa, vinyl sheet foam, polyurethane sheet foam, and Nomex honeycomb.

(c) Adhesive: Adhesives are utilised to secure the connection between the sandwich construction's face and core. Adhesives are made of resin compositions that were carefully created to provide a strong adhesion under a variety of exposure and stress situations. It must have the ability to transfer shear loads to and from the core. It should be able to provide a strong bond between the material components while also meeting the mechanical requirements of the construction. Epoxy resins, modified epoxies, phenolics, polyurethanes, urethane acrylate, etc. are the adhesives that are used the most frequently.

The fundamental idea behind sandwich constructions is to place stiff, thin faces far enough apart from one another to create a high stiffness to weight ratio. This is satisfied by the light weight core, which also offers the necessary resistance to shear and is robust enough to stabilise the facings in the desired configuration. The sandwich beam is similar to an I beam in that the sandwich facings and web both carry direct compression and tension stresses, while the sandwich core and flanges both carry shear loads. The fundamental design principles can be condensed into the following three conditions.

- Sandwich facings must be thick enough to withstand specified stresses when subjected to design loads.
- The core must be thick enough and strong enough and stiff enough in the shear direction to prevent overall sandwich buckling, excessive deflection, and shear failure under design loads.
- The core must have a high elasticity modulus.

1.2.1 SANDWICH WALL PANELS

The advantages of a typical prefabricated sandwich wall panel, such as durability, affordability, fire resistance, huge vertical intervals between supports, and use as shear walls, bearing walls, and retaining walls, are all present in sandwich panels. To accommodate building extension, they can be moved. In comparison to many alternative wall systems, the insulation offers higher energy efficiency and moisture protection. The sandwich panel's outside and interior hard surfaces offer resistance to theft, vandalism, and forklift damage, and if preferred, the finished product doesn't need any additional treatment. Figure 1.2 shows a lightweight sandwich wall panel.

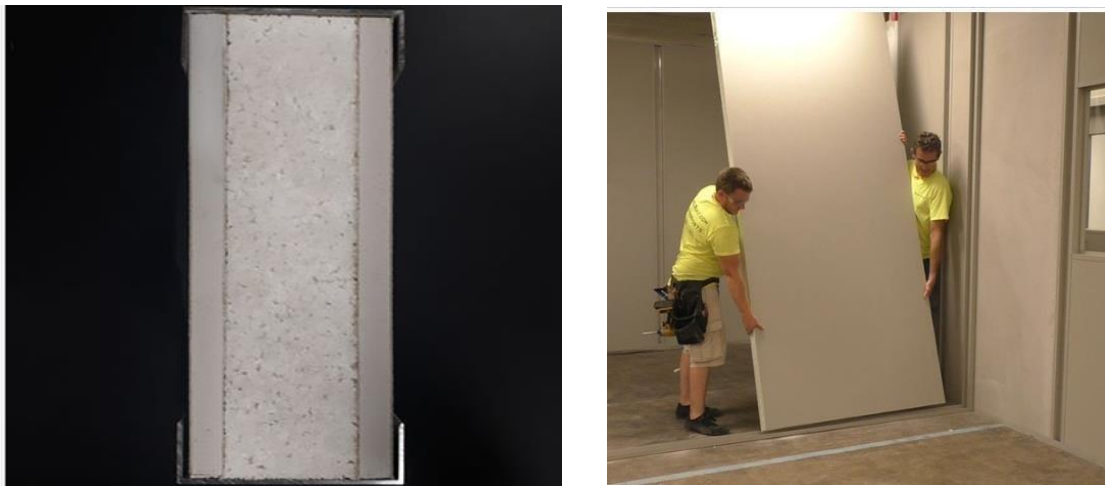


Figure 1.2: Sandwich wall panels

(<https://www.panelbuilt.com/blog/what-is-a-sandwich-panel>)

Some of the main advantages are listed below:

- Mass Production with Customization
- Incredible Convenience at the Job Site
- Thermal and sound insulation
- Strength, durability, and versatility
- Fast and lightweight installation
- Low building cost and installation cost
- Energy efficient
- Easily removable
- Suitable for any kind of building
- Fire and moisture protection

1.3 PROBLEM STATEMENT

Due to a severe housing scarcity, India has an enormous and expanding need for building materials. India needs new, energy-efficient building materials for sturdy, long-lasting housing that can be built quickly and affordably to meet this basic demand for urban habitat. The development of an energy-efficient and cost-effective material is the result of all these worries. Many of the aforementioned problems and worries can be resolved by using lightweight pre-fabricated Sandwich wall panels, which enable quick or faster construction and contribute to environmental conservation.

1.4 OBJECTIVES OF THE STUDY

- To model the PVC foam-filled honeycomb hybrid core sandwich panel by ANSYS workbench
- To analyse the effect of the change in core thickness on the behaviour of the PVC foam-filled honeycomb sandwich panel for axial and eccentric loads
- To analyse the effect of thickness of the face sheet in the behaviour of PVC foam-filled honeycomb sandwich panel for axial load
- To determine the effect of aluminium honeycomb core with varying cell size for axial load
- To compare the results and find the better panel combination

1.5 METHODOLOGY IN BRIEF

The following methodology was developed to achieve the aforementioned goals. The first step in the technique was to conduct a thorough literature review and gather the information needed to carry out this specific investigation. It contains the data regarding material properties under consideration that as Al alloy 6061 and PVC foam, the behaviour of sandwich panels under various loads, behaviour of hybrid core sandwich panels, and the effect of honeycomb sandwich panels with and without foam filling, etc. As the validation of the software, a numerical analysis of a sandwich panel was undertaken based on available literature.

After validation was successfully completed, as the first step, the project parameters are fixed. The dimensions of the panels, properties of the materials, loads, etc were fixed in this stage. Then the finite element model was developed by using the commercial software, ANSYS Workbench 2022 R1. Defining the properties of materials used, modelling the structure's

geometry, and setting up the interactions between various surfaces were crucial steps in the finite element modelling process. The models developed as per the specifications were studied parametrically utilizing generated models. In this phase, the effects of several parameters on the characteristics of sandwich constructions were assessed. These parameters included the thickness of the core, the thickness of the face sheet and the cell size of honeycomb core. After the analysis the results of sandwich wall panels with PVC foam filled honeycomb hybrid core obtained is compared with the sandwich panels without PVC foam.

1.6 SCOPE OF THE WORK

- Structural analysis of panel with aluminium face sheets
- Aluminium honeycomb –PVC foam hybrid core is used
- ANSYS workbench is used for the analysis
- Panel size: 500x1000mm
- Study deals with critical loads, skin stresses, core shear stresses
- Parameters used for the study:
 - Core thickness
 - Thickness of face sheets
 - Honeycomb cell size

1.7 ORGANIZATION OF THE REPORT

There are six main chapters in this thesis. The study's introduction, problem statement, the significance of the research, goals, objectives, a brief summary of the methodology used, and the study's scope and limits are all covered in chapter one.

The research that has been done on sandwich wall panels in the past are reviewed in Chapter 2. It concentrates on the literatures concerning various core materials used in sandwich panels, effect of use of hybrid core in a sandwich wall panel, and significant influencing factors that affect the behaviour of sandwich panels, etc.

In chapter three, the method employed for the study is described in detail. In this chapter, ANSYS software-based finite element models of test setups and parametric studies are described.

The software (ANSYS Workbench 2022 R1) validation is covered in Chapter 4. It goes into detail regarding comparing results from reference journals and outcomes from numerical analysis of simulated models.

The findings of numerical studies and the conclusions drawn from them are presented in Chapter 5. It mainly consists of the load – deformation curve of sandwich wall panels under axial and eccentric loads, the critical load that the panel can carry, the core shear stress, and skin stress. It also includes research on the effect of variation of core thickness, the thickness of the face sheet, and the cell size of the Al honeycomb core.

Conclusion presents the study's key results and recommendations, along with the identified future research directions for this particular field of study.

CHAPTER 2

LITERATURE REVIEW

2.1 SANDWICH WALL PANELS

Wang et al. (2016) developed an innovative load-bearing sandwich wall panel with glass fiber-reinforced polymer (GFRP) skins and a foam-GFRP web core which was manufactured using a vacuum-assisted resin infusion process. The test findings showed that increasing the web thickness, web height, and skin thickness might enhance axial strength, axial stiffness, displacement ductility, and energy dissipation. The ultimate axial strength and initial stiffness of wall panels can be improved by a thicker web, smaller web spacing, increased web height, and thicker skins; nevertheless, the deformability of panels can be slightly impacted by skin thickness.

Potluri et al. (2017) conducted a finite element analysis of cellular foam core sandwich structures. They came to the conclusion that there is an inverse relationship between core and skin thickness and equivalent maximum stress, shear stress, and deformation. Both Core and skin thickness have a direct effect on how stiff the sandwich structure is. Due to the sandwich structure's skin thickness, which is directly proportional to mass and inversely proportional to elastic strain, neither mass nor elastic strain significantly changes. The sandwich structure's core shear collapse is its primary flaw. From the foregoing, it can be inferred that in order to design a sandwich structure with metal skins and a foam core that is low in weight and highly rigid, the core thickness and foam structure should be optimised, and that keeping the skin thickness to a minimum can improve stiffness results since the core plays a major role. According to the results of the modal analysis, the frequencies 1, 2, and the remaining 4 frequencies drop with an increase in skin thickness since mode 1,2 has a larger stiffness. Due to mode 2's reduced rigidity, frequency 2 falls and frequencies 1, 3, 4, and 6 increase as core thickness increases.

Katarzyna Ciesielczyk and Robert Studzinski (2017) describe the experimental and numerical investigation of the stabilization of cold formed thin-walled Z-beams by sandwich panels. The results of the studies showed that the Z cross-capacity section's is greatly increased when sandwich panels and thin-walled beams are connected by fasteners. The quantity of fasteners affects how quickly the capacity of thin-walled beams increases. When eight fasteners are used per side, the critical load increases by 2.81, and when four fasteners are used per side, the critical load increases by 2.22. It's also important to note that even if the sandwich panel is

placed freely on the thin-walled beam, this still provides some partial bracing and causes the critical load to increase by 1.18.

Sushil et al. (2021) conducted study on Structural behavior of FRP grid reinforced geopolymer concrete sandwich wall panels subjected to concentric axial loading. The various SWP layers were joined together using GFRP tube connections. Experimental research was done on the impacts of slenderness ratio, connector spacing, and insulation thickness to wall thickness ratio. The axial load capacity of SWPs was predicted using a theoretical iterative process that included non-linear material features by comparing them to analogous solid wall panels.

2.3 HONEYCOMB SANDWICH PANELS

Sun et al. (2017) conducted experimental and numerical study on honeycomb sandwich panels under bending and in-panel compression. In this study, experiments on aluminium honeycomb sandwich panels with three-point bending (TPB) and in-panel compression (IPC) were carried out to investigate the crushing behaviours of honeycomb sandwiches. It is clear that foil thickness affects peak and mean loads favourably. With a larger core height, the load that causes skin to buckle could be heavier than for people with a lesser core height.

Safarabadi et al. (2020) investigated the Experimental and numerical study of buckling behaviour of foam-filled honeycomb core sandwich panels considering viscoelastic effects. According to experimental findings, the presence of foam raises the critical buckling load by 14% when the load is directed toward the fibres. The foam raises the critical buckling load by 73% for fibres that are perpendicular to the load. The composite panel becomes unstable due to the asymmetric core, which lowers the critical buckling load. More energy is absorbed by sandwich panels with foam-filled cores than by those with bare honeycomb cores.

Burlayenko and Sadowski (2010) described the effective elastic properties of foam-filled honeycomb cores of sandwich panels. The out-of-plane transverse young's modulus and effective shear moduli of the honeycomb structure are significantly increased by PVC foam H200 filling by 15% and 24%, respectively. The maximum stresses at crucial sections, like the intersection of cell walls, are slightly reduced by filling with PVC foam, which results in a more uniform stress condition within cell walls. The increasing density of the filler foam amplifies this impact.

Potluri et al. (2016) described the finite element analysis of cellular foam core sandwich structures. They came to the conclusion that both Core and skin thickness have a direct impact on how rigid the sandwich construction is. Due to the sandwich structure's skin thickness, which is directly proportional to mass and inversely proportional to elastic strain, neither mass nor elastic strain significantly changes. The sandwich structure's core shear collapse is its primary flaw.

Wang et al. (2016) conducted study on Structural behavior of load-bearing sandwich wall panels with GFRP skin and a foam-web core. The presence of GFRP webs allows for a maximum improvement in ultimate axial strength of approximately 142% when compared to conventional sandwich panels with a foam core. The ultimate axial strength and initial stiffness of wall panels can be improved by a thicker web, smaller web spacing, increased web height, and thicker skins; nevertheless, the deformability of panels can be slightly impacted by skin thickness. The findings showed that the web height had a significant impact on the energy ductility coefficient of the panels, and that panels with a higher web height can display enhanced post yield deformation.

Mozafari and Najafian (2017) conducted a numerical study on Vibration analysis of foam filled honeycomb sandwich panel. They came to the conclusion that the frequencies for the bending and torsional modes increased as the core thickness increased, despite a negligible drop in the lateral mode. The honeycomb core's foam filling changed the order of the vibration modes. Additionally, they discovered that as cell size increases, lateral mode frequency increases while second bending and torsional frequencies drastically reduce.

Lei et al. (2019) studied the Sandwich assemblies of composites square hollow sections and thin-walled panels in compression. In the experimental study, adhesively bonded sandwich specimens (AB) suddenly failed between the GFRP face sheets and inner SHS sections without overall buckling. Mechanical bolted sandwich specimens (MB) had lateral deformation that was clearly visible and the beginning of global buckling. incremental failures were discovered from the sandwich-bolted specimens. The axial stiffness of the AB specimens was marginally higher than that of the MB specimens with the same section width, according to load and displacement curves.

Sun et al. (2021) conducted experimental study on the structural parameters of honeycomb-core sandwich panels against low-velocity impact. The thickness of the face sheet, the size of

the honeycomb cells, and the thickness of the cell walls all play a significant role in the sandwich structure's failure mode, although the core height has little effect. Sandwich panels that have thin face sheets and a core of high-density honeycomb that has thick or small cells typically fail in mode A. The perforation threshold energy (or velocity) can be efficiently increased by increasing face sheet thickness. The progressive folding style of cell walls that starts at their front ends, which provides an effective energy absorbing mechanism, is what causes the crushing behaviour of honeycomb cores. In a sandwich panel that fails in mode A, the honeycomb core can absorb energy on a par with the front face sheet, however under a range of impact energies, it only accounts for a relatively steady portion of the sandwich panel's overall energy absorption.

Li et al. (2022) conducted experimental study on influences of skin thickness, core topology, depth and direction on flexural deformation and ductile failure of Al honeycomb-based sandwich structures. Skin thickness, core depth, and core direction have a major impact on a sandwich structure's failure mode, while core topology has little impact. Although particular peak load does not grow monotonously as core depth increases, it does result in higher peak load and more energy absorption and specific energy absorption. When compared to non-auxetic sandwich constructions and auxetic honeycomb-based sandwich structures, thicker skin increases peak load, energy absorption, and specific energy absorption while causing the specific peak load to decrease first and subsequently increase.

Gopichand et al. (2012) conducted a numerical investigation on design and analysis of corrugated steel sandwich structures using Ansys workbench. The structural study of the sandwich panel model created in PRO/e is successfully imported into Ansys Workbench, where the top face exhibits the maximum stress. For a structure with a certain length and height, the strength can be successfully increased by increasing the number of curved waves (3 waves to 4 waves). Strength increases to 66% with every 4% increase in weight.

2.4 SUMMARY OF LITERATURE REVIEW

Sandwich panels with thin face sheets are frequently utilized to address engineering challenges in recent times. Also sandwich constructions with a honeycomb core are frequently employed in a wide range of applications. Additionally, it is possible to use thin polymeric foams to enhance the structural properties of sandwich panels. Hybrid cored sandwich wall panels provide better performance.

2.5 GAPS IDENTIFIED

Gaps identified from the literature survey are as follows:

- PVC foam filled honeycomb core is not analyzed yet
- Studies related to comparison of with and without PVC foam were very less

CHAPTER 3

METHODOLOGY

3.1 GENERAL

Sandwich wall panel with PVC foam filled honeycomb hybrid core and aluminium face sheet was considered for analysis. Numerical investigation of structures offers an attractive technique of research due to its low cost, quick results, and ability to study several variables in depth. Therefore, a three-dimensional non-linear finite element model was built using commercial software Ansys Workbench. For conducting the analysis, the first step was the validation of Ansys software based on data from an experimental analysis conducted by Fatlawi et al. (2020). For the fulfillment of the defined objectives, the steps followed were structural modeling, nonlinear static analysis, parametric study, development of load deformation curve, and comparative study. The methodology of the project is outlined as flow chart in Figure 3.1 shown below.

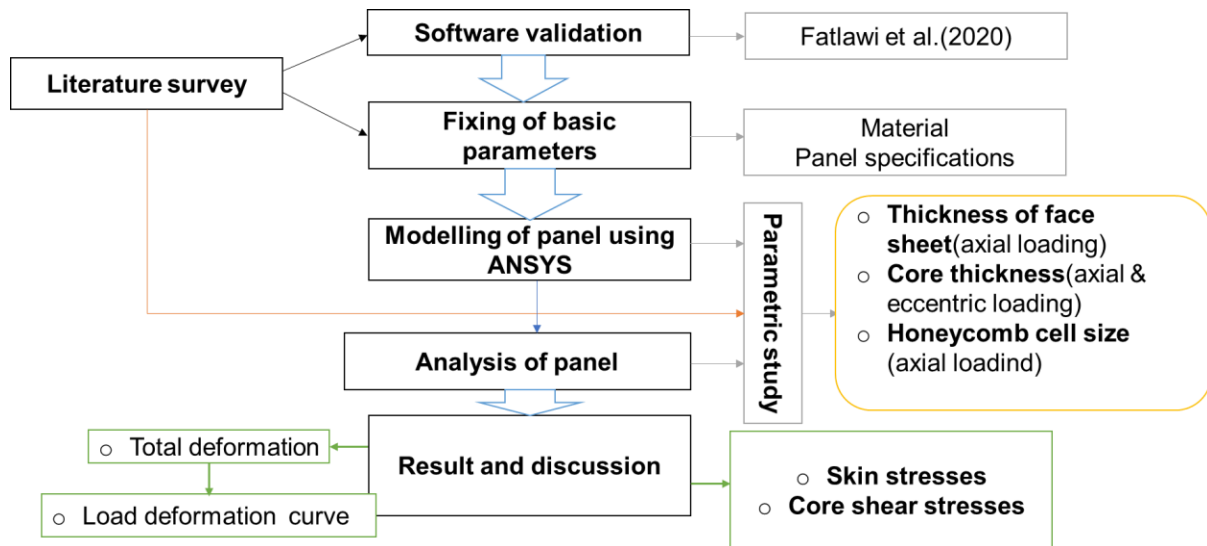


Fig 3.1: Flowchart of the proposed method

3.2 MATERIAL MODELLING

Data regarding material properties for aluminium 6061 and PVC foam was collected for the purpose of material modelling. The material properties are given in the following table 3.2.

Table 3.1: Material properties of Al alloy 6061 & PVC foam

Properties	Yield strength	Shear strength	Elastic modulus	Poisson's ratio
Al alloy 6061	276 MPa	207 Mpa	68.9 GPa	0.33
PVC foam	51.6 MPa	5.01 MPa	3.38 GPa	0.32

3.2.1 AL ALLOY 6061

The material of the face sheet and hexagonal honeycomb core is selected as Al alloy 6061. Figure 3.2 shows the Al alloy sheets used as the face sheet of the sandwich panel and hexagonal honeycomb core manufactured with Al alloy 6061. This is available in various thicknesses. The following are various advantages of Al alloy 6061.

- Medium to high strength heat-treatable alloy
- Good corrosion resistance
- Good weldability
- It has medium fatigue strength

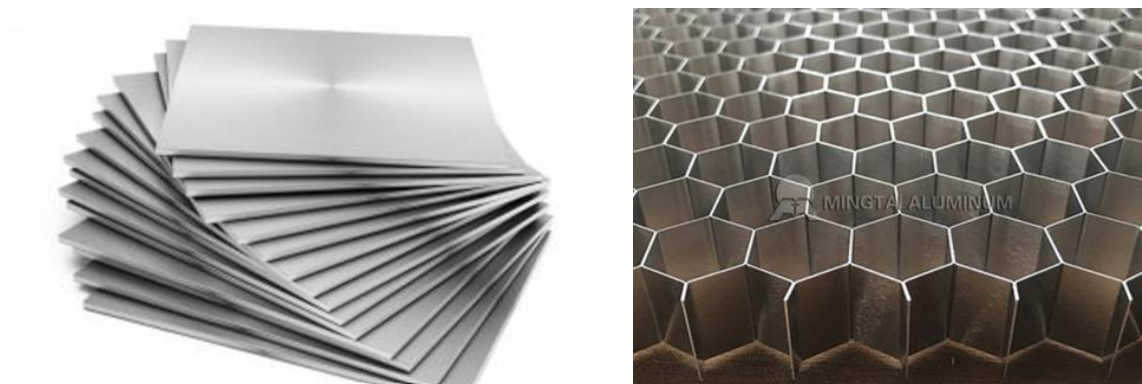


Figure 3.2: Face sheet and hexagonal honeycomb core manufactured using Al alloy 606

(<https://hiluminium.com/products/manufacturing-perfect-aluminium-alloy-6061-t6-profile/>)

Al alloy 6061's elasto-plastic behaviour under loading is modelled using the stress-strain data from Shinde et al (2012). Figure 3.4 shows the stress-strain model used for Al alloy 6061.

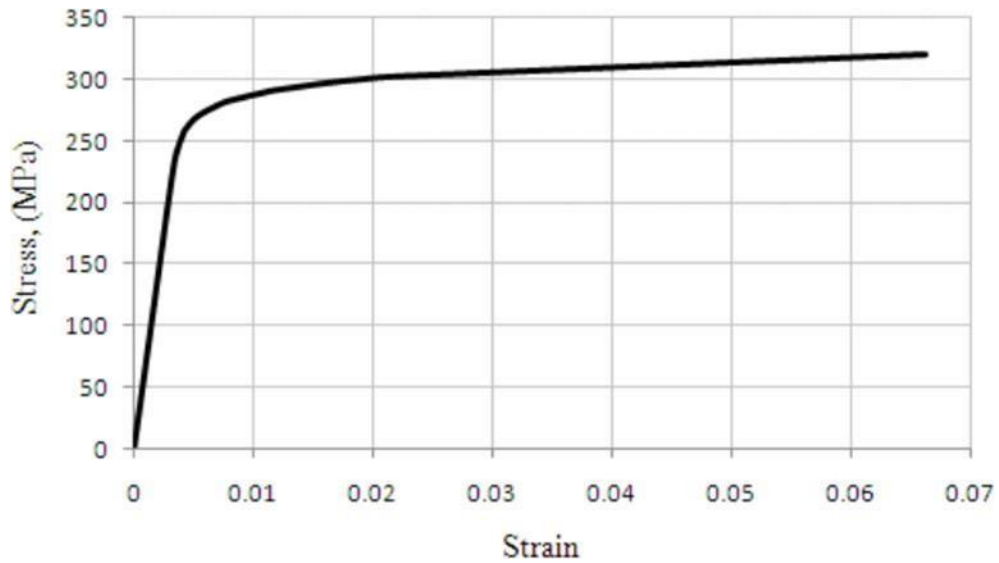


Figure 3.3: Stress strain curve of Al alloy 6061(Shinde et al.,2012)

3.2.2 PVC FOAM

The material PVC foam is used to fill the hexagonal honeycomb core. Then the core is acted as hybrid core. Figure 3.4 shows the PVC foam. The advantages of PVC foam are the following.

- Superior impact resistance
- High strength, great durability
- Low water absorption
- High corrosion resistance



Figure 3.4: PVC foam (<https://www.fibermaxcomposites.com/shop/pvc-foam-br-8020-p-500.html>)

The stress-strain curve of PVC foam with is shown in figure 3.5. The apparent density of PVC foam which were selected as the filler phase of honeycomb core is 60 kg/m³.

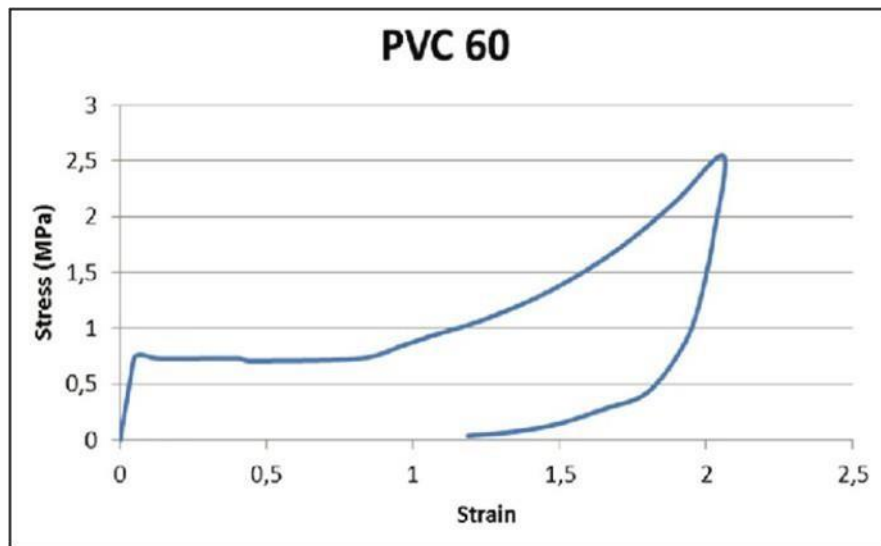


Figure 3.5: Stress–strain curve considered for PVC foam with density of 60 kg/m³
(Valladares et al.,2016)

3.3 FINITE ELEMENT MODELLING

3.3.1 MODELLING OF GEOMETRY

The 3D finite element models of bare and PVC foam filled honeycomb sandwich panels were developed by means of ANSYS software (ANSYS Workbench 2022 R1). The FE model consist of three major parts: one core and two outer face sheets.

PVC foam-filled honeycomb hybrid core sandwich wall panel with aluminium face sheet was modeled as shown in figure 3.6. A total of 12 models were considered for the analysis purpose while varying different parameters such as core thickness, face sheet thickness, and honeycomb cell size. Different combinations of values are adopted for different parameters for each model. The size of the sample panel is fixed as 500 X 1000 mm. The height (H), width (W), core thickness (t_c), skin thickness (t_s) is mentioned in figure 3.6.

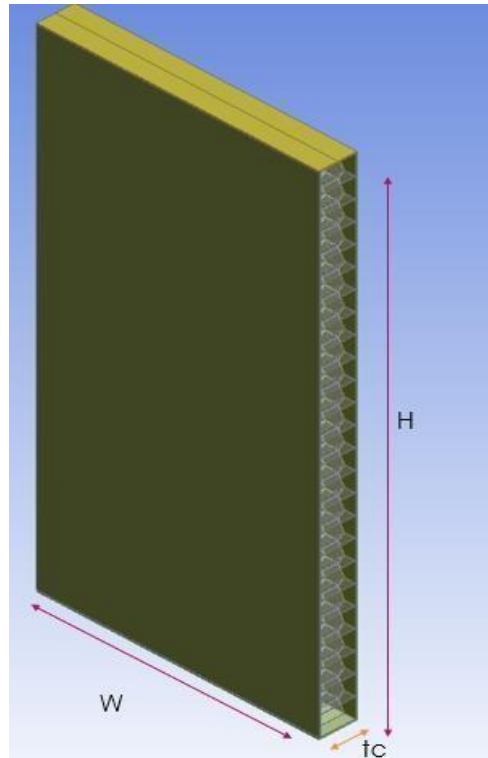


Figure 3.6: Sandwich wall panel of 500 x 1000 mm

Honeycomb core was an important factor. The shape of the honeycomb was selected as hexagon. The effect varying cell size of the hexagonal honeycomb core on the behaviour of the sandwich wall panel also included on the parametric study. The honeycomb cell size is the distance between the opposite walls of the hexagonal honeycomb. The cell size is illustrated in figure 3.7.

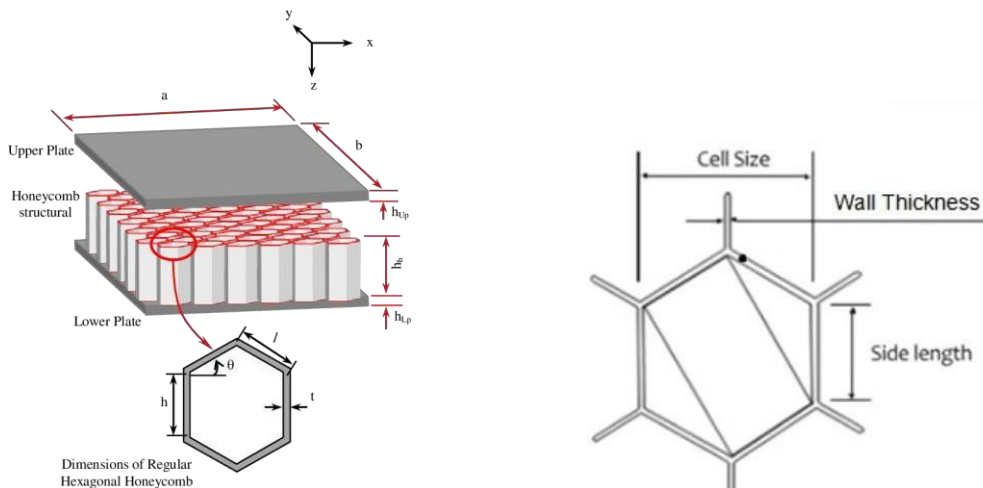


Figure 3.7: honeycomb cell size (Jweeg, 2016)

The Sandwich panel's specifications are listed in Table 3.2. The following table is divided into four groups: A, B, C, and D. For the parametric study, three different core thickness, skin

thickness and cell size are selected. The core thickness of the sandwich panel is varied as 40 mm, 50mm, 60mm. The skin thickness is varied as 2.4, 2.6, and 2.8 mm. The cell size is adopted as 40mm, 60mm, and 80mm.

Table 3.2: Specimen parameters

Group	Specimen	W (mm)	H (mm)	tc (mm)	ts (mm)	S (mm)
A	SP1	500	1000	40	2.4	40
	SP2	500	1000	50	2.4	40
	SP3	500	1000	60	2.4	40
B	SP4	500	1000	40	2.6	40
	SP5	500	1000	50	2.6	40
	SP6	500	1000	60	2.6	40
C	SP7	500	1000	40	2.8	40
	SP8	500	1000	50	2.8	40
	SP9	500	1000	60	2.8	40
D	SP10	500	1000	60	2.8	60
	SP11	500	1000	60	2.8	80
	RSP	500	1000	60	2.8	40

The following figure 3.8 shows that the modelled structure of Al alloy honeycomb matrix done in ANSYS.

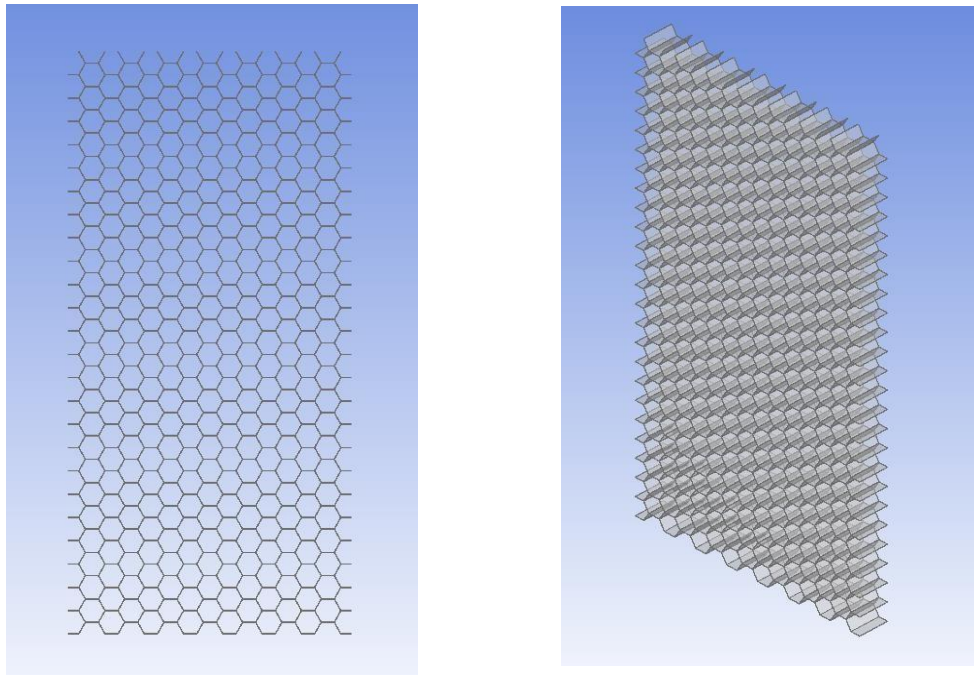


Figure 3.8: Model of honeycomb matrix

Figure 3.9 shows that the PVC foam is filled with Al alloy honeycomb core. Thus, it formed a hybrid core.

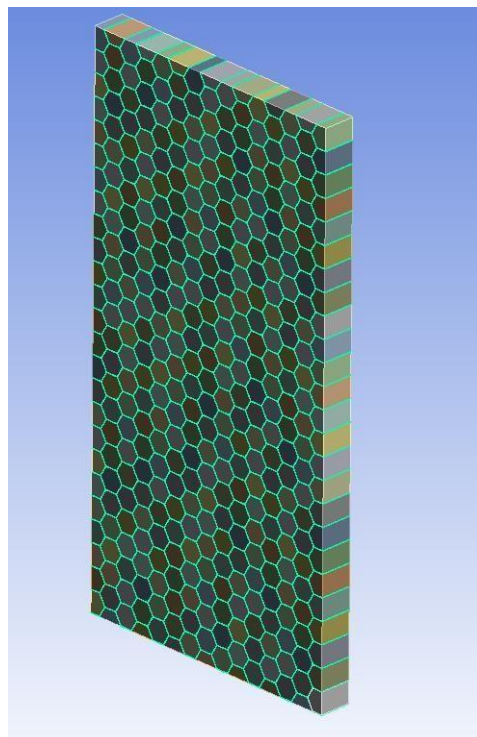


Figure 3.9: Model of PVC foam filled honeycomb matrix

Then the core is covered with aluminium face sheets. Figure 3.10 shows the model of PVC foam filled honeycomb hybrid core covered with face sheet of Al alloy 6061.

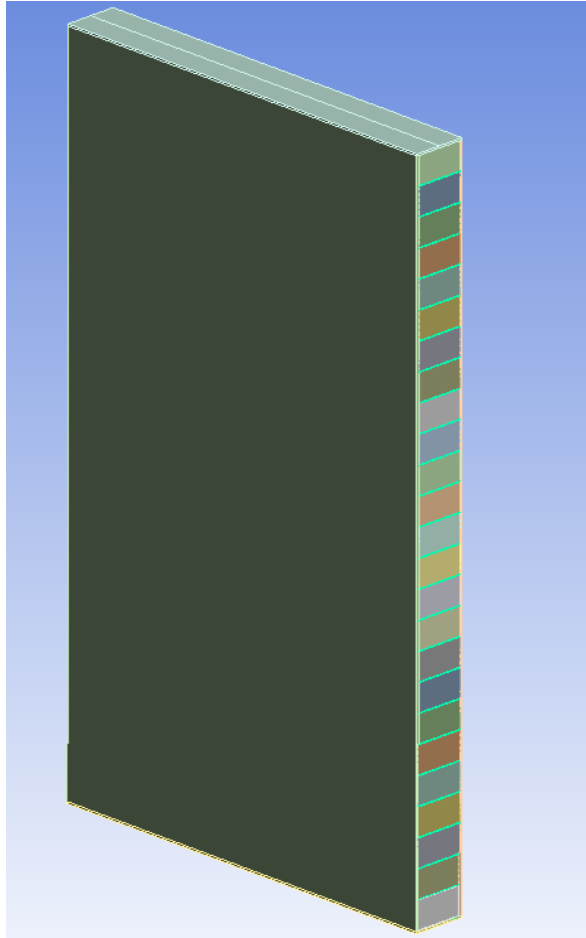


Figure 3.10: Model of PVC foam filled honeycomb hybrid core sandwich wall panel

3.3.2 FINITE ELEMENT MESHING

It is the process of turning geometrical entities to finite element entities, and all components of the sandwich structure employ the 4-node element. The mesh size is given as 30 mm. Figure 3.11 shows the meshed model of PVC foam filled honeycomb hybrid core sandwich wall panel.

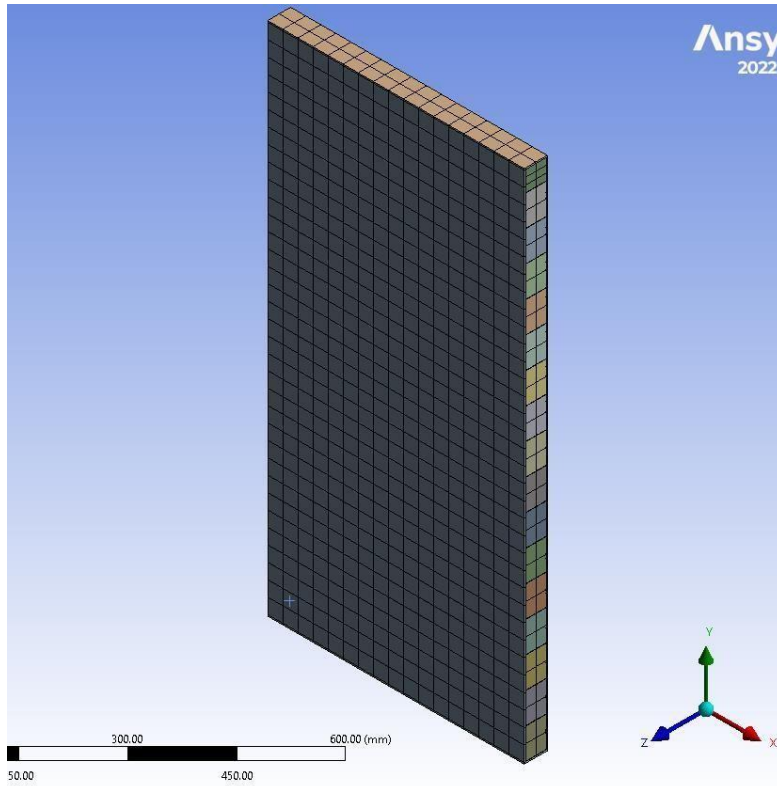


Figure 3.11: meshed model of sandwich wall panel

3.3.3 CONTACT SURFACE MODELLING

In this case, the adhesive layers are modelled as the bonded contact between the face sheets and the core since this kind of modelling best suits the adhesive layer's primary function. As a result, the face sheets and the core maintain constant contact during the examination.

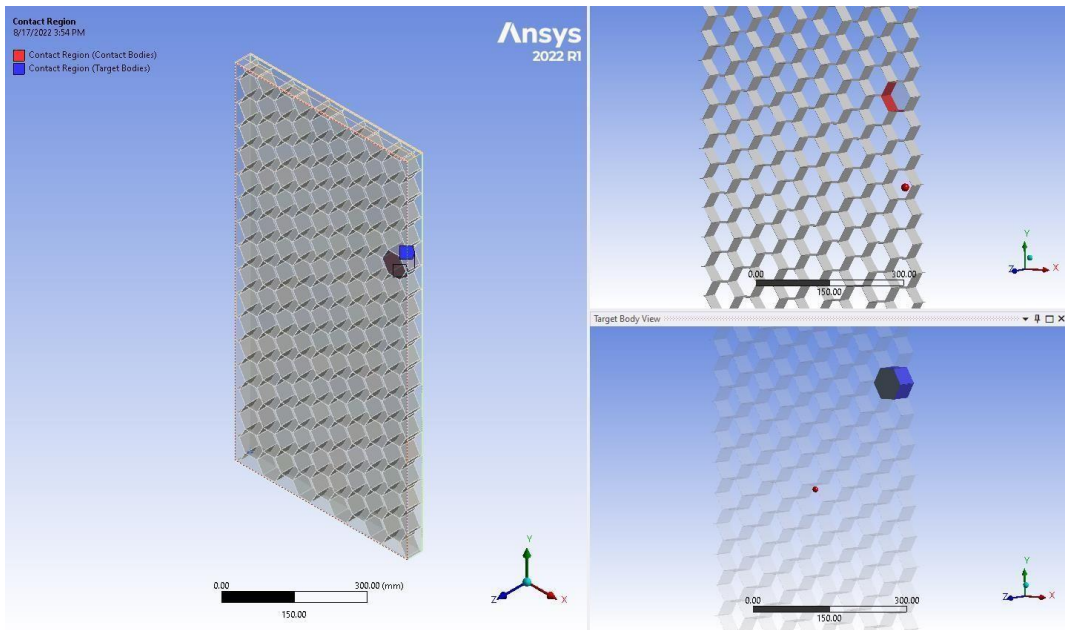


Figure 3.12: PVC foam is in bonded with honeycomb core

PVC foam is bonded with the face sheet of the panel was shown in figure 3.13. Likewise, the contacts between each part was defined as bonded in ANSYS.

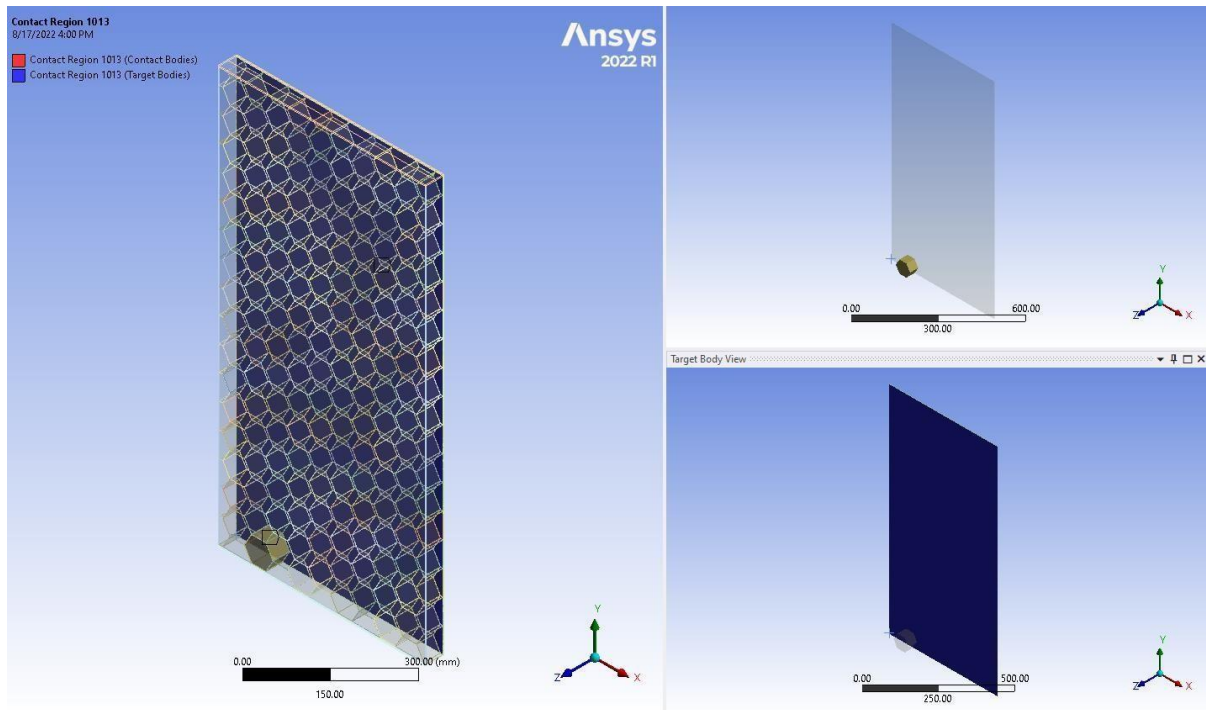


Figure 3.13: PVC foam is bonded with aluminium face sheets

3.3.4 LOADS AND BOUNDARY CONDITIONS

The bottom of the sandwich panel is fixed. The in-plane axial load is applied quasi statically on the top face of the panel.

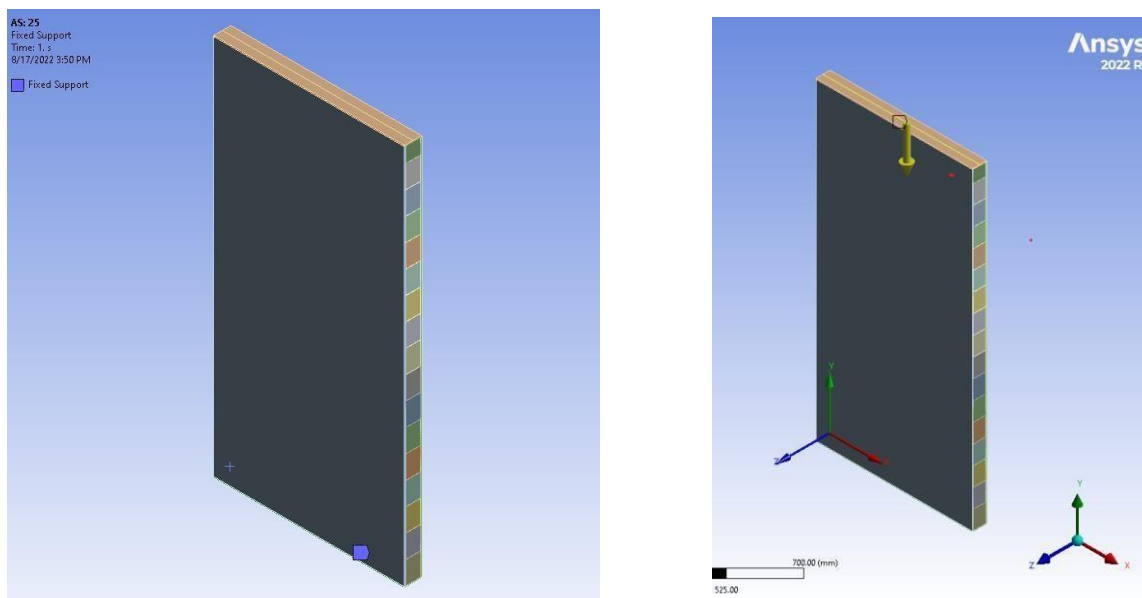


Figure 3.14: Loads and boundary conditions for static analysis

CHAPTER 4

VALIDATION

4.1 ANSYS WORKBENCH

ANSYS Workbench is a simulation software for solving engineering problems with the aid of the finite element method. In the finite element method, a body is divided into a numerous number of smaller elements whose joining points are called nodes or nodal points. This division process is done by meshing in this kind of software. The properties of each smaller element will be then assembled to get the properties of the whole body. ANSYS applications allow you to specify parameters such as geometry parameters, material properties, and boundary conditions. From easy, automatic meshing to carefully crafted mesh, meshing in ANSYS compresses the analysis process and helps ensure accurate solutions [Workbench User's Guide 15.0].

4.2 VALIDATION

The validation for the ANSYS workbench was conducted by replicating the analysis procedure from existing literature, "Theoretical and Numerical Analysis of an Aluminium Foam Sandwich Structure" by fatlawi et al., (2020). The analysis was a three-point bending test on a sandwich panel using E-glass fibre reinforced polymer as face sheets and Aluminium foam as the core. The face sheet was composed of four plies with fibre orientation of 0, 90, 0, 90 degrees respectively. The deformation, skin stress and core shear stress were the parameters to be validated.

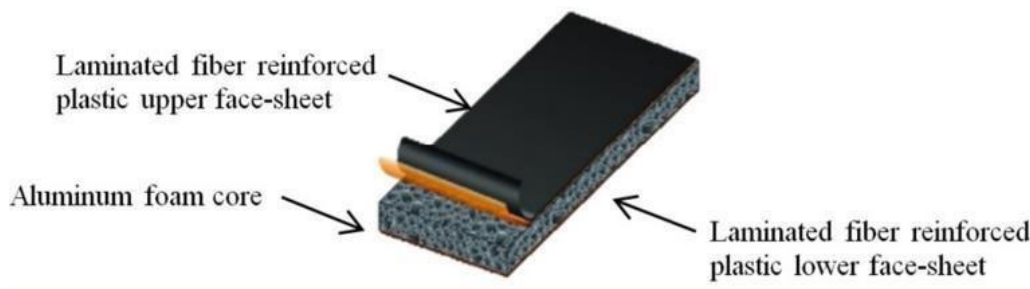


Fig 4.1: Aluminium foam core sandwich structure with laminated composite face-sheets

4.2.1 SPECIMEN DETAILS

Table 4.1: Data relating to the structural elements of the investigated sandwich structure

Length of the sandwich structure	L(mm)	1000
Width of sandwich structure	b(mm)	100
Height of the sandwich structure	h(mm)	24
Thickness of core	t_c (mm)	20
Thickness of flange	t_f (mm)	2
Density of E glass	ρ_g (Kg/m ³)	1900
Density of core	ρ_c (Kg/m ³)	300
Weight of the core	W_{core} (Kg)	0.6
Weight of the skin	W_{skin} (Kg)	0.38
Total weight of sandwich structure	W_t (Kg)	1.36

Aluminium foam core

The foam core is closed cell formed from Al alloy. The mechanical properties of the core make it ideal for several applications. These properties include high strength and stiffness to weight ratio and high energy absorption as shown in Table 4.2.

Table 4.2: Data of Cymat A35620SC 030SS stabilized aluminium foam

Compressive modulus	1200	MPa
Poisson's ratio	0.33	
Shear modulus	1000	MPa
Compressive strength	4	MPa
Shear strength	1	MPa
Density	300	Kg/m ³

E-glass fibre face-sheets

Al foam core sandwich structure with 4- layers in the upper and 4-layers in the lower skin face-sheets made of a fabric of E-glass fiber/epoxy resin with fibre orientation (0°, 90°, 0°, 90°).

Table 4.3: Mechanical properties of E-glass fibre

Property	E-glass	units
Young's Modulus 0°	25	GPa
Young's Modulus 90°	25	GPa
In-plane Shear Modulus	4	GPa
Major Poisson's Ratio	0.2	
Ultimate Tensile Strength	440	MPa
Ultimate Compression Strength	425	MPa

4.3 RESULT

The figure 4.2 shows that the meshed model of sandwich panel.

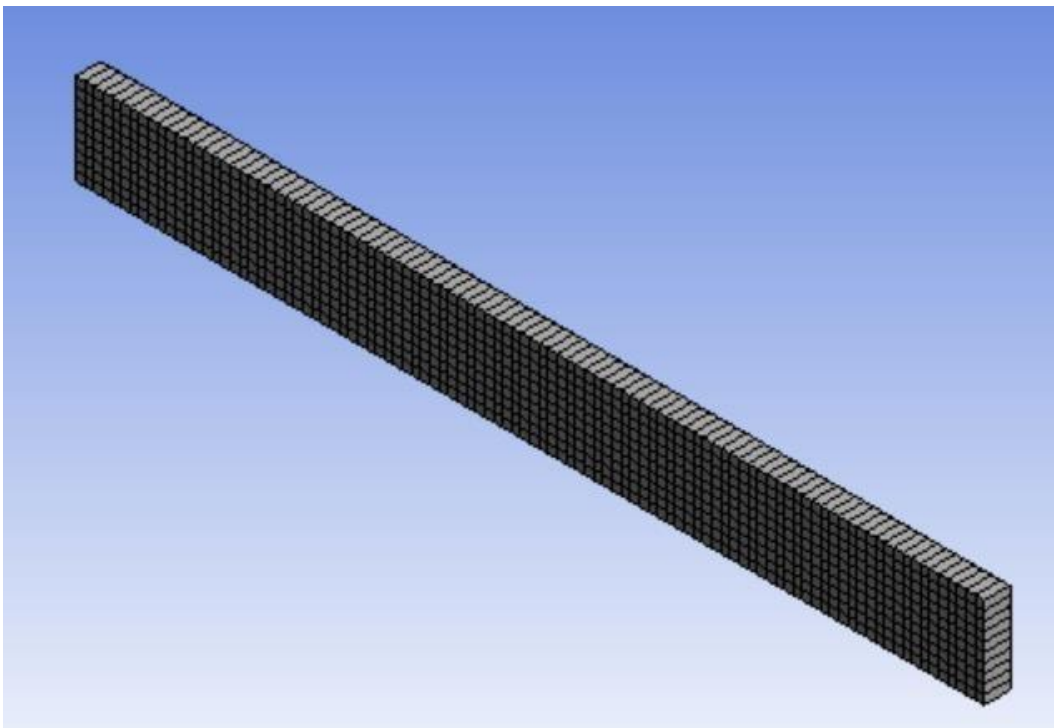


Fig 4.2: 3D mesh modelling of sandwich panel

After conducting the three-point bending test, the total deformation and skin stress is obtained is shown in figure 4.3 and 4.4.

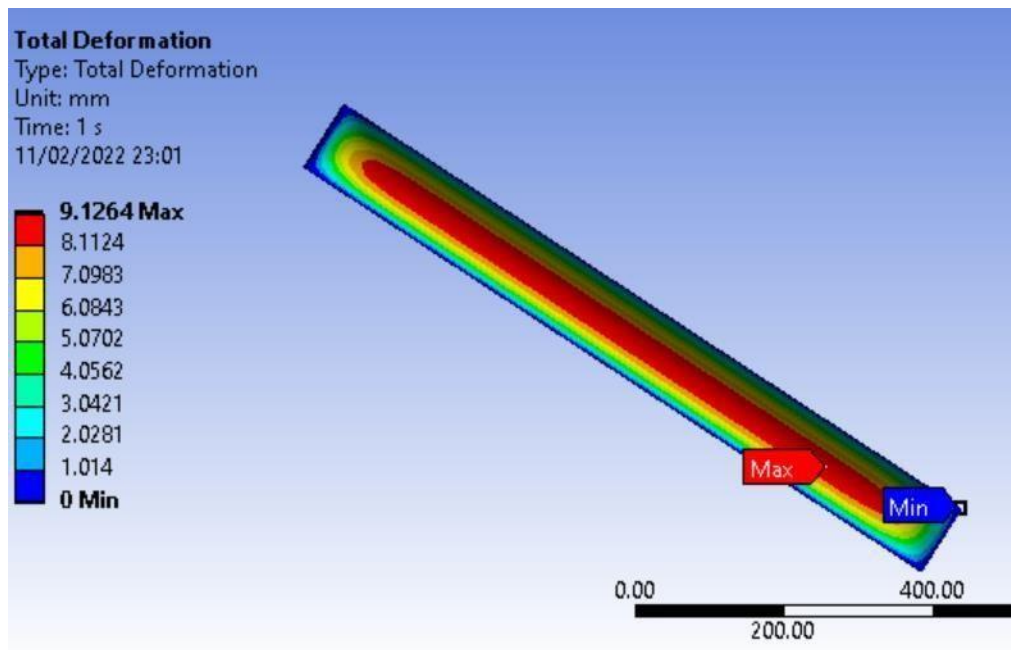


Fig 4.3: Total deformation of the panel

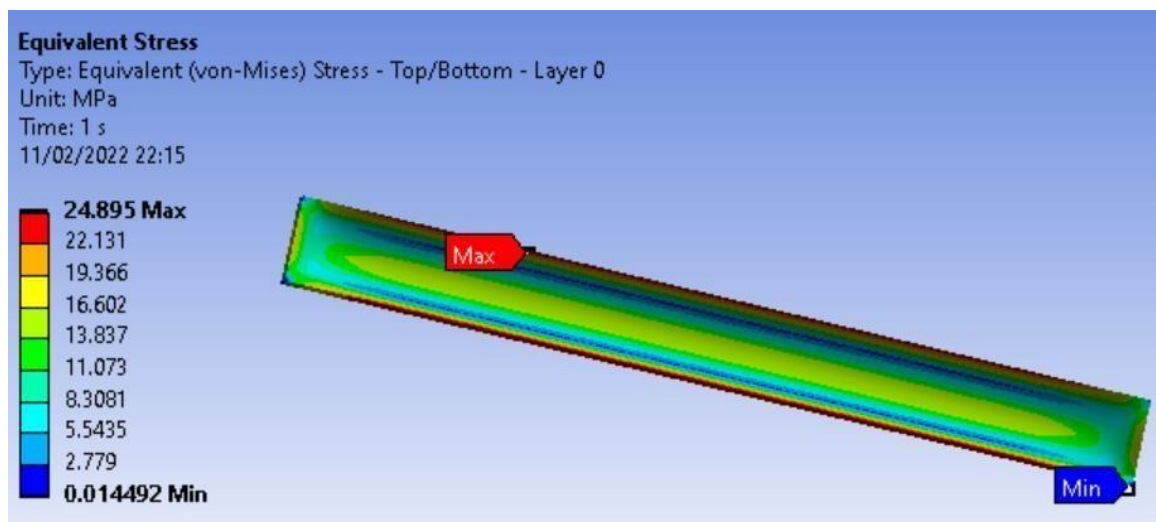


Fig 4.4: Skin stresses of sandwich panel

Table 4.4: Validation results

	Analysis result on journal	Validation results	% Error
Deformation δ (mm)	9.887	9.126	7.5
Skin Stress σ_{skin} (MPa)	25.6	24.895	2.7

Comparison of total deformation and skin stresses on journal and the results obtained after the numerical analysis on ANSYS workbench 2022 was shown in table 4.4. While comparing these two results, it was found that FE results were within the acceptable limits. Hence, software was considered as validated.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 GENERAL

In this research, for numerical analysis of sandwich panels, all constraining conditions are the same as in which the lower face is fixed. At the same time, the upper one is constrained to move only in a longitudinal direction of the composite panel. Analysis of finite element models of sandwich wall panels under axial and eccentric loads conducted. Results obtained through this study and their subsequent inferences are discussed below.

5.2 LOAD - DEFORMATION CURVE

5.2.1 LOAD-DEFORMATION CURVE UNDER AXIAL LOAD

The load-deformation curve for the first 3 panels under axial loading is shown below. SP1, SP2, and SP3 have varying core thicknesses of 40 mm, 50 mm, and 60 mm respectively, and a constant face sheet thickness of 2.4 mm. As the core thickness increases, it is observed that the load-carrying capacity of the sandwich wall panel increases. The peak loads of SP1, SP2, and SP3 were 667kN, 972kN, and 1098 KN respectively. From that, it was understood that the critical load of SP3 was much higher than the other two panels. Also, it was observed that the SP1 failed suddenly compared to the other two. Therefore, the core thickness also has an effect on the failure of sandwich wall panels.

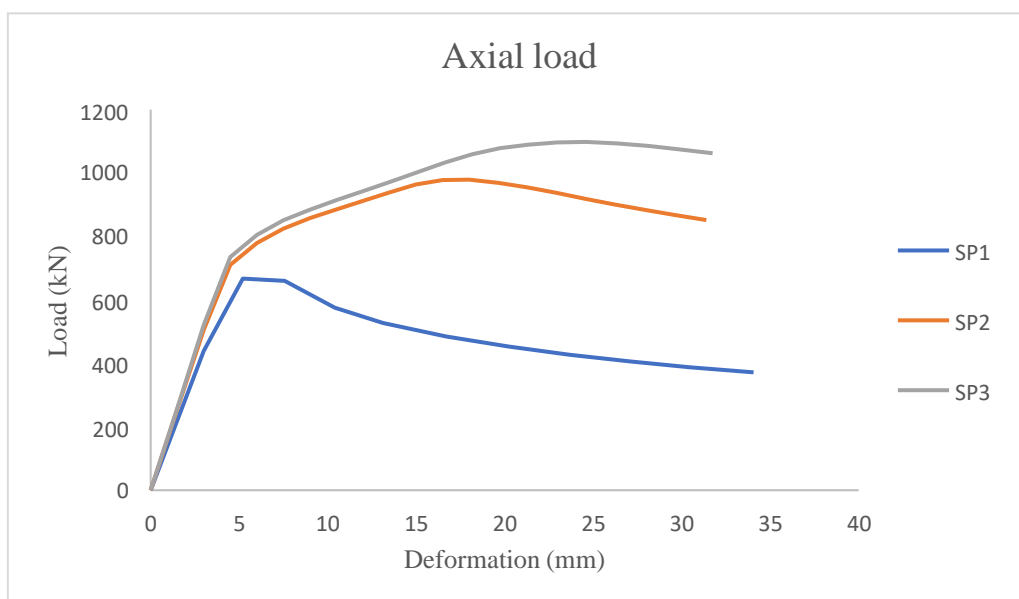


Figure 5.1: Load – deformation curve of SP1, SP2 & SP3

The sandwich wall panels SP4, SP5, and SP6 have varying core thicknesses of 40 mm, 50 mm, and 60 mm. The face sheet thickness of the panel is 2.6 mm. When the face sheet thickness increases from 2.4 mm to 2.6 mm, a slight increase in peak load was observed. Figure 5.2 shows the load-deformation curve of SP4, SP5, and SP6. The corresponding critical loads were observed as 904kN, 918kN, and 1122kN. Here also the same trend was seen. As increasing the core thickness, the load carrying capacity increases. But as the face sheet thickness increases, the panel will take more loads.

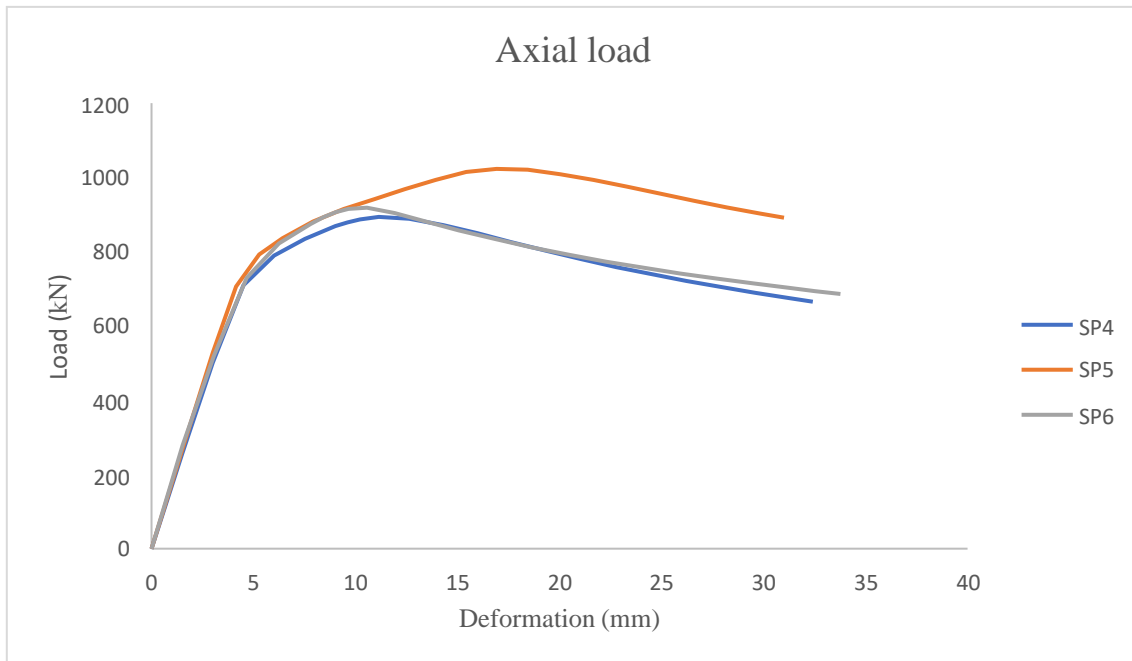


Figure 5.2: Load – deformation curve of SP4, SP5 & SP6

SP7, SP8, and SP9 have a face sheet thickness of 2.8 mm. the load-deformation curve of SP7, SP8, and SP9 under axial load is shown in figure 5.3. The critical loads of corresponding panels were observed as 945kN, 918kN, and 1210kN. SP9 had the maximum load-carrying capacity among all the combinations of panels. SP 9 has a core thickness of 60 mm and a face sheet thickness of 2.8 mm. It was observed that the load-carrying capacity of the panel became 2x when the core thickness increased from 40 mm to 60mm and the skin thickness increased from 2.4 mm to 2.8 mm. That is, the critical load of SP1 was observed as 667kN, and that of SP9 was 1210kN.

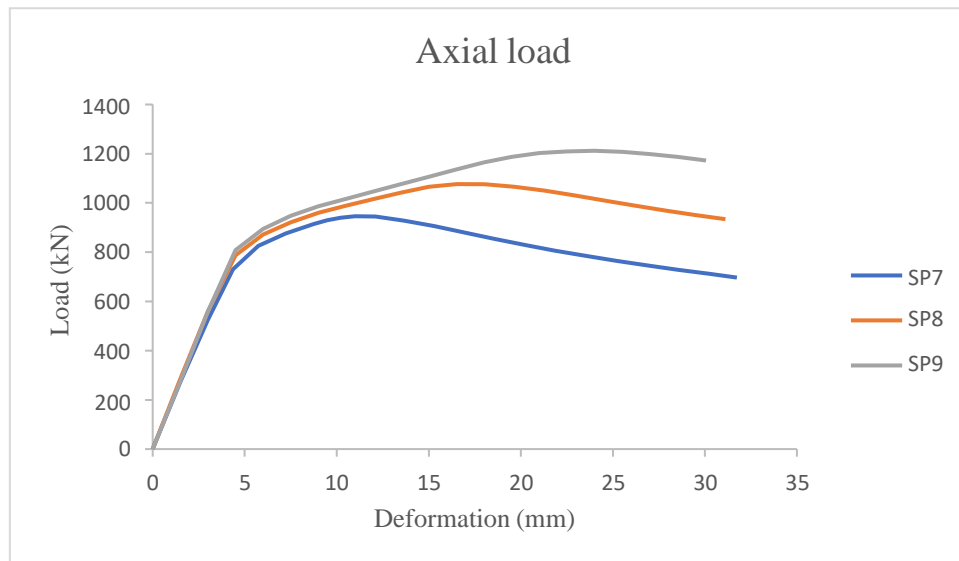


Figure 5.3: Load – deformation curve of SP6, SP7 & SP8

5.2.2 LOAD-DEFORMATION CURVE UNDER ECCENTRIC LOAD

An eccentric load is one that acts on a structural member at any point other than the member's centroid. A concrete slab sits on the top of a wall. Uneven span or uneven loads on the slab on either side of the wall will cause eccentric loading on the wall.

It was observed that when an eccentric load acts on a sandwich wall panel, the load carrying capacity will be decreased. Figure 5.4 shows the load-deformation curve of SP1, SP2, and SP3 under eccentric loading. It was found that the critical loads of SP1, SP2, and SP3 were 169kN, 247kN, and 333kN. The load that can be carried by the SP3 under eccentric loading was decreased by 3x than that under axial loading.

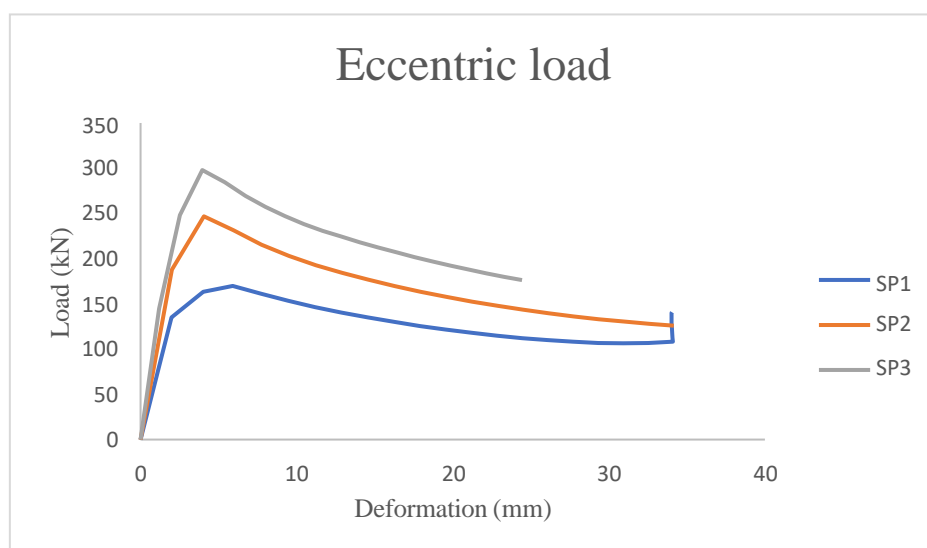


Figure 5.4: Load-deformation curve of SP1, SP2, and SP3 under eccentric load

But the increase in core thickness and face sheet will affect the peak load under the eccentric loading. Figure 5.5 is the load-deformation curve of SP4, SP5, and SP6 under eccentric load. The peak loads observed are 187kN, 266kN, and 346kN. Also, it was observed that the panels fail suddenly after attaining the critical loads.

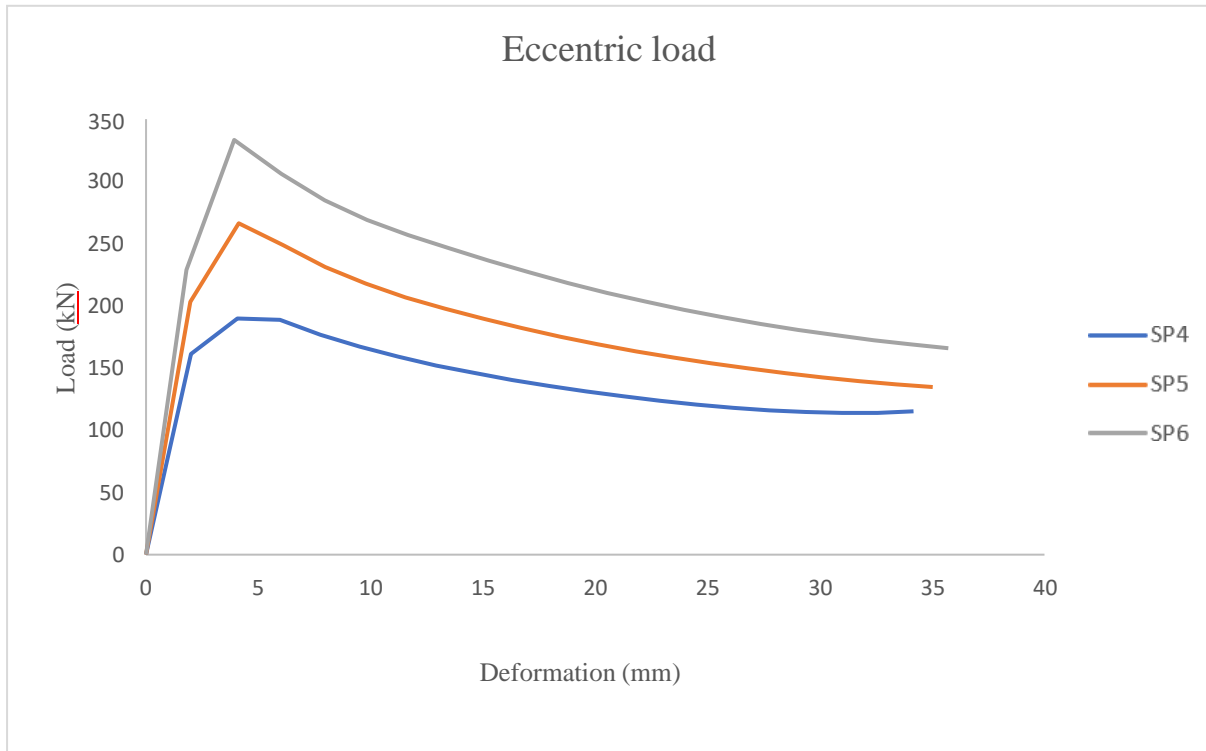


Figure 5.5: Load-deformation curve of SP4, SP5, and SP6 under eccentric load

The load deformation curve of SP7, SP8, and SP9 under eccentric load shown in figure 5.6. The critical loads were 203kN, 306kN, and 396kN. The peak load of 9th panel (core thickness = 60mm, face sheet thickness = 2.8 mm) under axial load is 1210kN. But under the eccentric loading, it was reduced to 396kN. Although, increase in core thickness and skin thickness has significant effects on load carrying capacity of sandwich wall panels.

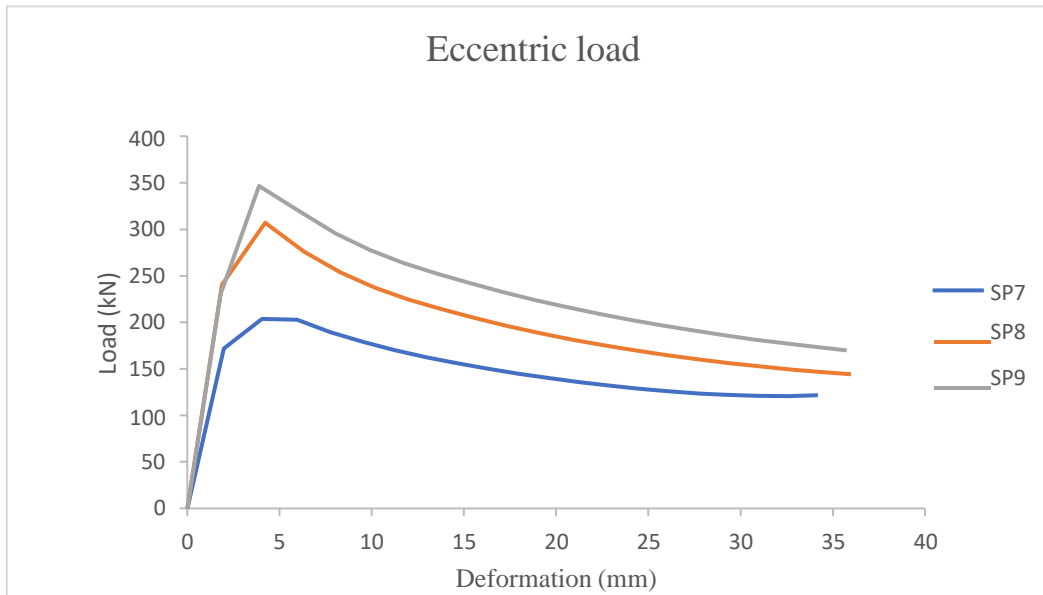


Figure 5.6: Load-deformation curve of SP7, SP8, and SP9 under eccentric load

5.2.3 PEAK LOAD UNDER AXIAL AND ECCENTRIC LOADING

Comparison of critical loads of sandwich wall panels under axial and eccentric load are shown in figure 5.7. The load-carrying capacity of sandwich wall panels under axial load is almost 3x higher than that under eccentric loading. Also, the core thickness and thickness of face sheet has significant effect on the behaviour of sandwich panel.

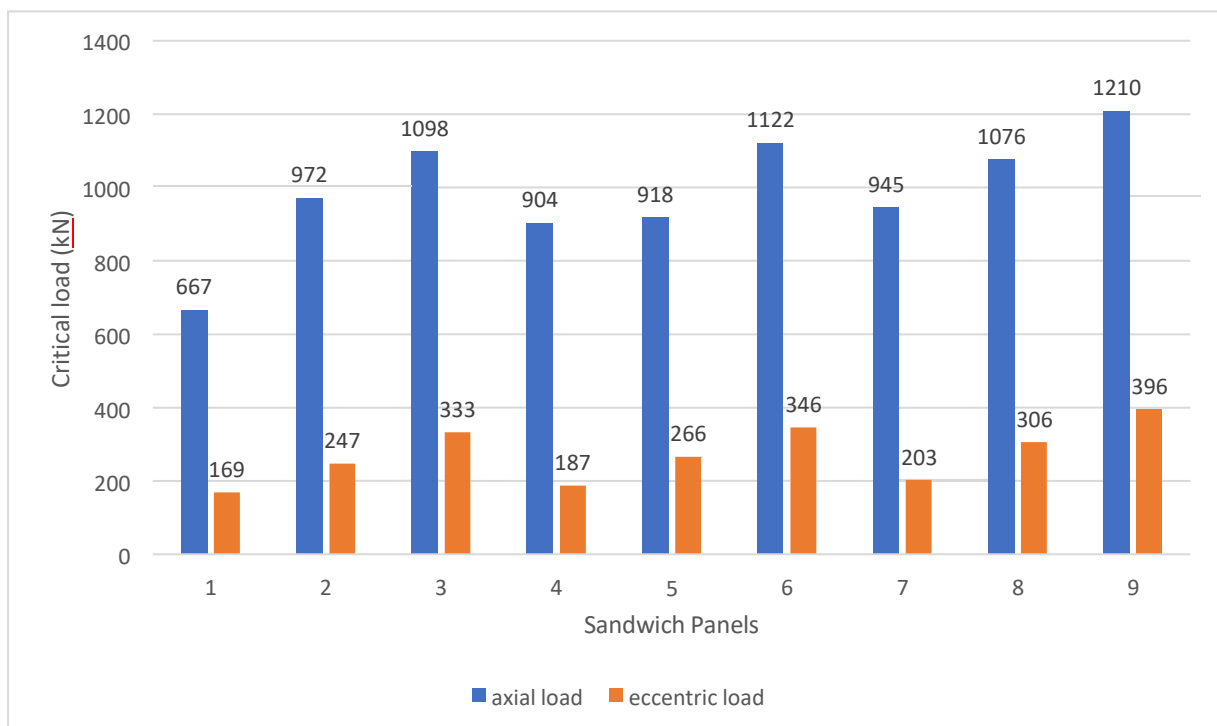


Figure 5.7: Comparison of critical load

5.3 EFFECT OF CORE THICKNESS

5.3.1 CRITICAL LOAD VS CORE THICKNESS

As the core thickness increased, it was observed that the load-carrying capacity of the sandwich wall panel also increased. Figure 5.8 shows the graph between the critical load and the core thickness. The core thickness is varied from 40 mm, 50 mm, and 60mm. The critical load increased from 667kN to 1210kN. The load-carrying capacity of the sandwich wall panel doubled when the core thickness went from 40 to 60 mm.

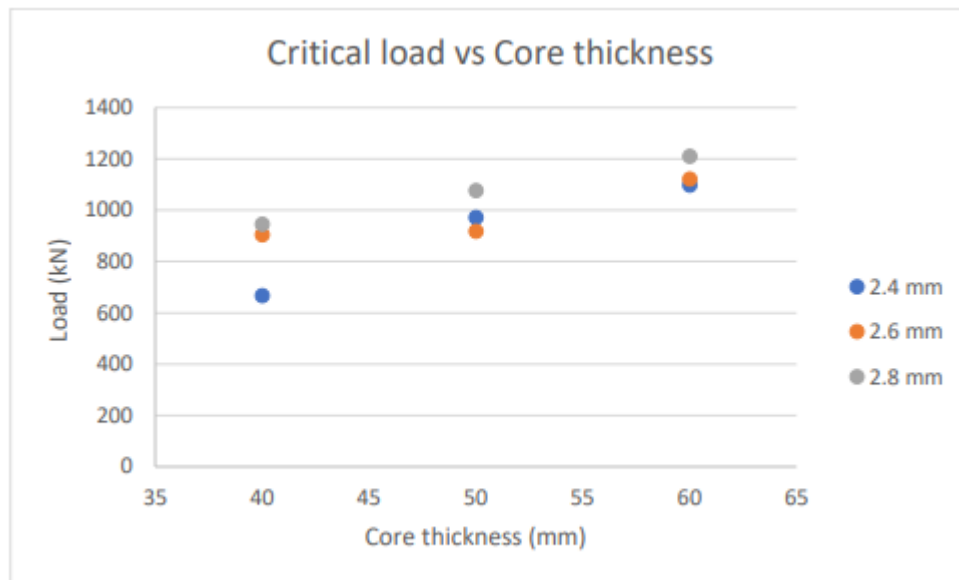


Figure 5.8: Graph of critical load vs core thickness

5.3.2 CORE SHEAR STRESS VS CORE THICKNESS

Since the core has low stiffness and strength and is lightweight, the core is of particular interest for sandwich panels. As the core of a sandwich experiences the majority of the shear deformation, the core's shear characteristics become crucial. If the core characteristics are not high enough, it will result in core shear failure or significant shear deflections. The sandwich materials should then be evaluated in terms of fatigue for long-term use, with a focus on the core's shear behaviour.

It was observed that the core shear stress decreased when the core thickness increased. Figure 5.9 shows the plot between shear stress and core thickness under axial load. The characteristics of the sandwich composite improved with core thickness. Less stresses and deformations are observed under the same load conditions. when the thickness of the face sheet was 2.4 mm, the

maximum stress developed in the core of the sandwich wall panel of 40 mm thickness was found to be 154.17 MPa. The core shear stress decreased by almost 10 MPa when the thickness of the core was increased to 60mm. The sandwich wall panel of face sheet thickness of 2.6 mm also exhibited similar behaviour as that of panel with 2.4 mm thick face sheet. The performance of the sandwich panel improved significantly when the thickness of the face sheet was 2.8 mm. Even at 40 mm core thickness, the intensity of shear stress developed was very low compared to the other two cases. However, the shear stress decreased by only 2 MPa with the increase of core thickness from 40 mm to 60mm.

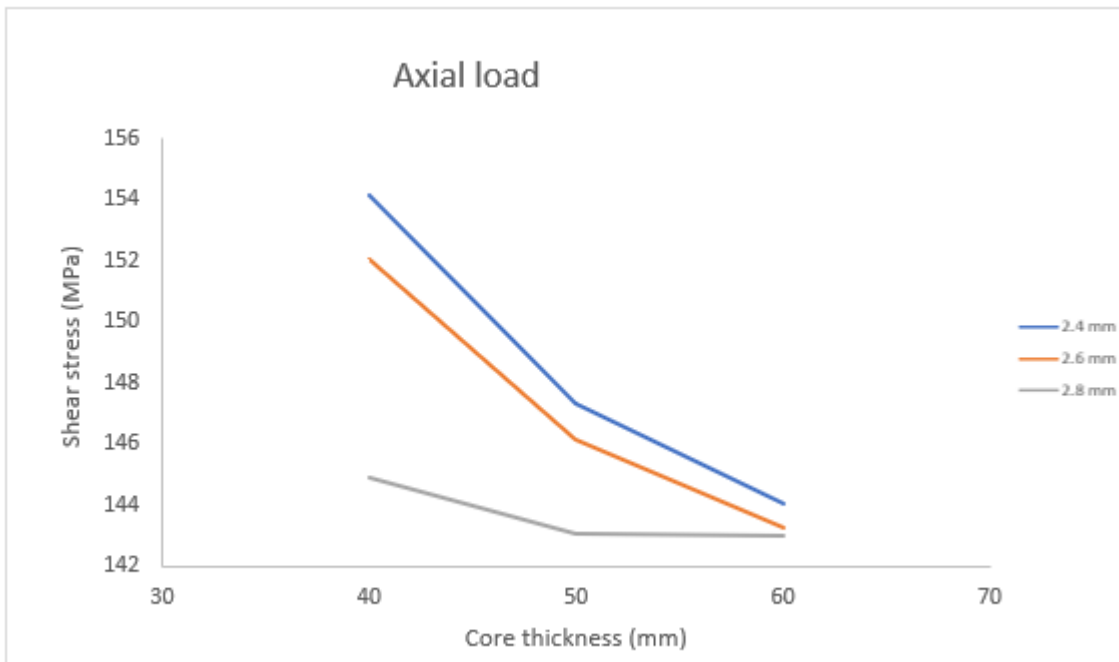


Figure 5.9: Graph of shear stress vs core thickness under axial load

Figure 5.10 shows the graph of core shear stress versus core thickness under eccentric loading. The stress developed under eccentric loading was comparatively less than that of axial loading. When the thickness of the face sheet of 2.4 mm, the graph shows a gradual decrease by 2MPa in core shear stress with the increase of core thickness from 40 to 50mm. when the core thickness increases from 50 to 60 mm, the stress is reduced rapidly by 8MPa. For the sandwich wall panel of face sheet thickness of 2.6 mm, the shear stress varied almost linearly with the core thickness. When the core thickness increases from 40 to 50mm the stress was reduced by 4MPa. The stress was lowered by 6MPa when the core thickness went from 50 to 60mm. But the graph of the 2.8 mm face sheet shows a rapid variation initially then a gradual variation.

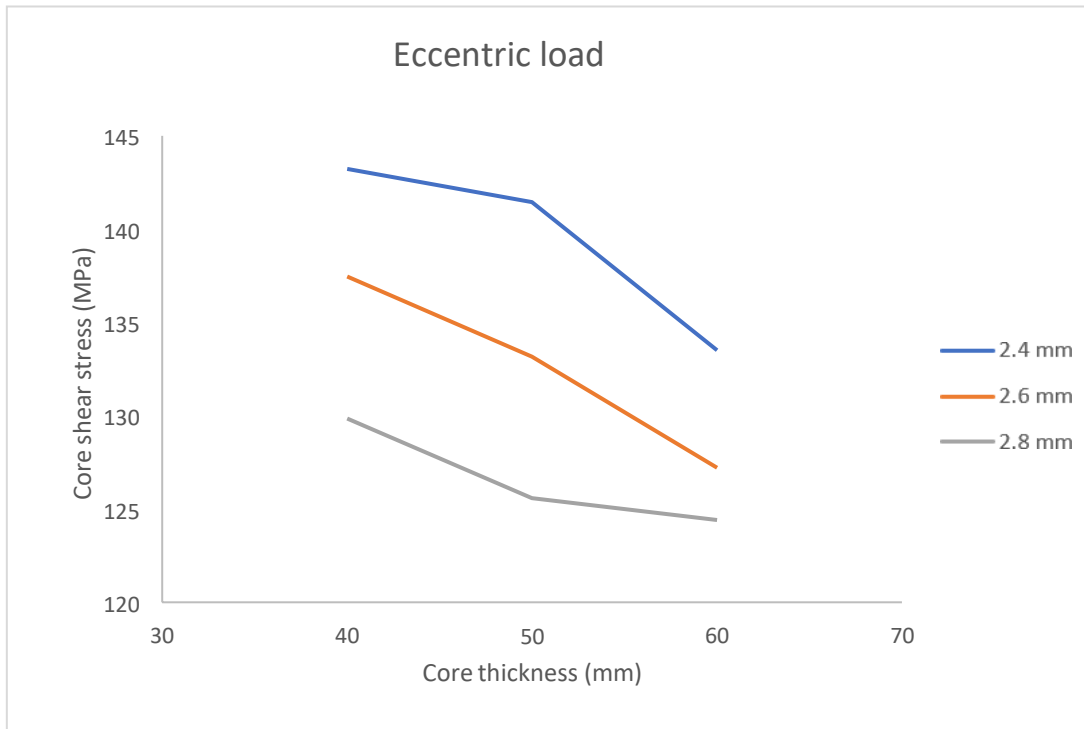


Figure 5.10: Graph of shear stress vs core thickness under eccentric load

5.3.3 SKIN STRESS VS CORE THICKNESS

Figure 5.11 shows the effect of core thickness on skin stress under axial load. It was found that as core thickness increased, skin stress decreased. For the sandwich wall panel of face sheet thickness of 2.4 mm, the skin stress varied almost linearly with the core thickness. For the panels of both 2.6 mm and 2.8 mm, the graph exhibits similar behaviour. When the thickness of the face sheet of 2.6 mm, the graph shows a gradual decrease in skin stress with the increase of core thickness from 40 to 50mm. When the core thickness increases from 50 to 60 mm, the stress is reduced rapidly. The lowest value of skin stress, that is 314MPa, was developed in the sandwich panel with core thickness of 60mm and face sheet thickness of 2.8mm.

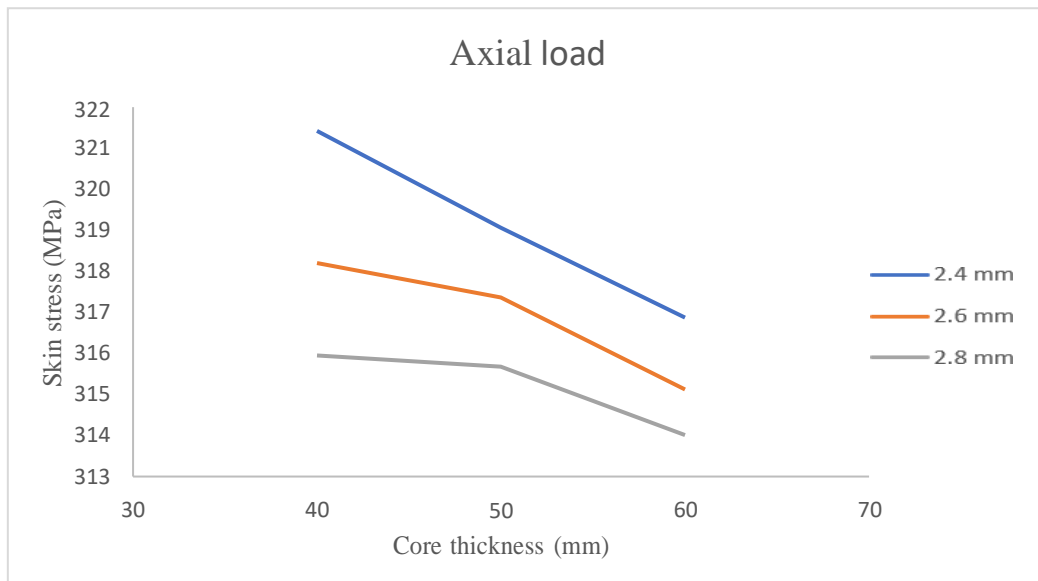


Figure 5.11: Graph of skin stress vs core thickness under axial load

Figure 5.12 shows the graph of skin stress versus core thickness under eccentric loading. From the graph, it can be observed that the stress developed in the face sheet decreases with the increase in core thickness.

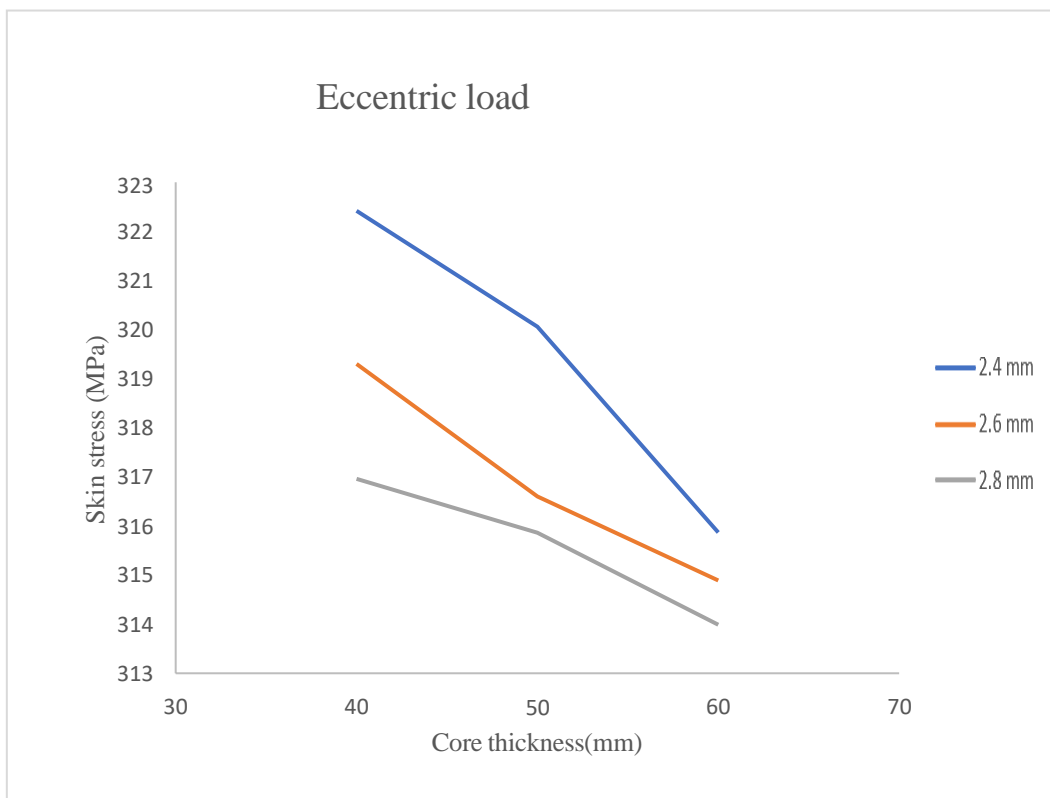


Figure 5.12: Graph of skin stress vs core thickness under eccentric load

5.3 EFFECT OF FACE SHEET THICKNESS

5.3.1 CRITICAL LOAD VS SKIN THICKNESS

Figure 5.13 shows the force-deformation relationship for wall panels with varying plate thicknesses. It was observed that when the plate thickness was increased it improved the load-deformation behaviour of the wall panel as it increased the overall stiffness of the structure. When the plate thickness was increased from 2.4mm to 2.8 mm it was found that the load carrying capacity was improved by more than 3 times.

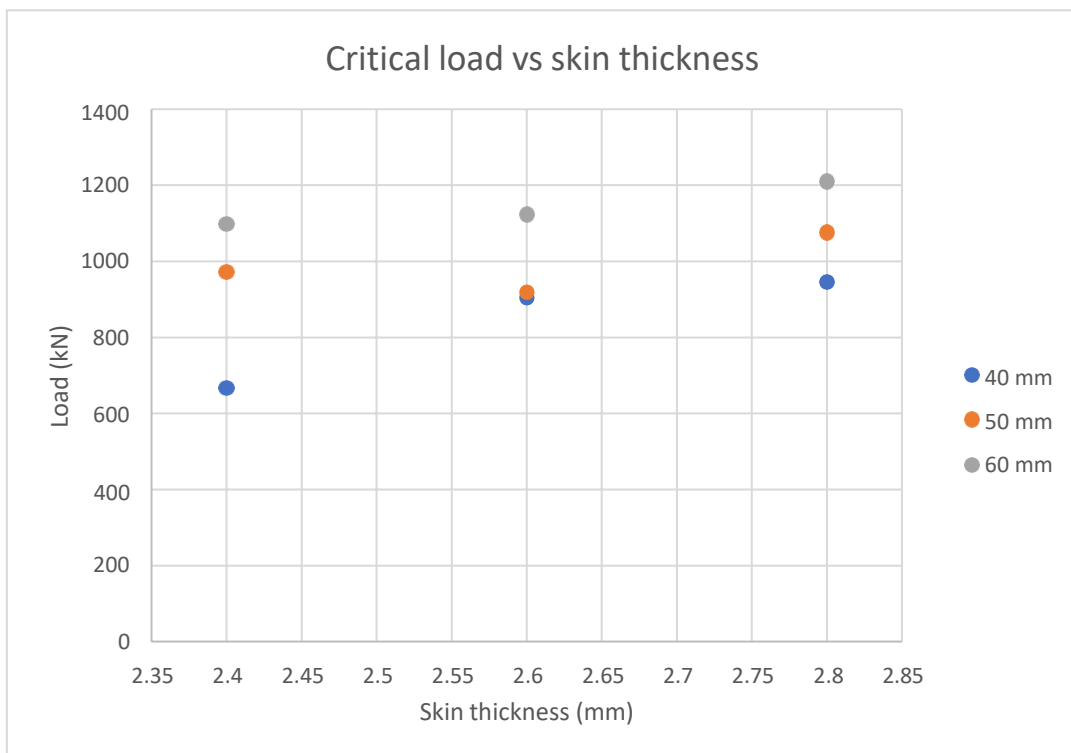


Figure 5.13: Graph of critical load vs skin thickness

5.3.2 CORE SHEAR STRESS VS SKIN THICKNESS

Figure 5.14 shows the graph of core shear stress versus the thickness of face sheet. Core shear stress was found to decrease with an increase in face sheet thickness. When the face sheet thickness was 2.4 mm high core shear stress was developed in the sandwich panel of core thickness of 40 mm. The stress was rapidly reduced by 10MPa when the face sheet thickness increased by 0.4mm.

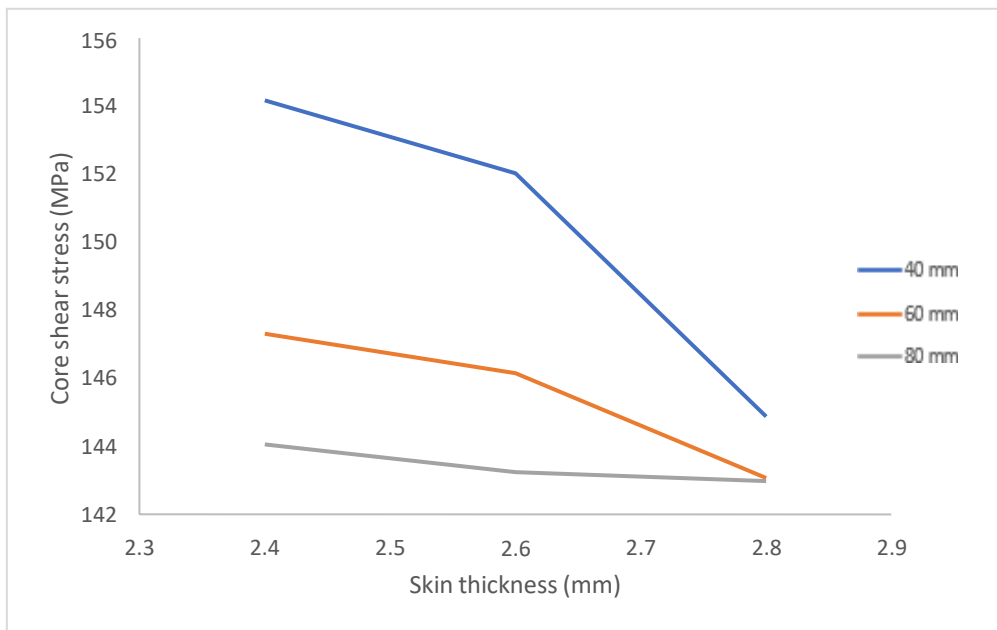


Figure 5.14: Graph of core shear stress vs skin thickness

5.3.3 SKIN STRESS VS SKIN THICKNESS

Figure 5.15 shows the plot between the skin stress and the thickness of face sheet. It was found that the skin stresses decrease as the increase in thickness of the face sheet. It was found that the properties of the sandwich wall panel have improved.

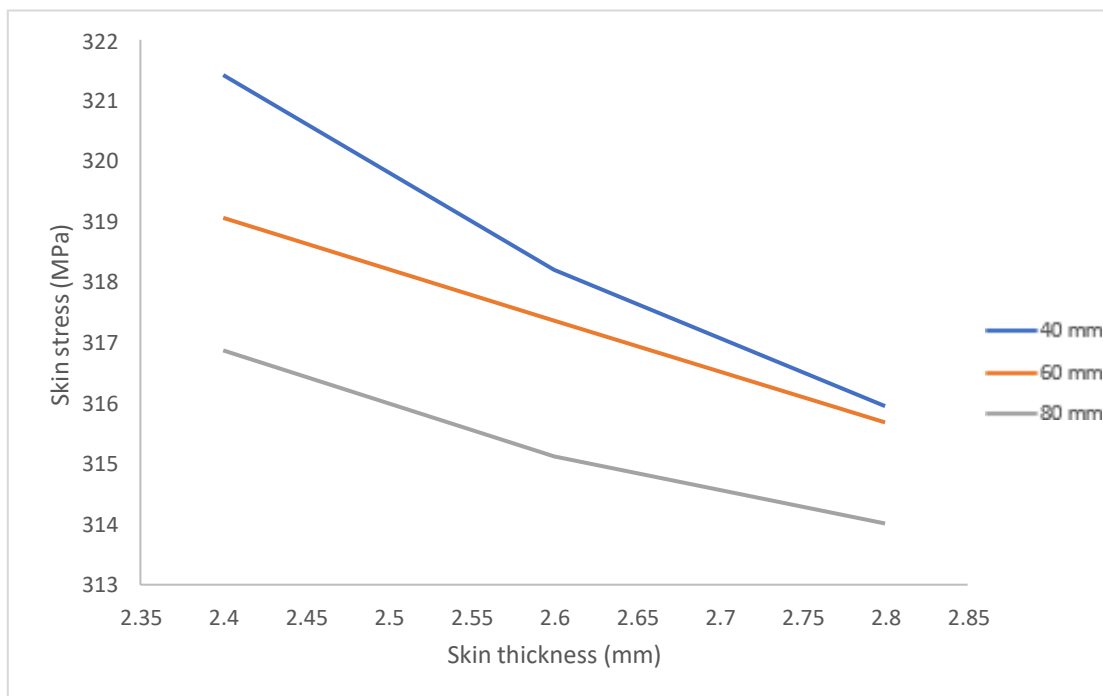


Figure 5.15: Graph of skin stress vs skin thickness

5.4 EFFECT OF CELL SIZE OF HONEYCOMB

The honeycomb cell size varied from 40mm, 60mm, and 80mm. It was observed that the sandwich panel of cell size 40mm shows the maximum load carrying capacity. The peak load obtained as 1210kN. But in the case of the sandwich wall panel of cell size equal to 60mm, the load carrying capacity reduced by 1/3. The peak load observed was 400kN. When the cell size of 80mm, the peak load observed was 245kN. So, it was better to keep the cell size minimum.

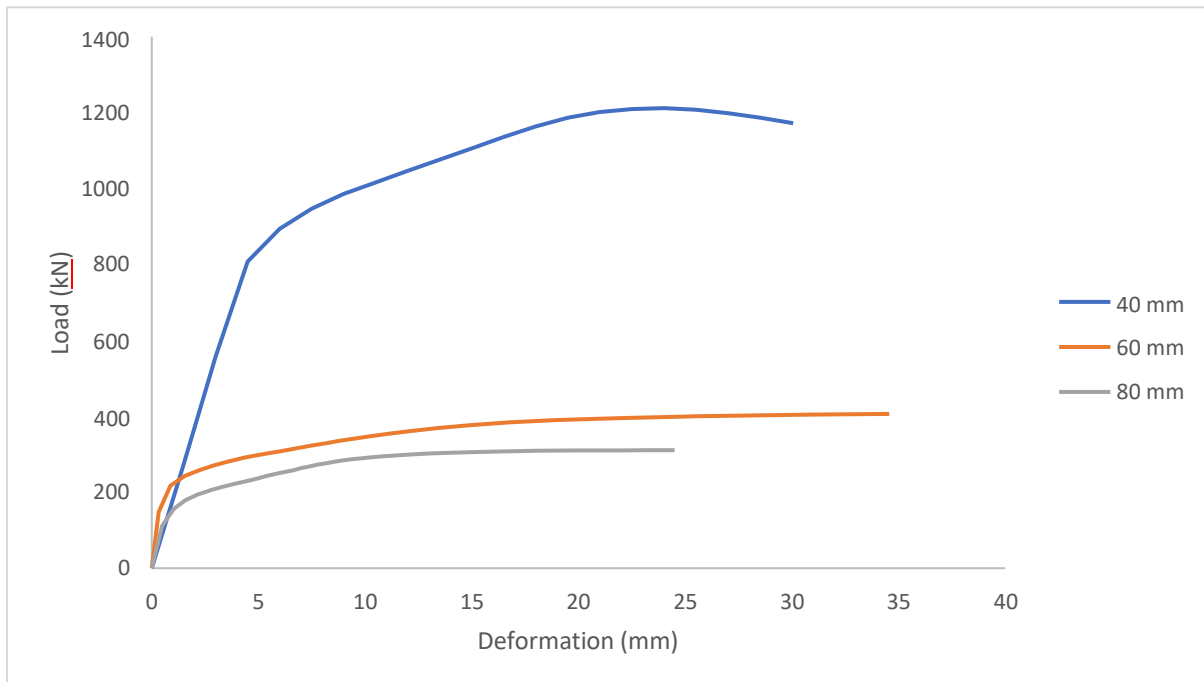


Figure 5.16: load-deformation curve of panels of honeycomb cell size 40mm,60mm, and 80mm

5.5 COMPARISON OF WALL PANELS WITH OR WITHOUT PVC FOAM

5.5.1 MODEL AFTER FEM ANALYSIS

Figure 5.17 shows PVC foam-filled honeycomb hybrid honeycomb sandwich wall panel. Figure 5.18 shows the bare panel that is the panel without PVC foam filling. After the structural analysis, it was observed that the sandwich panel without PVC foam shows large deformations. The sandwich without the PVC foam found to be buckled more.

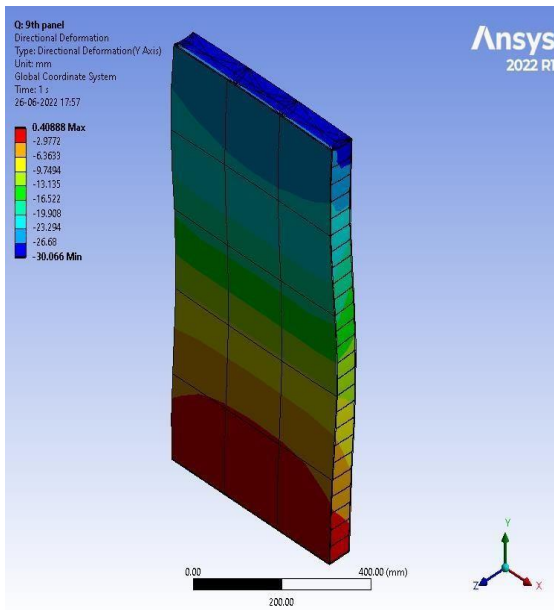


Figure 5.17: SP 9 under axial load

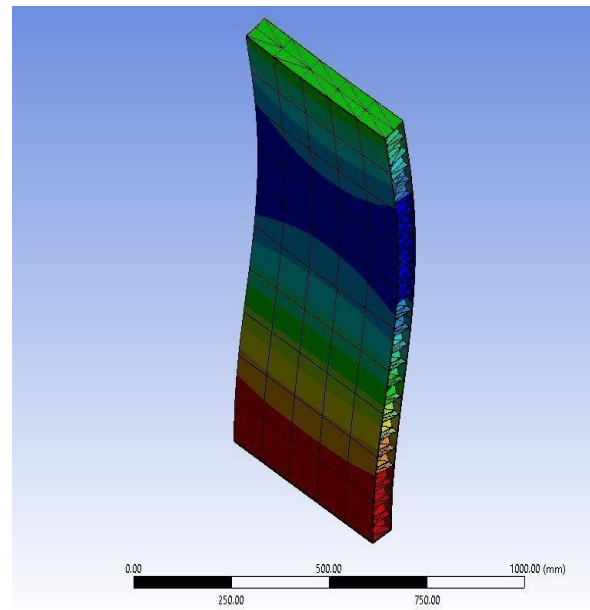


Figure 5.18: Reference panels under axial load

5.5.2 CRITICAL LOAD

Figure 5.19 is the comparison plot between the PVC foam-filled sandwich panel and the sandwich wall panel without the PVC foam. The red line in the graph was the load-deformation curve of SP9. SP9 was the panel combination having core thickness of 60mm, and the face sheet thickness of 2.8 mm. RSP was the reference sandwich panel with the same specification of the sample SP9. While comparing both wall panels, it was observed that the load-carrying capacity of the PVC foam-filled honeycomb hybrid core sandwich wall panel was almost 2 times that of the wall panel without the PVC foam. The critical load of sample SP9 was obtained as 1210kN. But in the case of RSP, it was observed that 624kN. Therefore, the stiffness of the panel was also improved. The hybrid core sandwich panel has enhanced properties compared to the bare core panel.

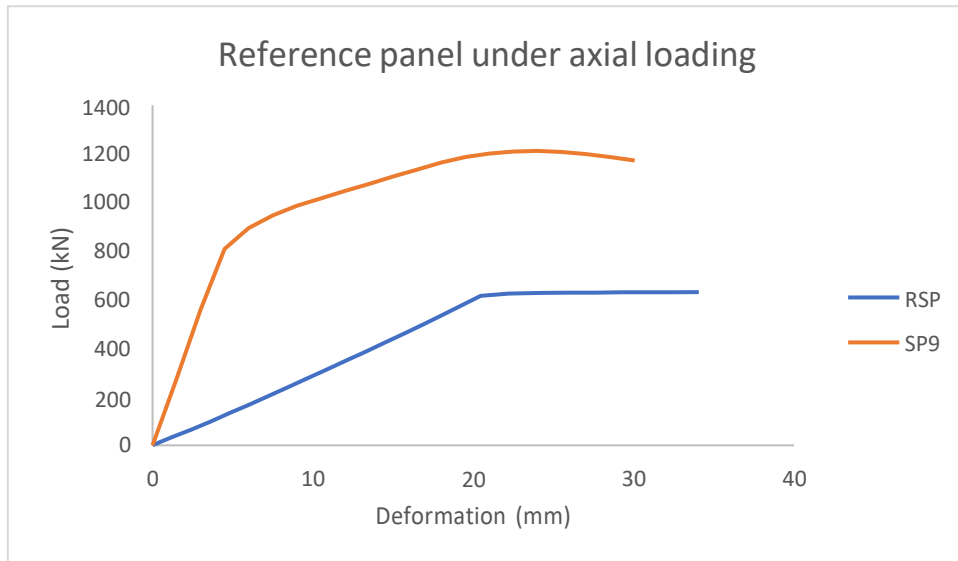


Figure 5.19: Reference panel under axial loading

Figure 5.20 shows the graph of the comparison of the load-carrying capacity of the SP9 and RSP under eccentric loading. As mentioned in 5.2, the load carrying capacity is very low under the eccentric loading.

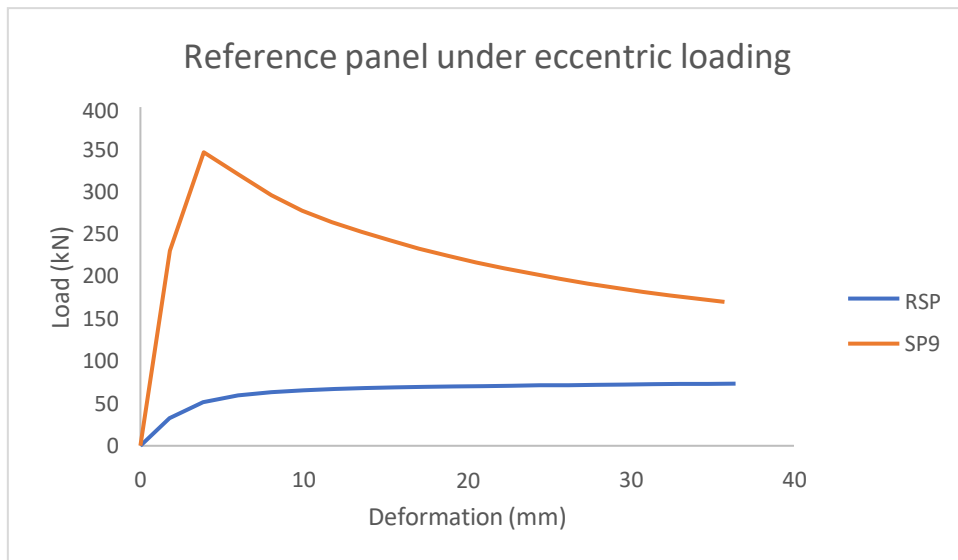


Figure 5.20: Reference panel under eccentric loading

5.5.3 CORE SHEAR STRESS AND SKIN STRESS

The table 5.1 shown below gives the comparison of sandwich wall panels with or without PVC foam. That is the SP9 and the RSP. Comparing the SP9 with RSP, it was found that the PVC filled honeycomb hybrid core sandwich wall shows better performance under the same axial load as well as the eccentric load. The load carrying capacity of SP9 is almost double the RSP.

Likewise, the core shear stress of the SP9 is more than twice of the reference panel. The core shear stress of SP9 obtained as 142.28MPa, and that of RSP was 394.66MPa. The stress developed on the face sheet of SP9 was also found three times lesser than that of RSP. The skin stress on the SP9 was observed as 314.01MPa and that of RSP was 923.5MPa.

Therefore, the overall performance of sandwich panel with PVC foam was better compared to the sandwich wall panel without the PVC foam.

Table 5.1: Comparison of sandwich panels with or without PVC foam

	SP 9	RSP
Critical load	1210kN	545kN
Core shear stress	142.28MPa	394.66MPa
Skin stress	314.01MPa	923.5MPa

CHAPTER 6

CONCLUSION

6.1 GENERAL

In this particular study, the numerical analysis of PVC foam filled honeycomb hybrid core sandwich wall panels while varying important parameters were carried out. The performance of the panel was then compared with the honeycomb core sandwich wall panel without the PVC foam. This chapter describes the major findings from the study and scope for future studies in this area.

6.2 MAJOR FINDINGS

From the studies conducted following conclusions were derived

- The Sandwich panel 9 (SP9) shows better performance and load carrying capacity among the panels. The load critical load observed as 1210kN.
- The load carrying capacity sandwich wall panel under axial load is higher than that under eccentric loading (5.2.2). The load that can be carried by the sandwich panel under eccentric loading was decreased by three times than that under axial loading.
- Core thickness and skin thickness has significant effect on the behaviour of sandwich wall panels.
- As the increase in core thickness as well as the thickness of face sheet, the load carrying capacity improved. The load-carrying capability of the sandwich wall panel doubled when the core thickness went from 40 to 60 mm (5.3). When the plate thickness was increased from 2.4mm to 2.8 mm it was found that the load carrying capacity was improved by more than 3 times.
- Also, the core shear stress and the skin stresses decreased with increase in core thickness and skin thickness.
- Honeycomb cell size should be minimum. Large cell size will cause large deformations and less load carrying capacity. The sandwich wall panel of cell size 40mm shows maximum load carrying capacity. It was observed as 1210kN. When the panel of cell size equal to 60mm, the load carrying capacity reduced by one-third. When the cell size of 80mm, the peak load reduced again and it was observed as 245kN.

- The hybrid core sandwich panel has enhanced properties compared to the sandwich wall panel without PVC foam filled honey comb core. The load-carrying capacity of the PVC foam-filled honeycomb hybrid core sandwich wall panel was almost 2 times that of the wall panel without the PVC foam. Also, the core shear stress and skin stresses were found very low compared to the reference panel.

6.3 SCOPE FOR THE FUTURE STUDY

This particular study was limited in few aspects, which can be addressed in future studies.

Future scope for expanding the work can be identified on the following aspects:

- Energy absorption of the sandwich wall panels can be explored.
- Thermal analysis of sandwich wall panels can be done.
- Moisture effect on performance of sandwich wall panels can be explored.
- Different shapes of honeycomb cells can be included on parametric study.

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