Design and Fabrication of corrugated sandwich panel

Tig welded corrugated sandwich panel

[1]MohdYousuf Ahmed, [2]MdMisbahuddin, [3] Syed AquibAhmed, [4]Owais Uddin Farooqui, [5]Mohd Azmathullah
[1]Professor, [2]Assistant Professor, [3-5]Student
Mechanical Department,
Lords Institute of Engineering and Technology, Hyderabad,India

*Abstract :*A sandwich panel is composed of the upper and lower skins separated by a lightweight core, for instance, foams, truss, honey combs and corrugated cores and each kind of cores has various structural forms. Sandwich structures offer attractive structural advantages in terms of higher specific flexural strength and stiffness in comparison to single skin or monolithic structures. These panels are widely used in the shipbuilding, shop floor, bridges and bus tray.

In this project work the static analysis of the corrugated core sandwich panel for different geometric configuration or parameters such as the corrugation pitch (2p),thickness of core(t c),thickness of face sheets (tf),distance of middle surfaces of face sheets(h),depth of corrugation measured from the center line at crest to center line at trough or depth of core(h c),length of corrugation flat segment(f) and corrugation angle (ɵ)= 60°. Analysis is done with both end fixed boundary condition, uniformly distributed load of 1000kg and changing length for one particular geometric parameter or configuration case. Also carried out the theoretical calculation for deflection and stress. Static analysis is performed using ANSYS workbench 14.5.

***IndexTerms* -Panel, core, welding, stress, sandwich, static analysis and corrugation.**

I. INTRODUCTION

Sandwich structures composed of stiff outer layers connected by a relatively low-density core result in high specific strength and stiffness, which may lead toward substantial design advantages. Properly designed steel sandwich panels offer substantial resistance to static and dynamic loads due to their high relative stiffness and inherent energy absorbing capacity. To that end, steel sandwich construction has great potential for use in bridges, buildings, ships and other structures. Laser welded steel sandwich panels perform especially well in situations of hazard reduction due to their high energy absorbing potential. Steel sandwich construction also has other advantages. They also noted that difficulty in fabrication and reliability of the face-sheet core connection has been a continual problem. Laser welding of the face sheet to the core using a stake weld overcomes this problem. Assessment of the strength of the weld and connection details is essential to the implementation of laser welded steel sandwich panels. The use of sandwich panels offers many advantages as it leads to the structure that are lightweight, cost effective and durable. In the past, sandwich panels have been commonly used in many aeronautical applications.

II. MANUFACTURING TECHNOLOGY

There is a very wide range of forming and joining techniques available for manufacturing of the sandwich structure. These techniques are well known and understood for traditional 'monolithic' construction. However there are a number of special considerations when a sandwich design is proposed.

III. ADHESIVE BONDING OF STEEL SANDWICH PANEL

This technique has a number of advantages, and in the case of low-density foam cores, it may be the only practical method of attaching the skins. The techniques produce little or no distortion, provides continuous attachment of the skins to the core, and gives a smooth, stain-free external surface. From the performance point of view panels fabricated in this way usually have limited resistance to elevated temperatures ,and may be subjected to long-term degradation in service .From the production point of view, the curing times for the adhesives may be inconveniently long, and fabrication procedures need to be closely controlled to avoid defective joints .Although stress distributions in adhesively bonded joints have been a subject too much study, many engineers remain skeptical concerning the design of such joints for structural connections. However sandwich construction is mainly attractive for long-span panels, and since a large width is normally available for bonding, and since optimum panels tend to have thin skins it is usually found that average shear stresses in the bonds are quite modest. The limitations of adhesive bonding may be overcome to great extent by using adhesives as part of a hybrid joining method.

Stainless steels alloys have often proved to be difficult to bond, because of their inherently passive, non-interacting surfaces, which characterizes these alloys .As a consequences of this, then mechanical and chemical pretreatments are often used to modify the surface of stainless steel adherEd, in order to improve joint performance. The development of the toughened adhesives has helped to relieve the problem, toughened acrylic and single part epoxy types will bond these alloys well, giving high initial joint strengths. Abrasion fallowed by a solvent wipe may be sufficient for low load applications although chemical treatments will almost invariably be necessary when good durability in demanding environments is a requirement.

IV. CORRUGATED CORE SANDWICH PANEL

Most popular materials of sandwich cores are soft and light such as balsa wood and foam. Conventional forms of sandwich cores are honeycomb-shaped. Honeycomb cores currently provide the greatest shear strength and stiffness to weight ratios but require special care in ensuring adequate bonding to the facing sheets.

In the early literature on the instability of sandwich constructions, much attention was devoted to wrinkling phenomena. This type of failure is made possible by the finite resistance of the core to deformations perpendicular to the faces and is of special importance when the core is made of an expanded material. However, modern sandwich cores are made of high strength materials that have a high resistance in this respect, such as a corrugated steel sheet. For the purposes of an analysis it can be assumed that the transverse normal stiffness of the core is infinitely large. The innovative corrugated-core sandwich plate consists of a corrugated sheet laser welded between two face sheets. Unlike soft honeycomb shaped core, a corrugated core resists not only vertical shear but also bending and twisting. In this thesis, a corrugated-core sandwich plate is analyze.There are two types of the corrugated core

- Unsymmetrical type of a corrugated-core sandwich plate
- Symmetrical type of a corrugated-core sandwich plate

Abbreviationsand Acronyms

Abbreviations

KN	kilo-newton
kg	kilogram
N	newton
P	pitch
mm	millimeter
cm	centimeter
t_f	thickness of plate
f	length of plate
MPa	mega pascal
N-mm	newton-millimeter
H_c	height of corrugated panel
l	length
W	Total uniformly distributed load acting on the
δ	Deflection
G	Shear modulus
h	Distance between the upper and lower plate
w	load per unit length
ft	Feet
E	young's modulus of panel
I	moment of inertia of the panel
I_c	Moment inertia of the Core
θ	Corrugation angle
I_c	moment of inertia of the core
A	Amps

Acronyms

UDL	uniformly distributed Load
UTM	universal testing machine
CRE	constant rate of extension
FEA	finite element analysis
GTAW	gas tungsten arc welding
TIG	tungsten inert gas
Ar	argon
DCEN	Direct current negatively charged electrode
SS	stainless steel

3.1 Objectives of the project

- The basic step is to FE modeling the corrugated core sandwich panel for the different geometric parameters such as the core depth (h_c), corrugation pitch(p), facing sheet thickness core (t_f),core thickness (t_c), distance between the upper and lower face plate(h) and corrugation angle (ө)= 60°.
- The behavior of the panel is depending on the geometry of the panel hence theoretically evaluating the deflection of the panel.
- Static analysis of the plate is to be performed with Ansys Workbench 14.5 with the different loading and boundary conditions. Loading condition is 1000kg weight uniformly distributed over panel; boundary conditions are panel fixed at the corrugation ends
- To performing analysis for different lengths of the single panel with one geometric configuration.
- To compare the results-deflection and stress of panel of different geometric configuration and interprets.

3.2 Problem formulation

To analyze the bending behavior of the corrugated-core sandwich plate, the following assumptions are made:

1. The plate is symmetrical type corrugated-core sandwich plate shown in below Fig.3.1
2. Therefore, both face plates are identical in material and thickness.
3. The material of the corrugated-core & sandwich plate is isotropic.
4. The deformation of this plate is small.
5. Facing plates are thin compared with the corrugation depth. Consequently, the local bending stiffness of the face sheets is negligible.
6. The core contributes to the more panel flexural stiffness in the *Y*-direction but not in the X-direction.
7. The elastic modulus of the plate in the *z*-direction is assumed to be infinite.
8. The core can resist the transverse shear stresses and also contribute to the flexural and extensional stiffness.
9. The transverse shortening of the core is ignored.
10. The corrugation angle α 60° is fixed.
11. Deflection of the panel below downward z-direction is to taken as the negative deflections.
12. Residual stresses that may exist in the structure because of welding, manufacturing process, have not been considered and the analysis carried out for stress free structure because of the face sheet & core different material the 3D corrugated-core sandwich plate can be reduced to a 2D structurally orthotropic continuum.

Equations

Moment of inertia of the core(I_c)

$$I_c = \left[\frac{f \times tc \times hc^2}{2}\right] + \left[\frac{tc \times hc^3}{12 sin\theta}\right] \quad (1)$$

$$p = f + (h_c/\tan \theta) \quad (2)$$

$$f = p - (h_c/\tan \theta) \quad (3)$$

Distance between the upper plate & lower plate

$$h = h_c + t_c + t_f \quad (4)$$

Moment of inertia of the upper and lower face plates

$$I_f = 2[2p \times t_f \times (\tfrac{h}{2})^2] \quad (5)$$

Total moment of inertia of the panel

$$I = I_f + I_C \quad (6)$$

Deflection of the sandwich panel due to bending

$$\delta = \frac{wL^4}{384EI} \quad (7)$$

Total deflection = Bending+ Shear deformation

$$\delta = \left[\frac{wL^4}{38 \times E \times I}\right] + \left[\frac{w \times L}{8 \times A \times G \times h}\right] \quad (8)$$

Total area of the panel = Area of upper plate +Area of core + Area of lower plate

$$(t_f \times 2p) + [(2 \times (l \times t_c)] + (t_f \times 2p) \quad (9)$$

Maximum bending moment at the centre of the panel

$$M_{max} = \left[\frac{wL^2}{12}\right] \quad (10)$$

The bending stress in the panel

$$\sigma_b = \frac{Mmax \times y}{I} \quad (11)$$

I. LITRATURE REVIEW

The static analysis of the corrugated core sandwich panel is performed by analytical and validating with the FEM. The application of the sandwich panel in the recent years is increasing due to the light weight, higher strength and low cost. Pioneer application of the sandwich panel is found in aircraft, ship building, floor deck, and bridges etc.

Krzysztof Magnucki et.al.[1]: Described behavior of sandwich beams with corrugatedcores. The subject of the paper is a sandwich beam with a crosswise or lengthwise corrugated core. The beam is made of an aluminum alloy. The plane faces and the corrugated core are glued together. Geometrical properties and rigidities of the beams are described. The load cases investigated in the work are pure bending and axial compression. The relationship between the applied bending moment and the deflection of the beam under four-point bending is discussed. The analytical and numerical (FEM) calculations as well as experimental results are described and compared. Moreover, for the axial compression, the elastic global buckling problem of the analyzed beams is presented. The critical loads for the beams with the crosswise and lengthwise corrugated core are determined.

Wiernicki, Marsico et al.[2]: presented the sandwich construction can be a possiblesubstitute for sheet stringer to reduce the weight of an aircraft. US Navy has studied application of the laser welded corrugated core sandwich constructions & also studied for the applications cover bulkheads, decks on accommodation areas, deckhouses, deck edge elevator doors, and hangar by division doors.

Summary:

A sandwich panel is composed of the upper and lower skins separated by a lightweight core, for instance, foams, truss, honey combs and corrugated cores and each kind of cores has various structural forms. Sandwich structures offer attractive structural advantages in terms of higher specific flexural strength and stiffness in comparison to single skin or monolithic structures. These panels are widely used in the shipbuilding, shop floor, bridges and bus tray.

3.1 Methodology

- Theoretically evaluating the deflection and stress for the different geometric parameters cases of the single unit of the corrugated core sandwich panel.
- Comparing the numerical with the theoretical result for stress and deflection of the different geometric parameters of the panel.
- Finding out the effect of different geometric parameter on the deflection and stress on the sandwich panel.

3.2 Material and Geometry Selection

Grade 304 is the standard, it is the most versatile and most widely used stainless steel, available in a wider range of products, forms and finishes than any other. It has excellent forming and welding characteristics.Geometry details of corrugated core sandwich panel:

The corrugated-core sandwich plate consists of a corrugated sheet laser welded between two face sheets. In this case the sandwich panel unit is taken for the analyzing.

3.3 Design Calculation

Theoretical calculation of the deflection for the corrugated core sandwich panel.As per as the sandwich panel is with a boundary condition of both ends fixed and uniformly distributed mass of 1000kg or 1ton over the panel

The strength of the panel in the direction of corrugation (lengthwise) is greater than the perpendicular to the direction of corrugation (machine direction) when the panel is subjected to the transverse loading .The panel is fixed at both ends in y-direction i.e. direction of corrugation.

3.4.2.5 Theoretical Calculation

Moment of inertia of the panel= Moment of inertia of upper & lower plate (I_f) + Moment of inertia of the core (I_c)

$$I = I_f + I_c \qquad (1.1)$$

Moment of inertia of upper & lower plate (I_f)

$$I_f = 2[2p \times t_f \times (\frac{h}{2})^2] \qquad (1.2)$$

Where,

I_f –Moment of inertia of the upper and lower face plates p - Pitch length or corrugation pitch

t_f –Thickness of the upper & lower plate

h- Distance between the upper & lower plate &

Moment of inertia of the core(I_c)

$$I_c = [\frac{f \times tc \times hc^2}{2}] + [\frac{tc \times hc^3}{12 sin\theta}] \qquad (1.3)$$

Where,

I_c- Moment inertia of the Core

f -Length of the flat segment

t_c- Thickness of core

h_c- Depth of core

ɵ- Corrugation angle

Moment of inertia the core

$$I_c = [\frac{f \times tc \times hc^2}{2}] + [\frac{tc \times hc^3}{12 sin\theta}]$$

$$p = f + (h_c/\tan \theta) \quad (1.4)$$

$$f = p - (h_c/\tan \theta) \quad (1.5)$$

Distance between the upper plate & lower plate

$$h = h_c + t_c + t_f \quad (1.6)$$

Total UDL load acting on the panel

$$W = w \times L \quad (1.7)$$

$$w = W/L \quad (1.8)$$

Deflection of the sandwich panel due to bending

$$\delta = \frac{wL^4}{384EI} \quad (1.9)$$

Where,

w=load per unit length =24..525N/mm

L=length of the panel =400mm

E=young's modulus of panel =210×10^3 N/mm^2

I=moment of inertia of the panel =1996912.952mm^4

Total deflection = Bending+ Shear deformation

$$\delta = [\frac{wL^4}{38 \times E \times I}] + [\frac{w \times L}{8 \times A \times G \times h}] \quad (2.1)$$

Where,

W- Total uniformly distributed load acting on the panel=1000×9.81=9810N w- Load per unit length=24.525 N/mm

δ - Deflection

G-Shear modulus =80×10^3N/mm^2 or MPa

h- Distance between the upper and lower plate =87.33mm A-Area of cross section of the panel

Area of the panel

Total area of the panel = Area of upper plate +Area of core + Area of lower plate (2.2)

$$= (t_f \times 2p) + [(2 \times (l \times t_c)] + (t_f \times 2p$$

Where,

l =length of one corrugation- leg center line= f + (h_c/sinɵ)

Maximum bending moment at the centre of the panel

$$M_{max} = [\frac{wL^2}{12}] \quad (2.3)$$

The bending stress in the panel is due to bending

$$\sigma_b = \frac{M_{max} \times y}{I} \quad (2.4)$$

3.4.3.6Fabrication

We have used SS304 graded stainless steel sheet for our study based project. To get required dimensions, angle cutting machine is used. For bending purpose, hydraulic press bending machine is used to bend the sheet at 60^0. For strong hold of the material and the material should not loose most of its mechanical properties, we used Tig welding as novel option, so that it won't break off while load testing. For proper fixture of material before welding C-clamps were used. To rmove the unevenness from the surface, we used polishing disc so that the surface looks clean finished product.

V. RESULTS AND DISCUSSION

4.1 Results of Descriptive Statics of Study Variables

Case no.	Theoretical deflection inmm	Numerical deflection in mm
1.	3.94×10^{-3}	3.097×10^{-3}
2.	1.843×10^{-3}	1.714×10^{-3}
3.	1.149×10^{-3}	1.150×10^{-3}
4.	2.843×10^{-3}	2.540×10^{-3}
5.	1.340×10^{-3}	1.029×10^{-3}
6.	0.8435×10^{-3}	0.3617×10^{-3}
7.	2.055×10^{-3}	1.597×10^{-3}
8.	0.9770×10^{-3}	0.4786×10^{-3}
9.	0.6197×10^{-3}	0.2777×10^{-3}

Table 4.1: Descriptive Statics

In the numerical results of deflection the negative sign indicates deflection in negative Z-direction. The upper face of the panel is subjected to the more deflection than the core and the lower face plate. The upper face plate is subjected to the deflection in the direction of loading i.e. negative Z-direction, but the core deflects in the upward direction with small deflection value as compared to the upward face plate. The deflection of the panel decreases with increase in the depth of core, thickness of core and thickness of upper face plate. The maximum stress is at the upper face plate end i.e. weld portion, is more due to the clamped end.

For the case of geometric parameters with h_c=83.33mm, p=100mm, f=51.88mm as the thickness of the core and face plate increases region of the deflection at the core decreases.

FiguresandTables

TABLE 1 Properties & Applications of materials used in Sandwich Panel

S. NO.	**MATERIAL**	**DENSITY (P) IN TON/MM^3**	**YOUNG'S MODULUS (E) IN N/MM^2 (MPA)**	**POISSON'S RATIO (μ)**	**YIELD STRENGTH (Σ_Y)(MPA)**	**SHEAR MODULUS (G) (MPA)**
1.	STAINLESS STEEL 304(SS304	7.90×10^{-9}	210×10^3	0.3	240	$80x10^3$

Table 2. Geometric specification of single panel unit

S.No.	Description	Dimensions in mm
1	Length of the panel(L)	400-9000
2	Width of the panel(b)	200
3	Corrugation angle (ɵ)	60°
4	Material of the panel	Structural steel

TABLE 3. MOMENT OF INERTIA WITH DEFLECTION FOR DIFFERENT GEOMETRIC CONFIGURATION CASES

Case No	Pitch P	Core depth hc	Length of flat length segment f	Thickness of core tc	Thickness of upper and lower plate tf	Dictance between upper and lower plate H	Distance of neutral axis from its outer edge (Y)	Deflection δ
	mm	mm	mm	mm	mm	mm	mm	mm
1	100	83.35	51.88	2	2	87.35	48.36	3.94×10^{-3}
2	100	83.35	51.88	4	4	91.35	49	1.843×10^{-3}
3	100	83.35	51.88	6	6	95.35	50	1.149×10^{-3}
4	100	100	42.264	2	2	104	52	2.843×10^{-3}
5	100	100	42.264	4	4	108	54	1.340×10^{-3}
6	100	100	42.264	6	6	112	56	0.843×10^{-3}
7	100	120	30.71	2	2	124	62	2.055×10^{-3}
8	100	120	30.71	4	4	128	64	0.977×10^{-3}
9	100	120	30.71	6	6	132	66	0.6197×10^{-3}

Table 4. Theoretical deflection under loaded condition

S.No.	Load		Theoretical deflection(δ) mm	Distance between upper and lower plate (h)mm
	kN	Kg		
1	0	0	0	87.35
2	15	1529	0.0059	87.3441
3	22	2243.38	0.0087	87.3413
4	53	5404.49	0.0210	87.329
5	65	6628.15	0.0258	87.3242

Table 5. Numerical deflection under loaded condition

Case No	Load	Specifications
	kN	mm
1	15	p = 100
2	22	f = 51.88
3	53	hc =83.35
4	65	tc = 2 tf = 2

Table. 6. Numerical deflection under Loaded Condition

S.No	Load		Numerical deflection(δ)	Distance between upper and lower plate (h)mm
	KN	Kg	mm	
1	0	0	0	87.35
2	15	1529	0.006	87.3441
3	22	2243.38	0.009	87.341
4	53	5404.49	0.0218	87.3282
5	65	6628.15	0.026	87.3242

Table. 7. UDL testing

Case No	Load		Distance between upper and lower plate H	Experimental Deflection (UDL)
	KN	Kg	mm	mm
1	0	0	87.35	0.0
2	15	1529	87.342	0.008
2	22	2243.38	87.332	0.018
3	53	5404.49	87.31	0.04
5	65	6628.15	87.287	0.063

Table. 8. Comparison of results

Case No	Load		Numerical Deflection	Theoretical Deflection	Experimental Deflection
	kN	Kg	mm	mm	mm
1	0	0	0	0	0.0
2	15	1529	0.006	0.0059	0.008
2	22	2243.38	0.009	0.0087	0.018
3	53	5404.49	0.0218	0.0210	0.04
5	65	6628.15	0.026	0.0258	0.063

Figures

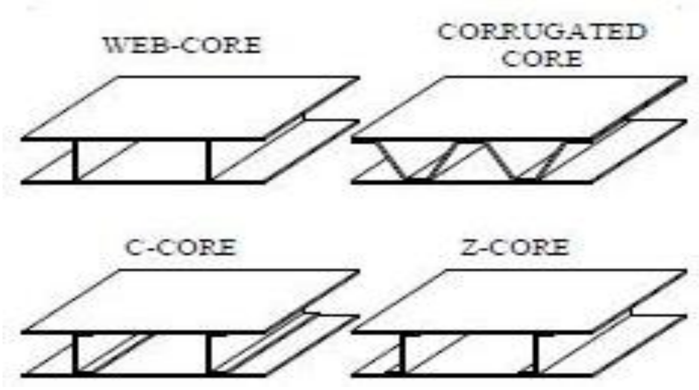

Fig. 1.Different types of all-metal sandwich plate topologies.

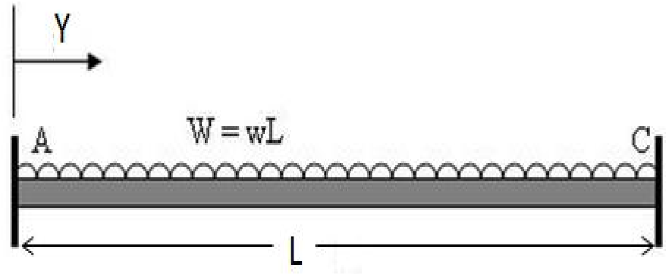

Fig. 2.Sandwich beam fixed at both ends with uniformly distributed load

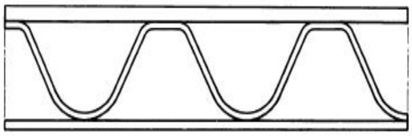

Fig. 3.Unsymmetrical type of a corrugated-core sandwich plate

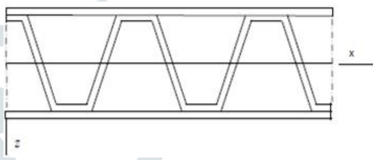

Fig. 4. Symmetrical type of a corrugated-core sandwich plate

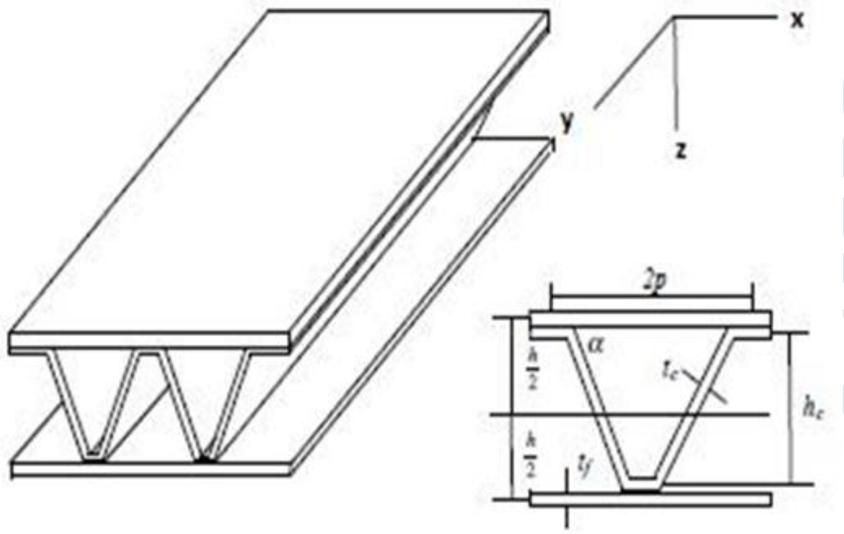

Fig. 5. Corrugated-Core sandwich panel and a panel unit

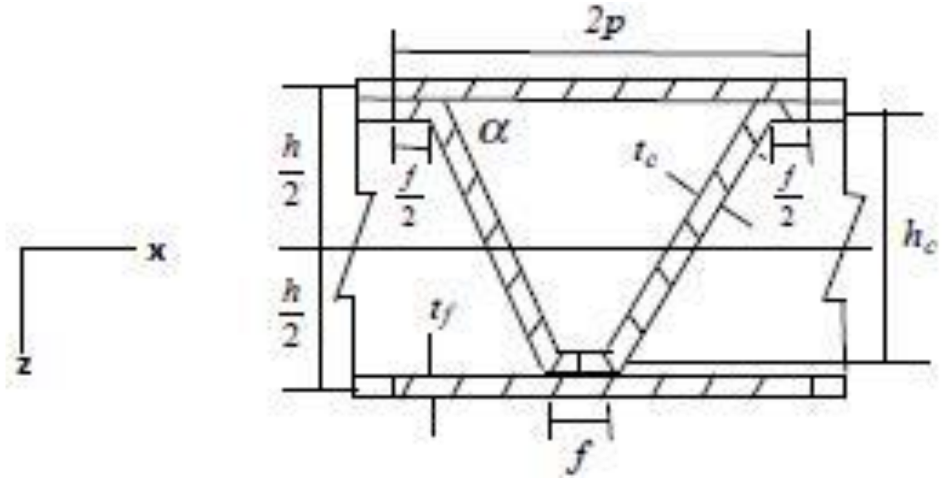

Fig. 6. Panel single corrugation unit

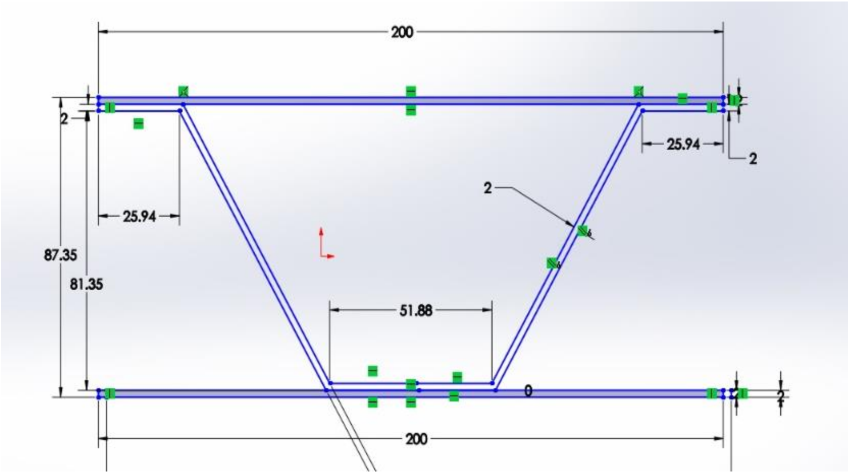

Fig. 7. Cross section of the single panel unit

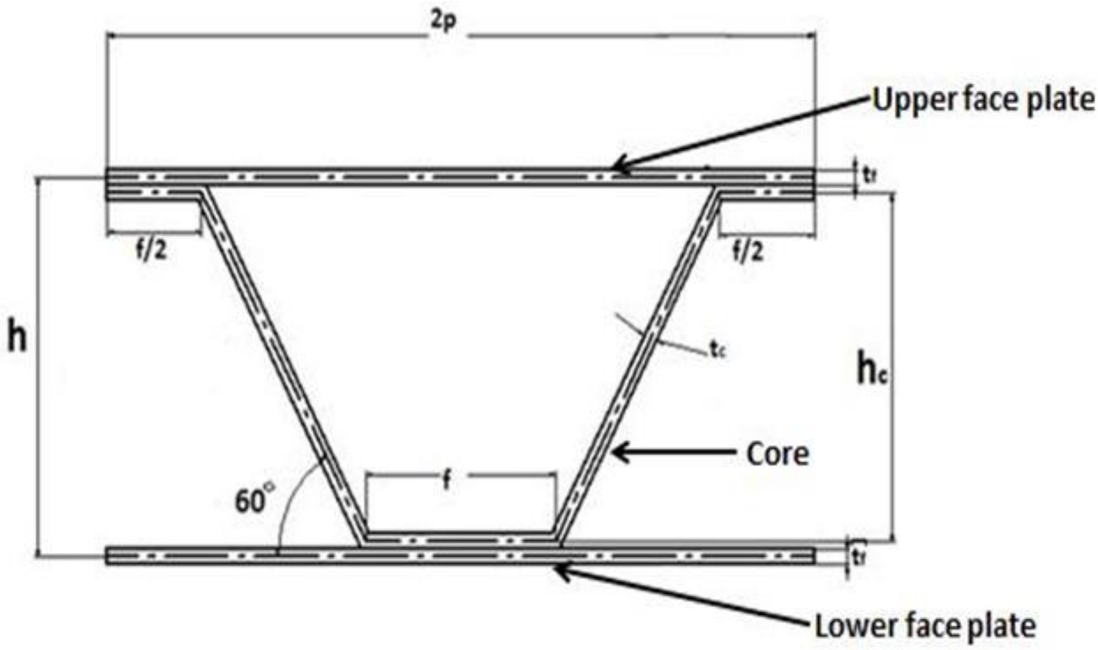

Fig. 8. Cross section of the single panel unit

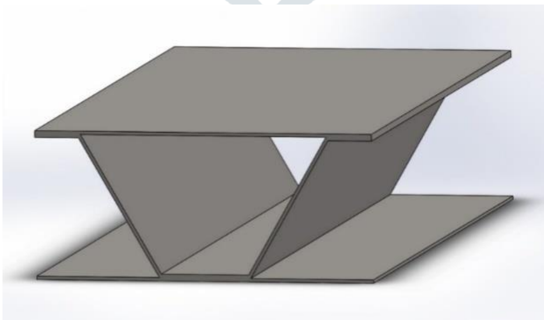

Fig. 9.Isometric view of the single unit of the panel

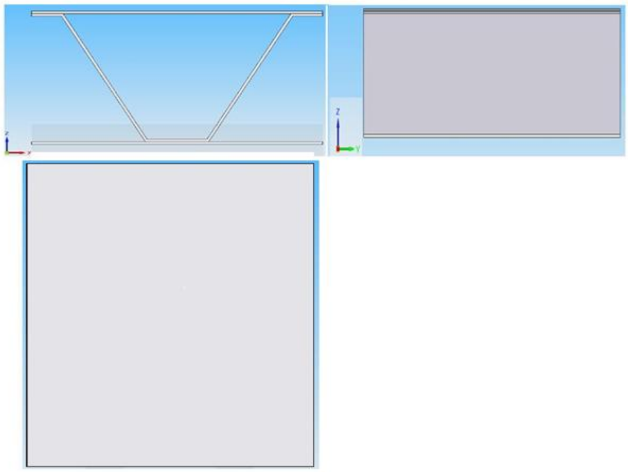

Fig. 10.Orthographic projection of single unit of corrugated core sandwich panel

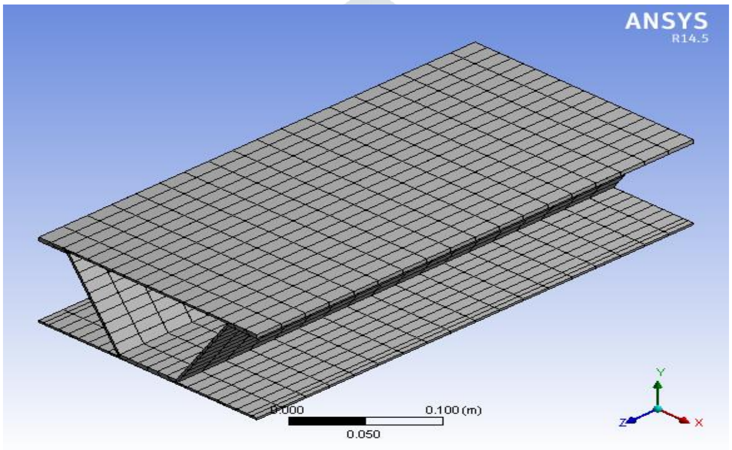

Fig. 11. Meshing in ANSYS Workbench 14.5

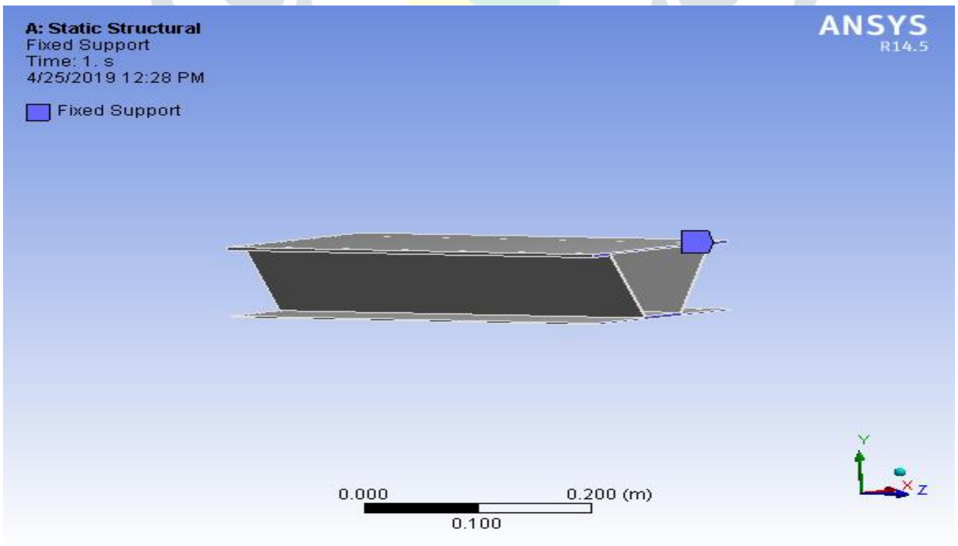

Fig. 12. Boundary conditions in ANSYS Workbench 14.5

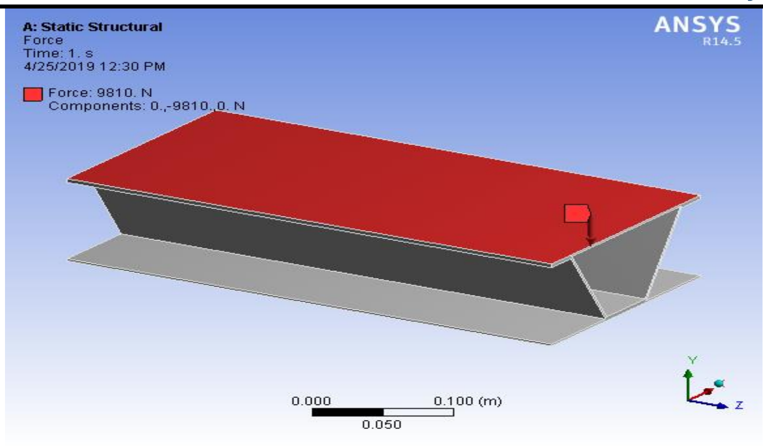

Fig. 13. Load Applied in ANSYS Workbench 14.5

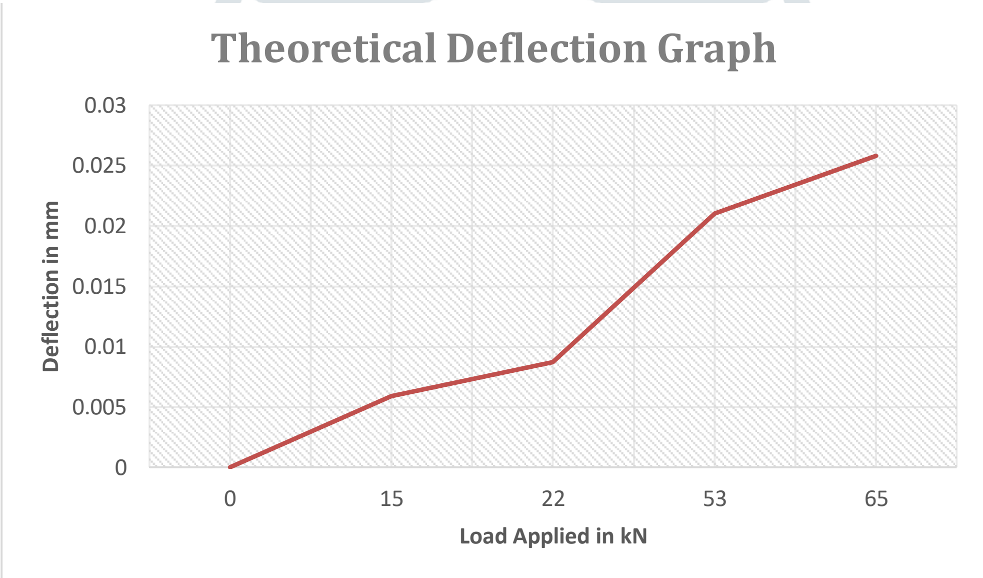

Fig. 14. Theoretical deflection graph

Case 1: Load Applied15kN or 1529kg

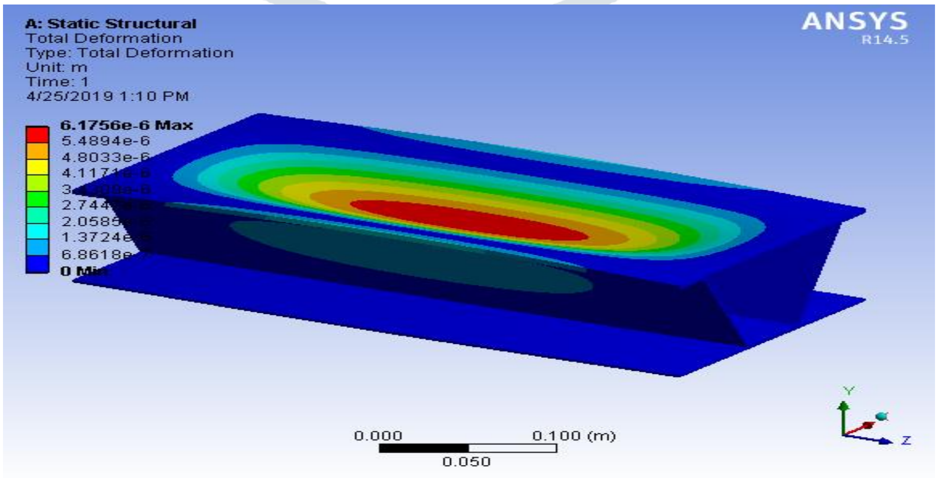

Fig. 15. Case-1 Total Deformation for case 1

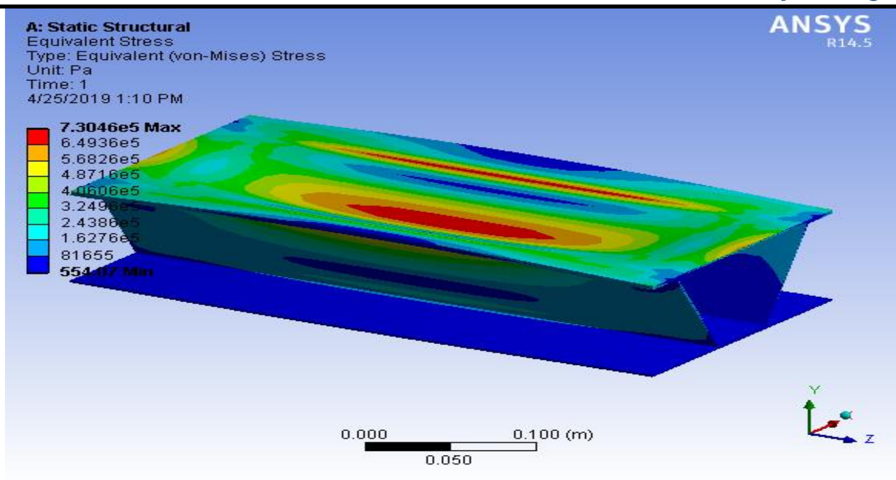

Fig. 16. Case-1 Von-Mises stress for case 1

Case 2: Load Applied 22kN or 2243.38kg

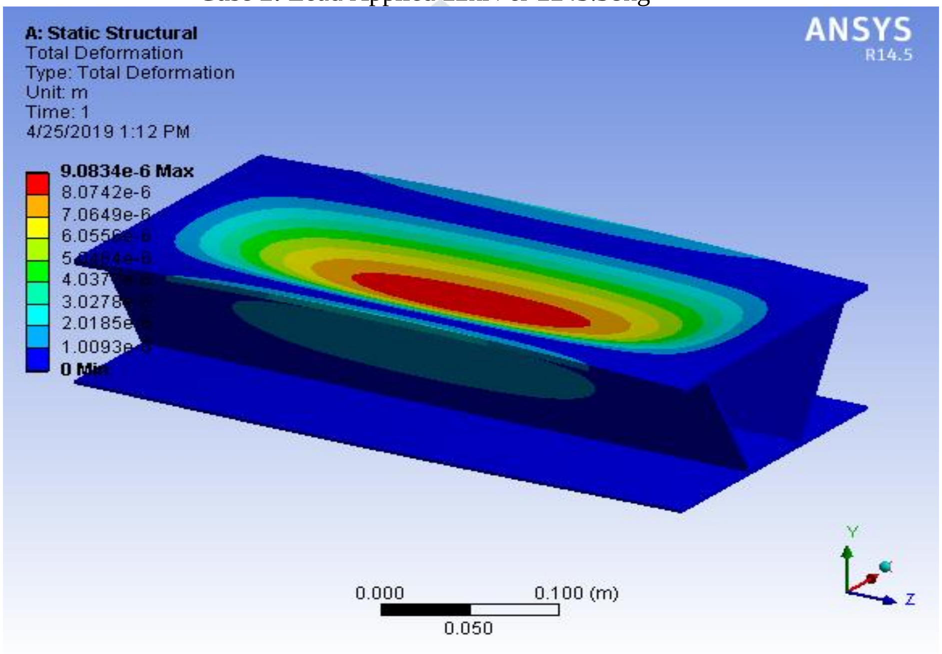

Fig. 17. Total deformation for case 2

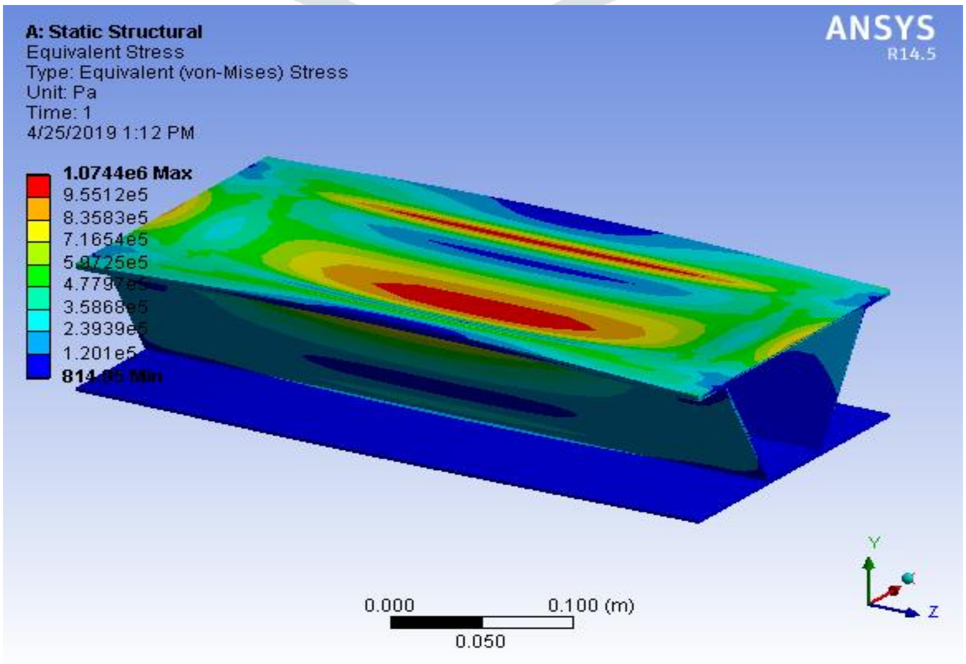

Fig. 18. Von-Mises stress for case 2

Case 3: Load Applied 53kN or 5404.49kg

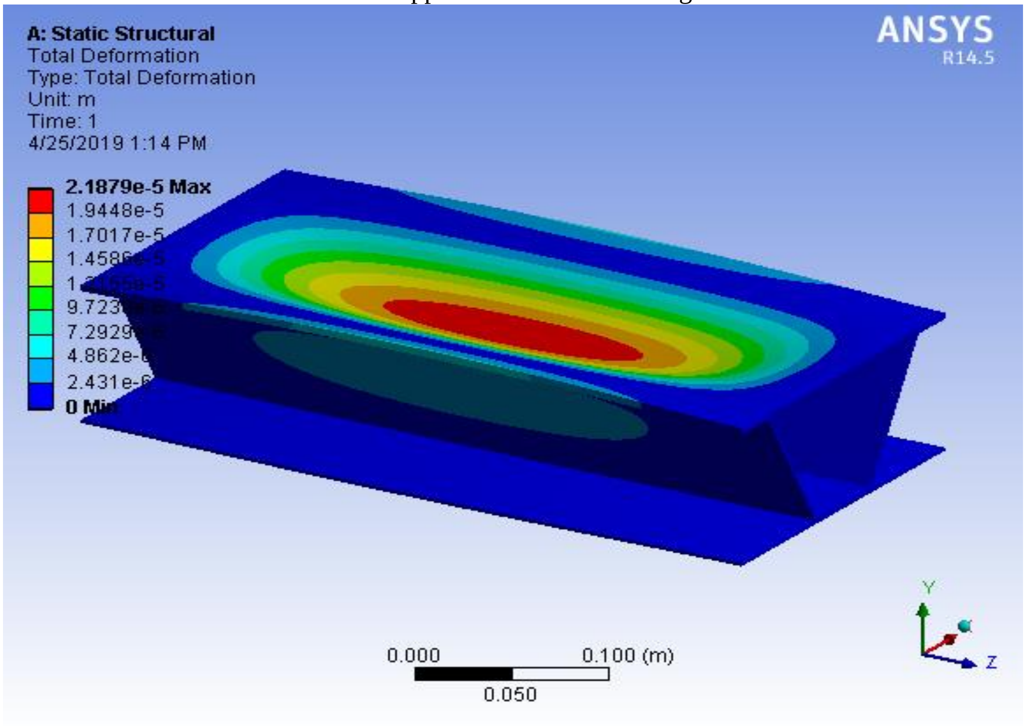

Fig. 19. Total deformation for case 3

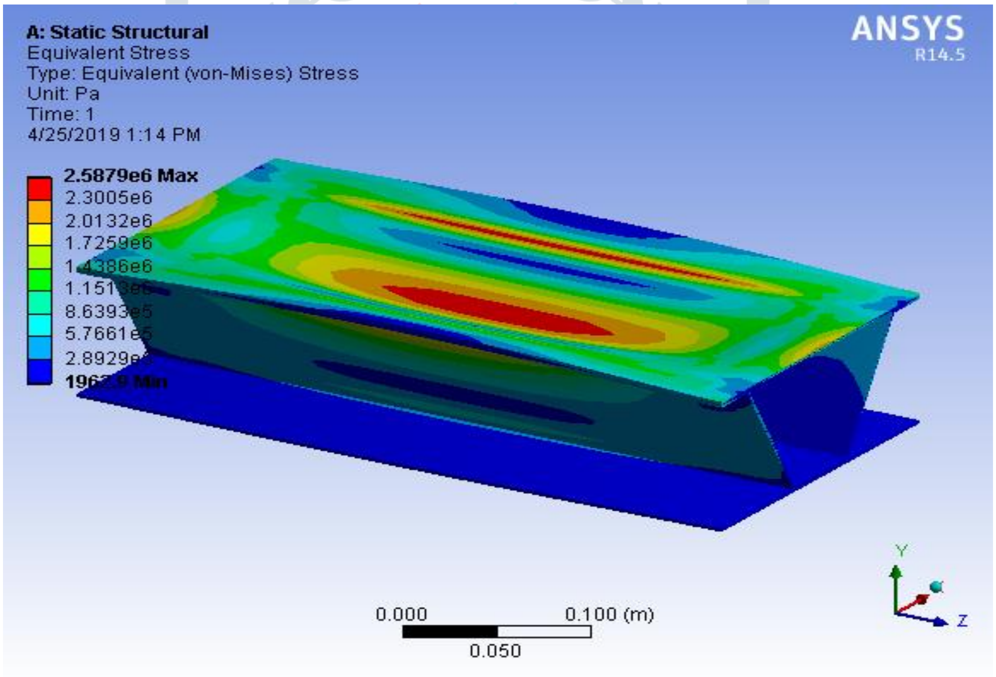

Fig. 20. Von-Mises stress for case 3

Case 4: Load Applied 65kN or 6628.15kg

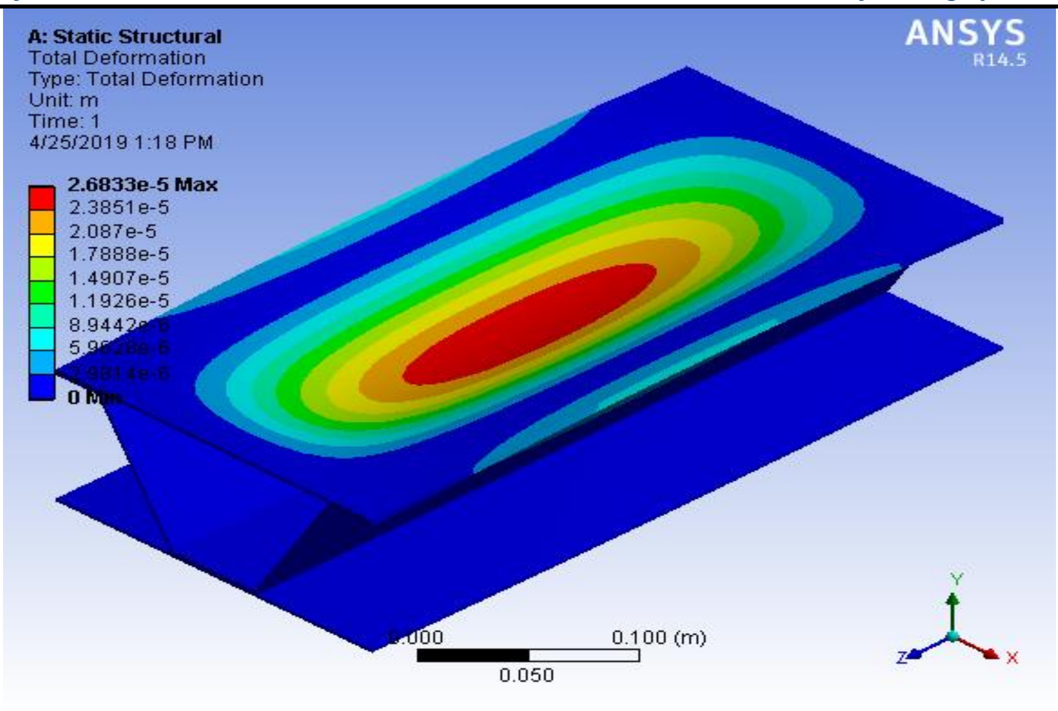

Fig. 21. Total deformation for case 4

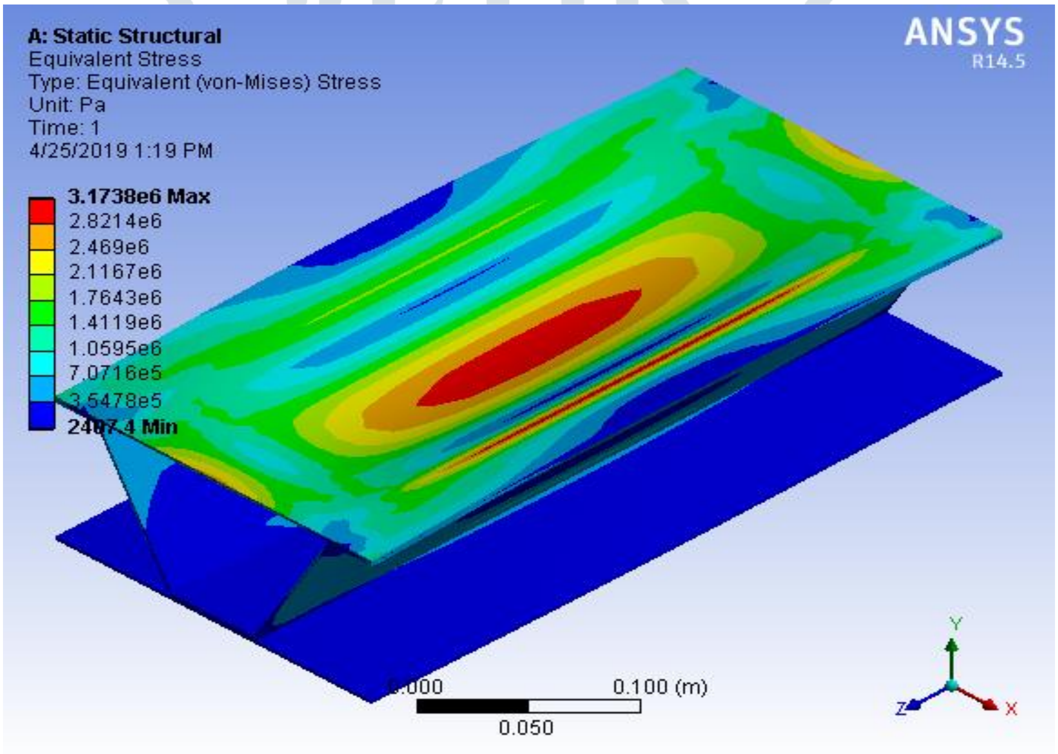

Fig. 22. Von-Mises stress for case 4

Fig. 23. Finished product of corrugated sandwich panel.

Fig. 24. Bending the sheet at 60^0 angle

Fig. 25. Removing excess material from the sheet after bending

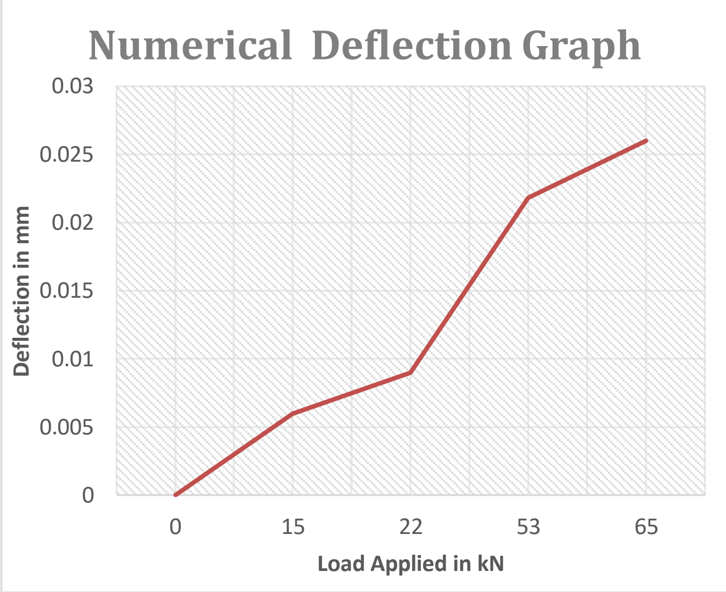

Fig. 26. Numerical deflection graph

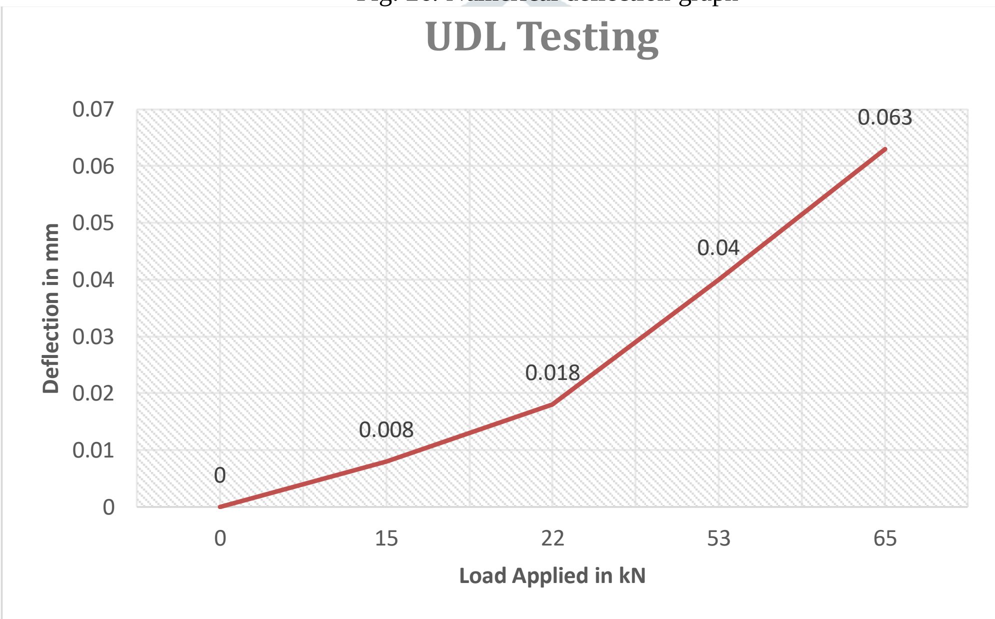

Fig. 27. UDL testing

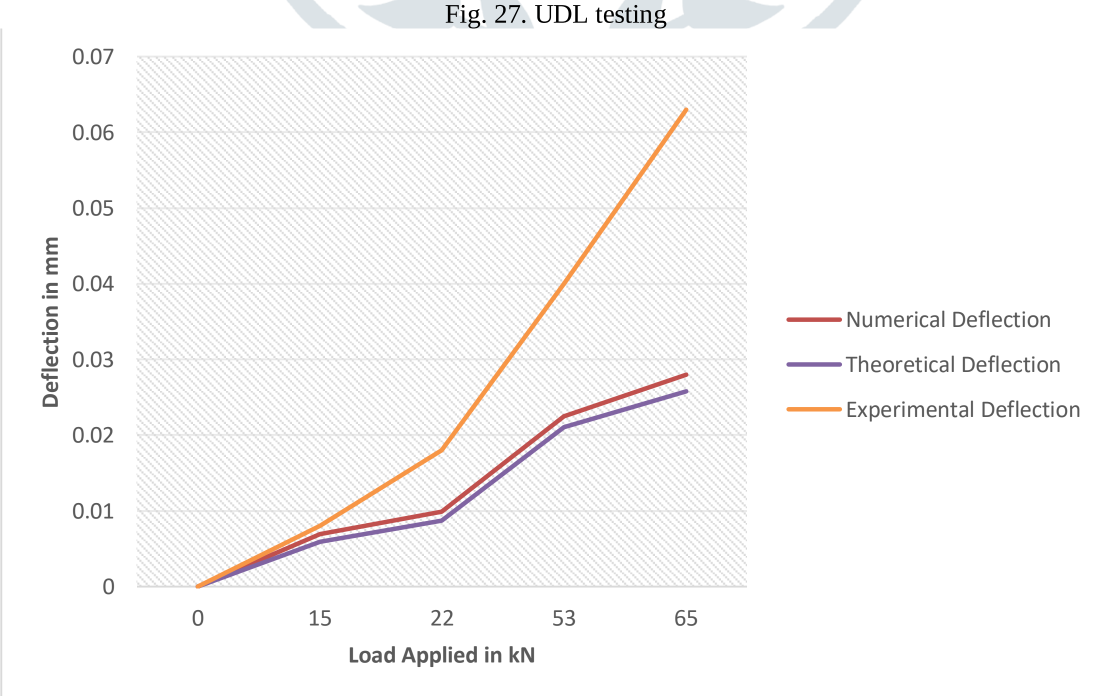

Fig. 27. Result comparison

VI. ACKNOWLEDGMENT

We would like to express our gratitude to all the people behind the screen who have helped us to transform an idea into a real time application. We would like to our heart -felt gratitude to our parent without whom we would not have been privileged to achieve and fulfil our dreams.

We express our sincerer gratitude to **Mr**. **MdMisbahuddin**, Assistant Professor Department of Mechanical Engineering, for his superb guidance and all the invaluable suggestions.

We express our sincerer gratitude to **Mr. Asif Kattimani**, Assistant Professor Department of Mechanical Engineering, who has given an opportunity to perform this project, has guided us regarding this project.

We proudly thank **Dr. Syed Azam Pasha Quadri**, Head of the Department of mechanical engineering, who has been an excellent guide, a great source of inspiration to my work.

We own our sincere gratitudein our, principal **Dr. MOHAMMED YOUSUF ALI** and also to our college management for giving the encouraged that us to complete the project successfully.

REFERENCES

[1] **[**Pergamon, Oxford, U.K.

[2] Bird, J. (1991). "Laser welded steel sandwich panels." DRA TM 91221.

[3] J. Jelovica, J. Romanoff ,S. Ehlers, P. Varsta “Influence of weld stiffness on buckling strength of laser-welded web-core sandwich plates”.

[4] Stefano Ferraris, Luis Mario Volpone “Aluminium alloys in third millennium shipbuilding: materials, technologies, perspectives” Fifth International Forum on Aluminum Ships

[5] M.E.Biancolini “Evaluation of equivalent stiffness properties of corrugated board”

Composite Structures 69 (2005) 322–328.

[6] S.Budano,M.Kuppers,H.Kaufmann,A.M.Meizoso,C.Davies “Appliction of high strength steel plates welded deck components for ships and bridges subjected to medium/high service loads” technical steel research,ISBN 92-79-05007-7,ISSN 1018-5593.

[7] V.Diwakar Reddy, A.Gopichand, G.Nirupama, G.Krishnaiah, “Design and fabrication of corrugated sandwich Panel using Taguchi method.” International Journal of Design andManufacturing Technology (IJDMT)**,** ISSN 0976 ISSN 0976 – 6995, ISSN 0976 –7002.

[8] Li He. Yuan-Sheng Cheng,Jun Liu, “Precise bending stress analysis of corrugated-core,

honeycomb-core and X-core sandwich panels” Composite Structures (0) 656–

1668.

[8] Deshpande, “The design of sandwich panels with foam cores” Paper 8 metallic foams Cambridge University 2002.

[9] Krzysztof Magnucki, PawełJasion, Marcin Krus, PawełKuligowski, eszekWittenbeck,

“Strength and buckling of sandwich beams with corrugated core” journal of theoretical and applied mechanics 51, 1, pp. 15-24, Warsaw 2013.

[10] Forbes, A. T. (1989). "Strength tests on laser welded corrugated steel sandwich panels." ARE TM 89215.