Design and Fabrication of corrugated sandwich panel

Laser welded corrugated sandwich panel

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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 produces the 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 the defective joining of the plates with core .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

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
ɵ	Corrugation angle
I_c	moment of inertia of the co

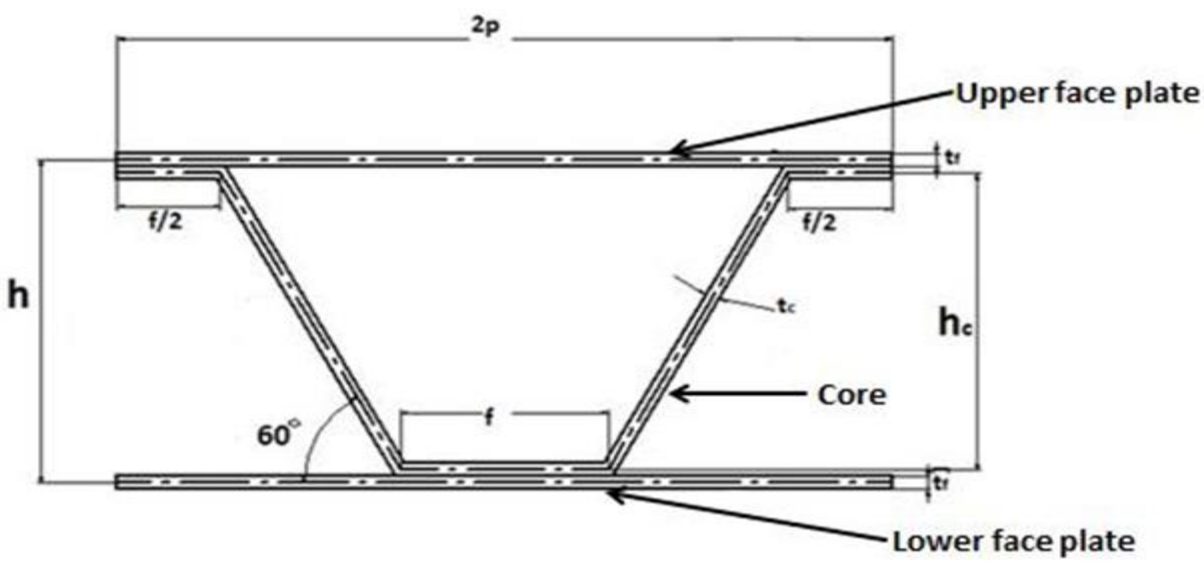


FIG:1 Corrugated core sandwich panel

4.1 Symmetric Corrugated Core Sandwich Panel

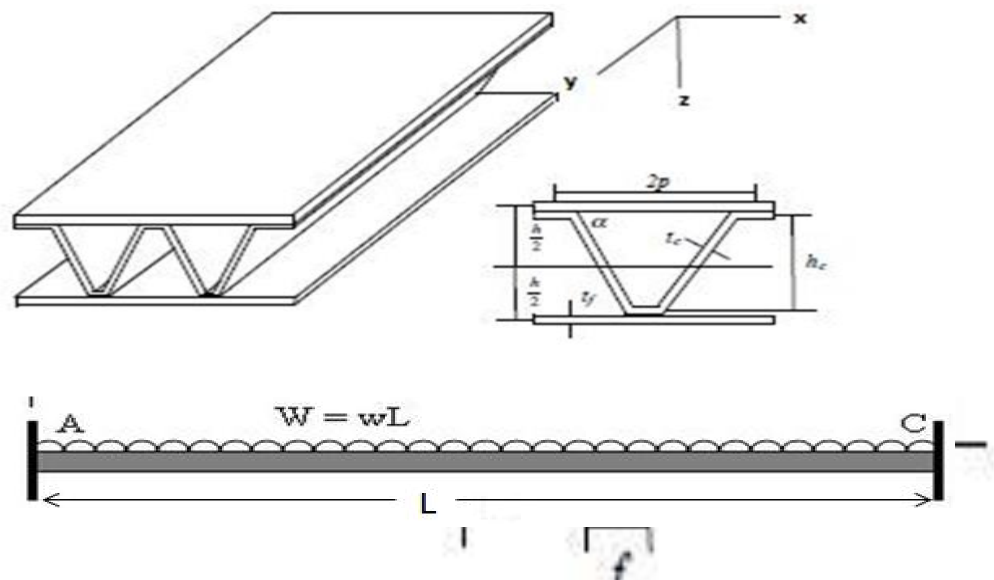


Fig 2; Symmetric corrugated core sandwich panel

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 (ɵ)= 60°.
- The displacement of the panel is depending upon the geometry of the panel and length
- In this project we are comparing the displacement of the panel analytically,FEA Analysis with the testing result under UDL loading condition
- Static analysis of the plate is to be performed with Ansys Workbench 14.5 with the different loading and boundary conditions.the load applied on the different geometric panel is 1000kg which is uniformly distributed over panel; after fixeing the ends of the plate.
- 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)

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

Pitch of the unit cell $P = f + (h_c/\tan\theta)$ (2)

Length of the flat segment $f = p - (h_c/\tan\theta)$ (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

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

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

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

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

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

Maximum bending moment at the centre of the panel

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

The bending stress in the panel

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

4.0 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.

Wan-Shu Chang, Edward Ventsel ,Ted Krauthammer,Oby John.[3]: Bending behaviorof corrugated-core sandwich plates

This paper presents the comprehensive analysis for the linear behavior of a corrugated-core sandwich plate. A closed form solution based on the Mindlin–Reissner plate theory is presented fordescribing the behavior of corrugated-core sandwich plate bending with various boundary conditions. A three-dimensional sandwich panel is reduced to an equivalent two-dimensional structurally orthotropic thick plate continuum. Also, the effect of geometric parameters of the corrugated-core sandwich plates with various boundary conditions on the plate behavior and strength were studied separately in this study.

William.L.Ko[4]: He presented the evaluation of elastic constants for the super plasticallyformed/diffusion-bonded corrugated core sandwich core, also studied the effect of face sheets thickness on the modulus of elasticity. Evaluation of bending stiffness for the super plastically formed/diffusion-bonded corrugated core. Comparison of stiffness made between the corrugated core & honeycomb core with titanium & corrugated core.

M.E. Biancolini [5]: This paper presents the evaluation of stiffness parameters for corrugated panel and is presented in this paper. The method is based on a detailed micromechanical representation of a region of corrugated board modeled by means of finite element analysis.

Marko Alenius,Hannu Hanninen[6]: This paper presents the review types of sandwichstructures, manufacturing technology.

Deshpande[7]: He discussed the stiffness and strength of sandwich beams and then use theanalytical expressions developed to design sandwich panels that can carry a given load at a minimum weight. Also discussed the sandwich effect.

4.1 Methodology

- Theoretically evaluating the deflection and stress for the different geometric parameters of the panel section of the single unit of the corrugated core sandwich pane.
- Comparing the deflection and von mises stresses analytically ,FEA Analysis with the experimental results of displacement and vonmises stresses for the different geometric parameters of the panel.
- Finding out the effect of different geometric parameter on the deflection and stress on the sandwich panel.

4.2 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.

4.3 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.

4.4Equipment Used

TIG Welding is used in the Fabrication setup.

4.4.1 Descriptive on TIG or GTAW

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area and electrode is protected from oxidation or other atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. A constant-current welding power supply produces electrical energy, which is conducted across the arc through a column of highly ionized gas and metal vapors known as a plasma.

4.4.2 Equipment

The equipment required for the gas tungsten arc welding operation includes a welding torch utilizing a non-consumable tungsten electrode, a constant-current welding power supply, and a shielding gas source.

4.4.2.1 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)

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

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 of the core

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

Pirch of the unit cell of panel $p = f + (h_c/\tan\theta)$ (1.4)

Length of flat degment $f = p - (h_c/\tan\theta)$ (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

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

Load per unit lengthw = W/L (1.8)

Deflection of the sandwich panel due to bending[8]

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

Where,

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

L=length of the panel =400mm

E=young's modulus of panel $=210\times10^3$ 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 $=80\times10^3$N/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

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

4.4.3.6Fabrication

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.

5.0 RESULTS AND DISCUSSION

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 (ө)	60°
4	Material of the panel	Structural steel

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

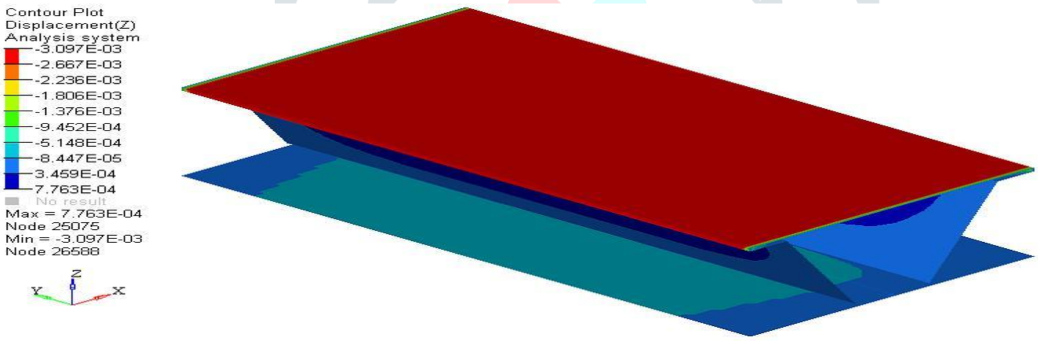
Case No	Pitch P	Core depth hc	Length of flat length segment f	Thickness of core tc	Thickness of upper and lower plate tf	Dictance between upper and lower plate H	Distance of neutral axis from its outer edge (Y)	Deflection δ
	mm	mm	mm	mm	mm	mm	mm	mm
1	100	83.35	51.88	2	2	87.35	48.36	3.945×10^{-3}
2	100	83.35	51.88	4	4	91.35	49	1.863×10^{-3}
3	100	83.35	51.88	6	6	95.35	50	1.159×10^{-3}
4	100	100	42.264	2	2	104	52	2.853×10^{-3}
5	100	100	42.264	4	4	108	54	1.350×10^{-3}
6	100	100	42.264	6	6	112	56	0.8435×10^{-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. Comparison between theoretical and numerical deflection for the different geometric parameter cases

Case no.	Theoretical deflection in mm	Numerical deflection in mm
1	3.945×10^{-3}	3.097×10^{-3}
2	1.863×10^{-3}	1.724×10^{-3}
3	1.159×10^{-3}	1.160×10^{-3}
4	2.853×10^{-3}	2.5600×10^{-3}
5	1.350×10^{-3}	1.069×10^{-3}
6	0.8435×10^{-3}	0.317×10^{-3}
7	2.055×10^{-3}	1.577×10^{-3}
8	0.9770×10^{-3}	0.4776×10^{-3}
9	0.6197×10^{-3}	0.2877×10^{-3}

4.1.1DISPLACEMENT AND STRESS CONTOUR CASE -1

The displacement and stress contour for the sandwich panel of geometric parameter i.e. h_c=83.33mm, p=100mm, f=51.88mm, t_c=2mm, t_f=2mm. is shown in Fig



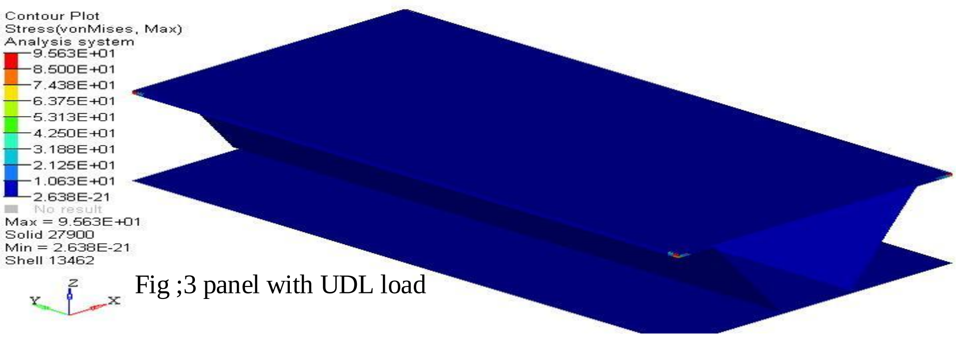


Fig ;3 panel with UDL load

4.1.2 DISPLACEMENT AND STRESS CONTOUR FOR THE CASE-2

The displacement and stress contour for the sandwich panel of geometric parameter i.e. h_c=80 mm, p=100mm, f=51.88mm, t_c=4mm, t_f=4mm

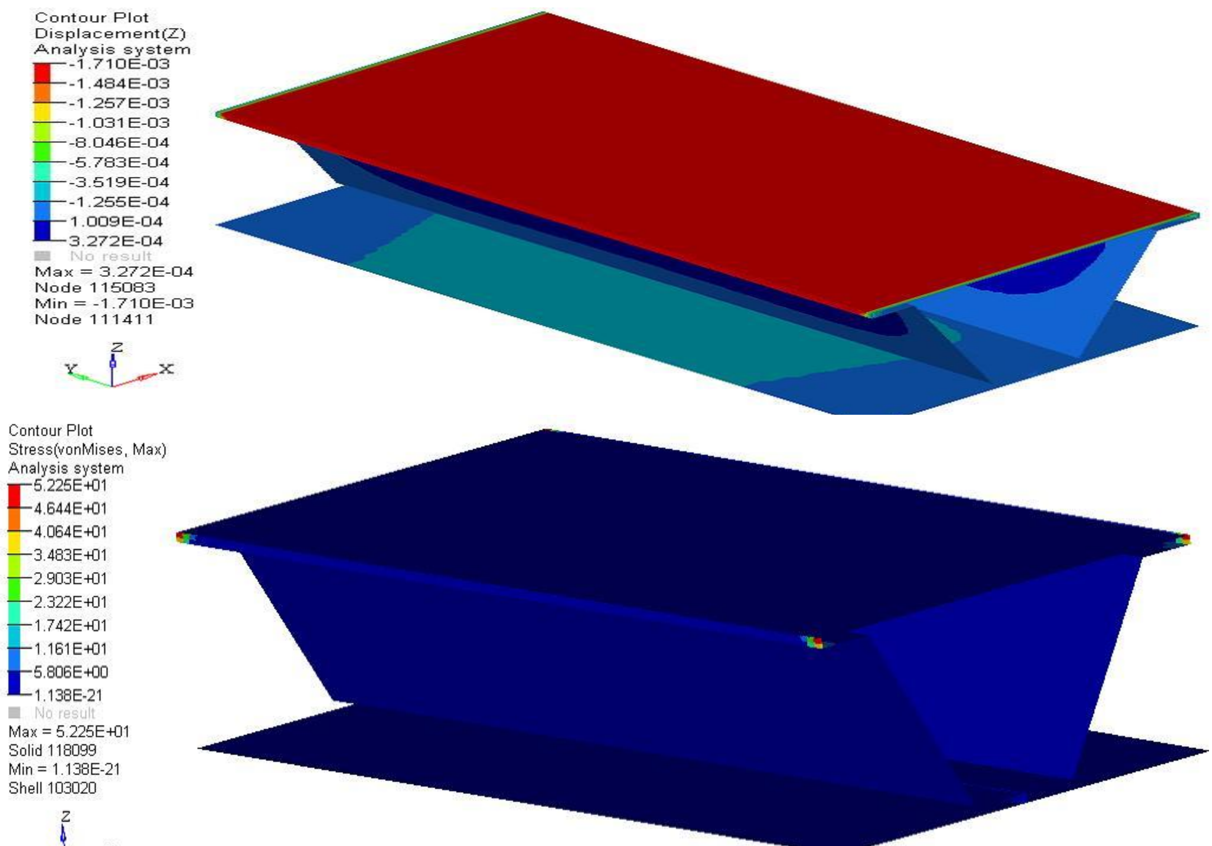


Fig5: 6000mm length Panel displacemenent with udl loading

4.1.3 Displacement and stress contour for the 6000mm length panel.

The displacement and stress contour for the 6000mm length of the panel is with geometric parameters case-1 i.e. h_C=80 mm, p=100mm, f=51.88mm, t_C=2mm,t_f=2mm is as shown Fig.4.42 and Fig.4.43 respectively.

Fig.6 : Displacement contour for the 6000mm length of panel

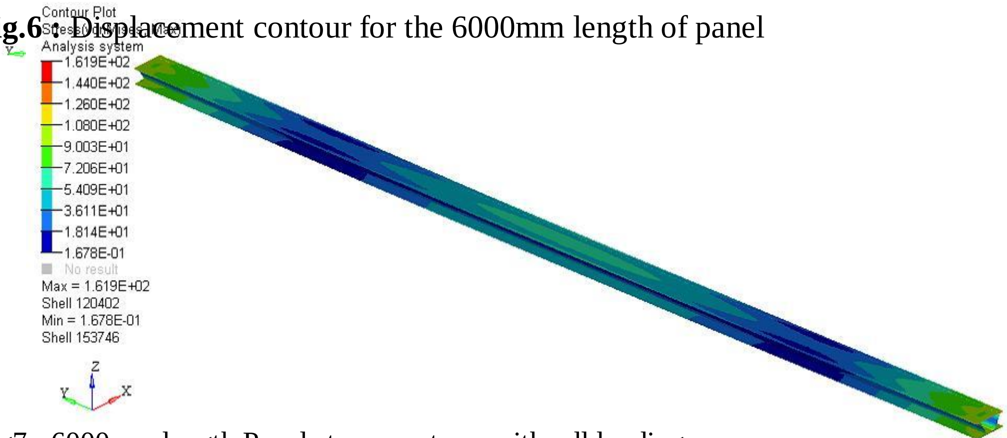


Fig7: 6000mm length Panel stress contour with udl loading

4.1.3 Displacement and stress contour for the 9000mm length panel.

The displacement and stress contour for the 6000mm length of the panel is with geometric parameters case-1 i.e. h_C=80mm, p=100mm, f=51.88mm, t_C=2mm,t_f=2mm is as shown Fig.4.44 and Fig.4.45 respectively.

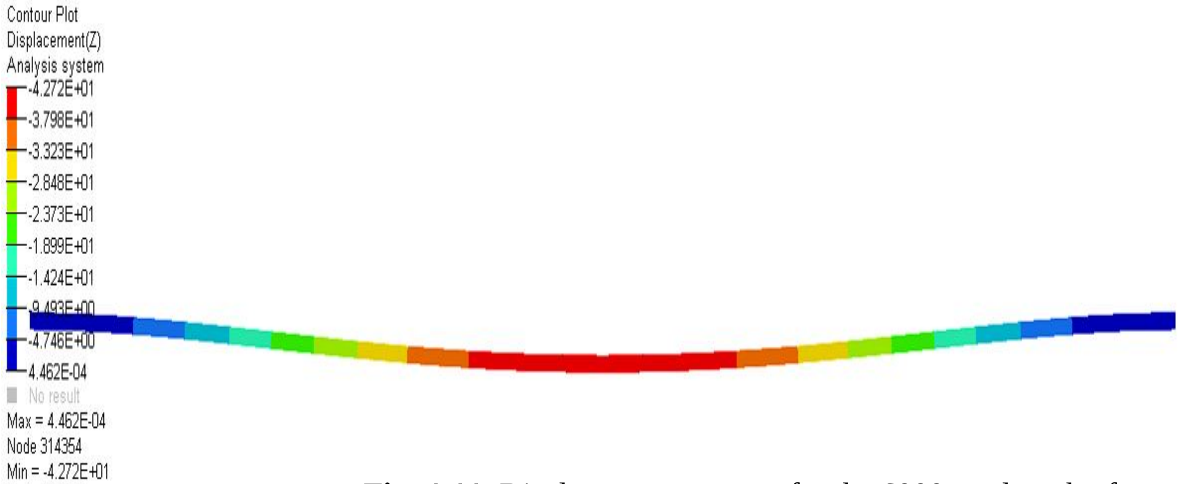
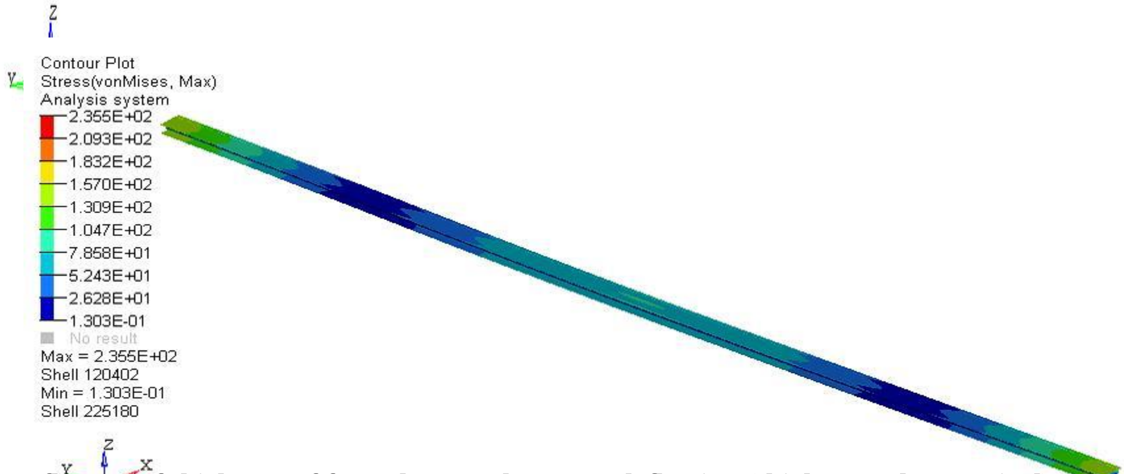
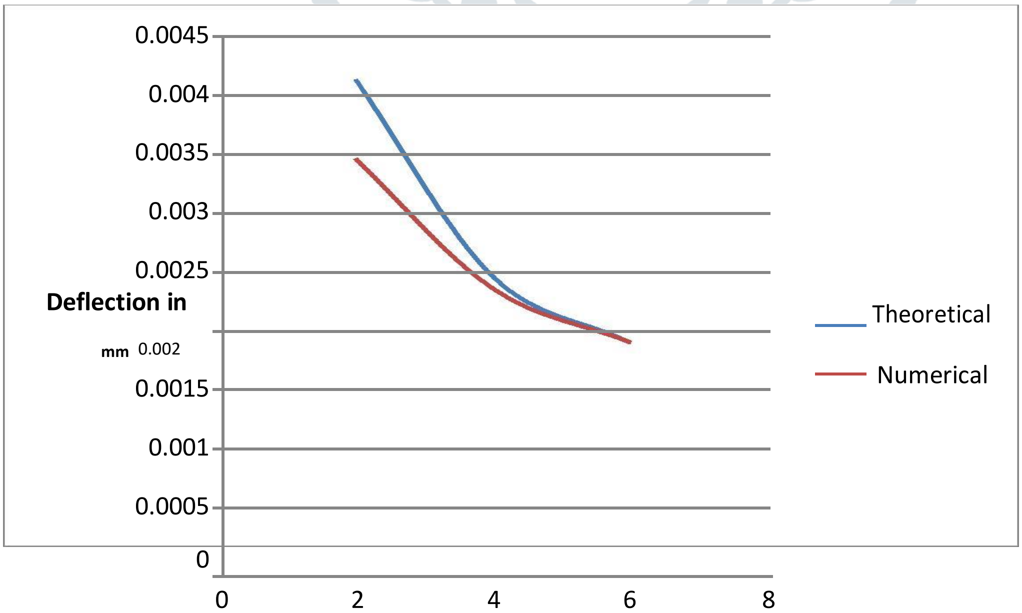


Fig. 4.44: Displacement contour for the 6000mm length of panel

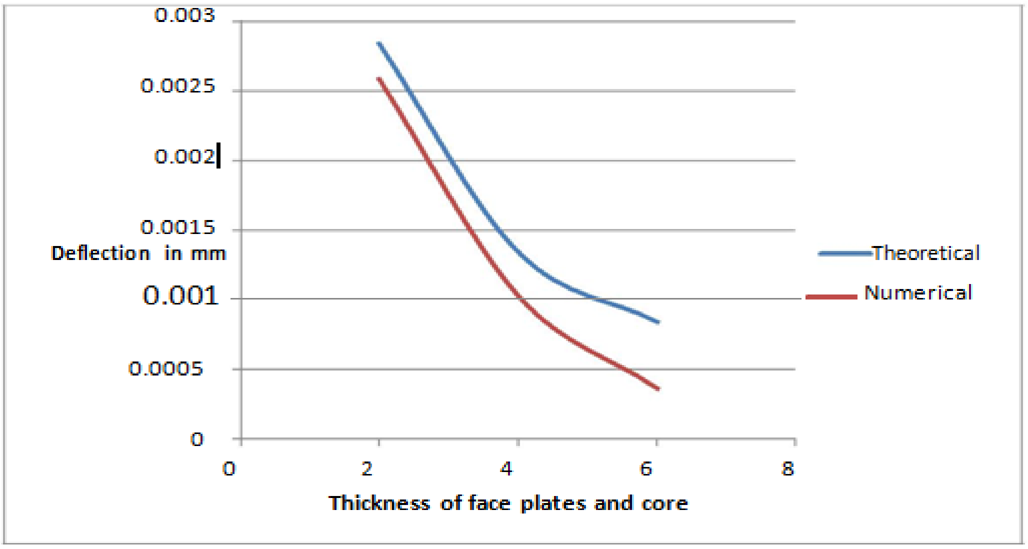


1 Influence of thickness of face plates and core on deflection (thicknesand numerical).

The Fig shows the variation of deflection versus the thickness of core as fallows



Graph1:Thickness of face plates and core Panel deflection versus thickness of face plates and core for h_c=80 mm,



Panel deflection versus thickness of face plates and core for h_C=100m f= 42.264 mm

Conclusion

Linear static analysis for deflection stress is performed on Laser welded corrugated core sandwich panel of structural steel for different geometric configuration or parameters. Also the deflection values are calculated theoretically from the Strength of material approach.It is observed that the results indicate the maximum deflection of the panel decreases with increase in face plates and core thickness.The same study is extended for the case of different length of the panel of particular geometric configuration. In this case the results obtained indicate the increase in both deflection and stress value as the length of panel increases.Thus results further can be used as design data for the selection of panel geometry and length.

Scope for future work

In this present work carried out static analysis carried out for the corrugated core sandwich panel with different geometric configuration load case of 1000Kg over the panel with length of 400mm and further extended to different length of the panel for the particular geometric configuration (case-1). The recommendation for the future work

1. In this case work clamped or fixed end of the panel is further extended to the different boundary condition such as both end simply supported, one end fixed other free, one end fixed and other end is simply supported.
2. In this case static analysis is carried out further it is extended to the dynamic analysis.

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