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Parametric Modelling of Anisotropic Plate Based on Elastic Strip Method of Homoginization

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Abstract Analytical modelling of structural anisotropic plate, represented as sandwich plate with corrugated cores is presented herein. it entails derivation of analytical models for evaluating in-plane extensional shear stiffnesses, out of plane bending stiffnesses, bending moments and deflection for sandwich plates, under transverse loading and boundary conditions. The combination of classical laminate theory and axis rotation in a smeared structure was adopted to evaluate the mechanical properties and the finite series was implemented to determine the structural characteristics. The analytical models are considerably simpler and reliable for handling the mechanical and structural behavior of sandwich plates with corrugated cores, compared to the existing models, because it reliably reproduced the in-plane extensional shear stiffnesses, out of plane bending and twisting stiffnesses, bending moments and deflections of the corrugated sandwich plate with striking accuracy when compared with the more refined finite element methods. It is therefore recommended that the proposed model be used for modelling of sandwich plate with corrugated cores, particularly the Integrated Thermal protection system used for space vehicles, since it is relatively less rigorous with respect to plain strain models developed by other researchers.

Keywords Anisotropic plate, CLT, Sandwich construction, stiffness, structural smearing.

1. Introduction

Research groups all over the world, are working hard to crate novel materials for construction purposes. When compared to monolithic constructions of identical weight, sandwich plates with corrugated cores typically exhibit lower bending deflection, high critical buckling loads, high natural frequencies, and larger transverse load carrying capacity. This provides a significant advantage in structural utilization. Sandwich construction finds application in the transportation and industrial sectors because of these benefits. They are usually used in vibration attenuation and sound insulation systems, ship panels, bridge decks, aircraft, grillages, muffin wings, storage systems, and packaging sectors. Due to its geometry and material heterogeneity, there are a number of analytically challenging techniques for analysing sandwich plates with corrugated cores. Elastic concepts in plate analysis are associated with rigorous mathematics. The plastic theories of analysis result in larger sections of steel, timber, plastic, and nonferrous concrete as well as over-reinforced sections of reinforced concrete. Due to the intricate geometry, numerical modelling of the corrugated sandwich panels is typically expensive. To homogenize this clearly heterogeneous construction, a number of homogenization techniques have been developed; however, these have increased resource, computational, and time-based constraints. Igor et al. (2015), Arthur et al. (2012), Abbes et al. (2010), Talbei et al. (2009), Buannic et al. (2003), Naoki et al. (1995), and more works provide a review of several homogenization methods. Huimine et al. (2019), Jian et al. (2018), Young Jo et al. (2015), Bartolozzi et al. (2013, 2014), Zheng et al. (2014), Weng et al. (2011), Biancolini et al. (2005), Brassoulis et al. (1986), and other works provide further details on the equivalent plate approach. In the same vein, some of the most authoritative works on the elastic method of plate analysis may be found in Orumu et al. (2022), Ozdemir (2018), Cheung et al. (1986), Timoshenko et al. (1959), and some other publications. For the plastic method of analysis, some reliable sources are Johnarry (1992), Kemp (1971), and Johansen (1962). The need for a simplified solution is recognized as a means to address the complexity of these methods and the high computational time and cost requirements that go along with them. Here, the plate bi-harmonic equation's finite series formulation is employed as an alternative model. The different stiffnesses to be applied in the finite series plate model are determined by combining the principles of smearing and parallel axis translation with the conventional classical laminate theory.

2. Governing Equations

2.1 Theoretical Frame Work

For the sandwich plate with corrugated cores shown in Figure 1, the mechanical properties such as the in-plane extensional shear stiffnesses and the out of bending and twisting stiffness from the lamina coordinate axis translation to the problem coordinate axis $\left(A_{ij}^{*}, B_{ij}^{*}, D_{ij}^{*}\right)$ can be obtained using structural smearing and the classical laminate theory approach.

2.2 Constitutive Equations

The sandwich composite plate with corrugated core depicted in Figure 1, with width in the longitudinal and transverse direction (a) and (b) respectively and core spacing (2p), can be modelled into an equivalent plate, acted upon by in plane and out plane actions that can be reduced to a unit cell shown in the extreme right corner of Figure 2.

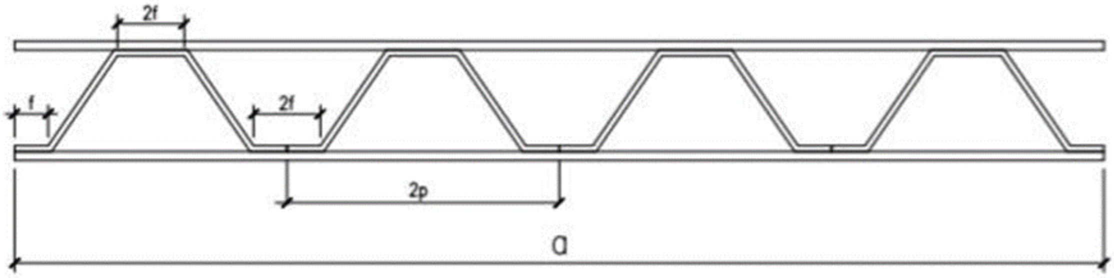
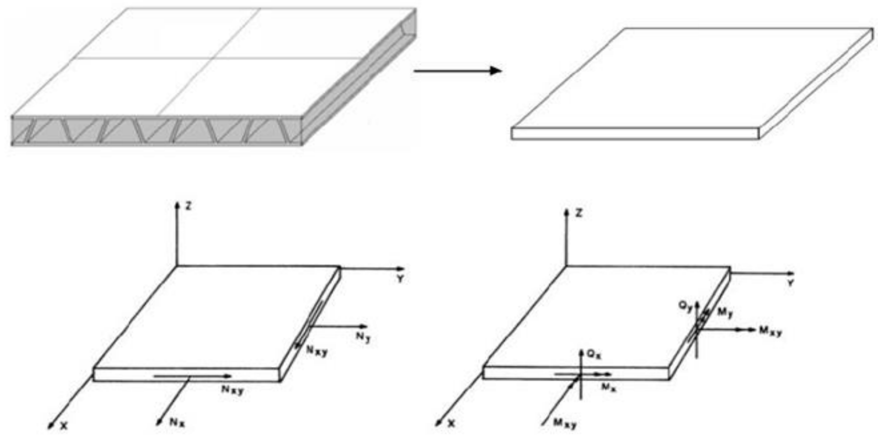


Figure 1: Sandwich plate with corrugated core.



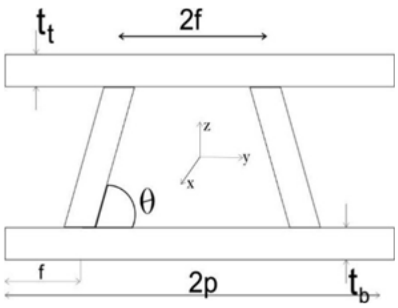


Figure 2: Cross section showing the sandwich construction modelled into a unit cell

2.2.1 Structural Smearing of The Sandwich Plate with Corrugated Cores

Structural smearing is an axisymmetric finite element structural analysis technique employed to evaluate the mechanical properties of sandwich plate with corrugated cores in the longitudinal, transverse, diagonal and twisting directions. Using the structural smearing analogy, the equivalent in-plane extensional stiffness of the sandwich plate with corrugated will be, the sum of the In-plane Extensional Stiffness of the individual face plates and the corrugated cores.

Thus

$$[A^{S*}{}_{11}]_{equi..} \approx [A_{11}]_{Faces} + n\,\frac{[\underline{A}_{11}]_{corr.cores..}}{a} \quad (1)$$

$$[A^{S*}{}_{12}]_{equi..} \approx [A_{12}]_{Faces} \quad (2)$$

$$[A^{S*}{}_{66J}]_{equi..} \approx [A_{66}]_{Faces} \quad (3)$$

$$[A^{S*}{}_{22}]_{equi..} \approx [A_{22}]_{Faces} + \frac{[\underline{A}_{22}]_{corr.cores..}}{2f} \quad (4)$$

Where $[A^{S*}{}_{IJ}]_{equi..}$, $[A_{ij}]_{Faces}$, $[A_{ij}]_{corr.cores..}$, $[\underline{A}_{ij}]_{single\ cores}$ and n_c are the equivalent in-plane extensional shear stiffness matrix of the sandwich plate with corrugated core, equivalent in-plane extensional shear stiffness matrix of face plates, equivalent in-plane extensional shear stiffness matrix of the corrugated core, in-plane extensional shear stiffness matrix of single core laminate in the problem coordinate axis and the number of corrugated cores in the sandwich construction

Similarly, the bending Stiffness of the sandwich plate with corrugated cores is equivalent to the sum of the bending Stiffness of the individual face plates and the corrugated cores.

Thus

$$[D^{S*}{}_{11}]_{equi..} \approx [D_{11}]_{Faces} + \frac{[\underline{D}_{11}]_{corrugated\ cores}}{a} \quad (5)$$

$$[D^{S*}{}_{12}]_{equi..} \approx [D_{12}]_{Faces} \quad (6)$$

$$[D^{S*}{}_{66J}]_{equi..} \approx [D_{66}]_{Faces} \quad (7)$$

$$[D^{S*}{}_{22}]_{equi..} \approx [D_{22}]_{Faces} + \frac{[\underline{D}_{22}]_{corr.cores..}}{2f} \quad (8)$$

Where $[D^{S*}{}_{IJ}]_{equi..}$, $[D_{ij}]_{Faces}$, $[D_{ij}]_{corr.cores..}$, $[\underline{D}_{ij}]_{cores}$ and n_c are the equivalent out of plane bending and twisting stiffness matrix of the sandwich plate with corrugated core, equivalent out of plane bending and twisting stiffness matrix of face plates, equivalent out of plane bending and twisting stiffness matrix of the corrugated core, out of plane bending and twisting stiffness matrix of single core laminate in the problem coordinate axis and the number of corrugated cores in the sandwich construction.

By integrating the contribution of the corrugated core into equations 1,2,3,4, 5, 6, 7 and 8 employing the parallel theory of axis rotation, the in-plane extensional stiffness becomes;

$$[A^{S*}{}_{11}]_{equi..} \approx [A_{11}]_{Faces} + n\,\frac{s_c[A''{}_{IJ}]_{corr.cores}}{a} \quad (9)$$

$$[A^{S*}{}_{12}]_{equi..} \approx [A_{66}]_{Faces} \quad (10)$$

$$[A^{S*}{}_{66J}]_{equi..} \approx [A_{66}]_{Faces} \quad (11)$$

$$[A^{S*}{}_{22}]_{equi..} \approx [A_{22}]_{Faces} + \frac{s_c[A''{}_{IJ}]_{corr.cores}}{2f} \quad (12)$$

And the out of plane bending and twisting stiffness becomes;

$$[D^{S*}{}_{11}]_{equi..} \approx [D_{11}]_{Faces} + \frac{\left(\frac{s_c^3}{12}\varphi\,[A''_{IJ}]+s_c[D''_{IJ}]\right)_{corr.cires}}{a} \quad (13)$$

$$[D^{S*}{}_{12}]_{equi..} \approx [D_{12}]_{Faces} \quad (14)$$

$$[D^{S*}{}_{66J}]_{equi..} \approx [D_{66}]_{Faces} \quad (15)$$

$$[D^{S*}{}_{22}]_{equi..}\, [D_{22}]_{Faces} + \frac{\left(\frac{s_c^3}{12}\varphi\,[A''_{IJ}]+s_c[D''_{IJ}]\right)_{corr.cires}}{2f} \quad (16)$$

$$\begin{bmatrix} A_{11}^* & A_{12}^* & A_{16}^* \\ A_{12}^* & A_{22}^* & A_{26}' \\ A_{16}^* & A_{26}^* & A_{66}^* \end{bmatrix} \begin{bmatrix} D_{11}^* & D_{12}^* & D_{16}^* \\ D_{12}^* & D_{22}^* & D_{26}^* \\ D_{16}^* & D_{26}^* & D_{66}^* \end{bmatrix} \quad (17)$$

Equations 9,10,11.12 and 13 ,14, 15, 16. are used to evaluate the equivalent in-plane extensional shear stiffnesses and the out of bending and twisting stiffness in the problem coordinate system for a unit cell in Figure 1.

For balance laminate with symmetric laminas about its mid plane, the left-hand side of equations 9,10,11.12 and 13 ,14, 15, 16. becomes equations 18 and 19.

$$\begin{bmatrix} A_{11}^{S*} & A_{12}^{S*} & 0 \\ A_{12}^{S*} & A_{22}^{S*} & 0 \\ 0 & 0 & A_{66}^* \end{bmatrix} \quad (18)$$

$$\begin{bmatrix} D_{11}^{S*} & D_{12}^{S*} & 0 \\ D_{12}^{S*} & D_{22}^{S*} & 0 \\ 0 & 0 & D_{66}^* \end{bmatrix} \quad (19)$$

2.2.2 Classical Laminate Theory (CLT)

The CLT is the most commonly used approach to analyze the behavior of laminated composite.

2.2.2.1 In-Plane Extensional Shear Stiffness Core Laminate in Problem Coordinate Axis.

From the classical laminate theory, the in-plane extensional shear stiffness and the out of plane bending and twisting stiffness in the problem coordinate axis for the face sheet, in the problem coordinate axis for core laminates stated in equations 9, 12, 13 and 16 are defined in equations 20 and 21 respectively.

$$\left|A_{ij}{}^{"}\right|_c = \sum_{k=1}^{n}\left[\bar{Q}_{ij}\right]_k t_k \quad (20)$$

$$\left|D_{ij}{}^{"}\right|_{c_{ij}} = \sum_{k=1}^{n}\bar{Q}_{ij}\left(\frac{t_k{}^3}{12} + t_k\check{Z}^2\right) \quad (21)$$

2.2.2.2 In-Plane Extensional Shear Stiffness and Out of Plane Bending stiffness for Face Sheet Laminate in Problem Coordinate Axis.

From the classical laminate theory, the in-plane extensional shear stiffness and out of plane bending and twisting stiffness in the problem coordinate axis for the face sheet laminates stated in equations 9, 10,11,12, 13,14,15 and 16 are defined in equations 22 and 23 respectively.

$$\left[A_{ij}\right]_{FACES} = \sum_{k=1}^{n}\left|\bar{Q}_{x-y}\right|_k (z_k - z_{k-1}) \quad (22)$$

$$\left[D_{ij}\right]_{FACES} = \sum_{k=1}^{n}\left|\bar{Q}_{x-y}\right|_k (z_k^3 - z_{k-1}^3)/3 \quad (23)$$

Where the subscript ij in both sub-sections 2.2.2.1 and 2.2.2.2 symbolizes 11,22,12 and 66, being stiffnesses in the longitudinal, transverse, diagonal and twisting directions respectively.

2.2.2.3 Stiffness Matrix in Problem Coordinate Axis.

From the classical laminate theory, stiffness matrix in problem coordinate axis stated in equations 22 and 23 are defined as

$$\bar{Q}_{11} = ¢_1 + ¢_2\cos 2\theta + ¢_3\cos 4\theta \quad (24)$$

$$\bar{Q}_{12} = ¢_4 - ¢_3\cos 4\theta \quad (25)$$

$$\bar{Q}_{22} = ¢_1 - ¢_2\cos 2\theta + ¢_3\cos 4\theta \quad (26)$$

$$\bar{Q}_{66} = ¢_5 - ¢_3\cos 4\theta \quad (27)$$

Where the ¢'s are the linear combination of material stiffnesses presented in equation 28

$$¢_1 = \frac{(3\,Q_{11}+3\,Q_{22}+2\,Q_{12}+4\,Q_{66})}{8}, ¢_2 = \frac{(Q_{11}-Q_{22})}{8}, ¢_3$$

$$= \frac{(Q_{11}+Q_{22}-2Q_{12}-4Q_{66})}{8} ¢_4 = \frac{(Q_{11}+Q_{22}+6Q_{12}-4Q_{66})}{8}, ¢_5 = \frac{(Q_{11}+Q_{22}-2Q_{12}+4Q_{66})}{8} \quad (28)$$

2.2.2.4 Stiffness Matrix in Material Coordinate Axis

From the classical laminate theory, stiffness matrix in material coordinate axis stated in equations 28 is defined 29

$$Q_{11} = \frac{E_1}{1-v_{12}v_{21}}\; Q_{22} = \frac{E_2}{1-v_{12}v_{21}}\; Q_{12} = \frac{E_2 v_{12}}{1-v_{12}v_{21}}\; Q_{66} = G_{12} \quad (29)$$

2.3 The Finite Strip Method

The finite strip method is a technique used in synergy with classical laminate theory and structural smearing to determine the structural characteristics of sandwich plate with corrugated cores.

This method considers each term in Bi-harmonic equation separately with its amplitude $A_x A_y, A_{xy} and A_{yx}$ as been equal to each other, for compatibility. It also assumes that, the load from the strip length multiplied by the perpendicular to the strip reaching the plate boundaries, are actually the load carried by each strip.

From the finite strip method, the load fractions in the short $stip$ f_x, long strip f_y, and diagonal strip strips f_{xy} are given by

$$f_x = \frac{n^4 D_{11}}{(n^4 D_{11}+D_{22}+2n^2{}_{xy}D_{xy})} \quad (30)$$

$$f_y = \frac{D_{22}}{(n^4 D_{11}+D_{22}+2n^2{}_{xy}D_{xy})} \quad (31)$$

$$f_{xy} = \frac{(1-n^4 D_{11}+n^4 D_{22})}{(n^4 D_{11}+D_{22}+2n^2{}_{xy}D_{xy})} \quad (32)$$

Substituting equations 13- 16, for D_{11}, D_{22}, D_{12} and D_{66} , into equations 30 to 32 yields;

$$f_x = \frac{n^4[D^{S*}{}_{11}]_{equiv.}}{\left(n^4[D^{S*}{}_{11}]_{equiv.} + [D^{S*}{}_{22}]_{equiv.} + 2n^2{}_{xy}([D^{S*}{}_{12}] + 2[D^{S*}{}_{66}]_{equiv.}).\right)} \quad (33)$$

$$= \frac{n^4[D^{S*}{}_{22}]_{equiv.}}{\left(n^4[D^{S*}{}_{11}]_{equiv.} + [D^{S*}{}_{22}]_{equiv.} + 2n^2{}_{xy}([D^{S*}{}_{12}] + 2[D^{S*}{}_{66}]_{equiv.}).\right)} \quad (34)$$

$$f_{xy} = \frac{[1-n^4 D_{11}+n^4 D_{22}]_{equiv.}}{\left(n^4[D^{S*}{}_{11}]_{equiv.} + [D^{S*}{}_{22}]_{equiv.} + 2n^2{}_{xy}([D^{S*}{}_{12}] + 2[D^{S*}{}_{66}]_{equiv.}).\right)} \quad (35)$$

Also from the finite strip method, the bending moments M_x, M_y and the twisting moments M_{xy} as well as deflections Δ_s are given by

$$M_x = f_x m_x + v f_y m_y \quad (36)$$

$$M_y = v f_x m_x + f_y m_y \quad (37)$$

$$M_{xy} = f_{xy} m_{xy} \quad (38)$$

$$\Delta_s = f_{xy}) \quad (39)$$

$Where\ m_x, m_y, m_{xy} and\ \Delta$ are the primitive moment in the short span, long span, diagonal strip and primitive deflection respectively of the sandwich plate.

short span, long span, diagonal strip and primitive deflection respectively of the sandwich plate.

3. Parametric Model

Based on the classical laminate theory in smeared and the finite series approach.

- Obtain the in-plane material stiffness from equation 29
- obtain the transformed stiffness matrix $\bar{Q}_{11}, \bar{Q}_{22}, \bar{Q}_{12}, \bar{Q}_{66}, \bar{Q}_{16}$, and $\bar{Q}_{26}$ from equation 28
- Obtain the in-plane extensional shear stiffness and out of plane bending stiffness for face Sheet laminate in problem coordinate axis using equations 22 and 23 respectively.
- Obtain the in-plane extensional shear stiffness core laminate in problem coordinate axis using equations 20 and 21.
- Obtain the equivalent in-plane extensional stiffness by substituting equation 20 and sc = $\frac{d_c}{\sin\varphi}$ into equations 9,10,11 and 12 respectively.
- Obtain the equivalent out of bending and twisting stiffness by substituting equation 21 and sc

- Obtain the strip coefficient by substituting values from equations 13,14,15 and 16 into equations 33,34 and 35respectively.

Obtain the bending and twisting moments as well as deflection by substituting values from the strip coefficient into equations 36 to 39.

3.1 Algorithm of Solution for the Parametric Model of the Sandwich Plate with Corrugated Cores.

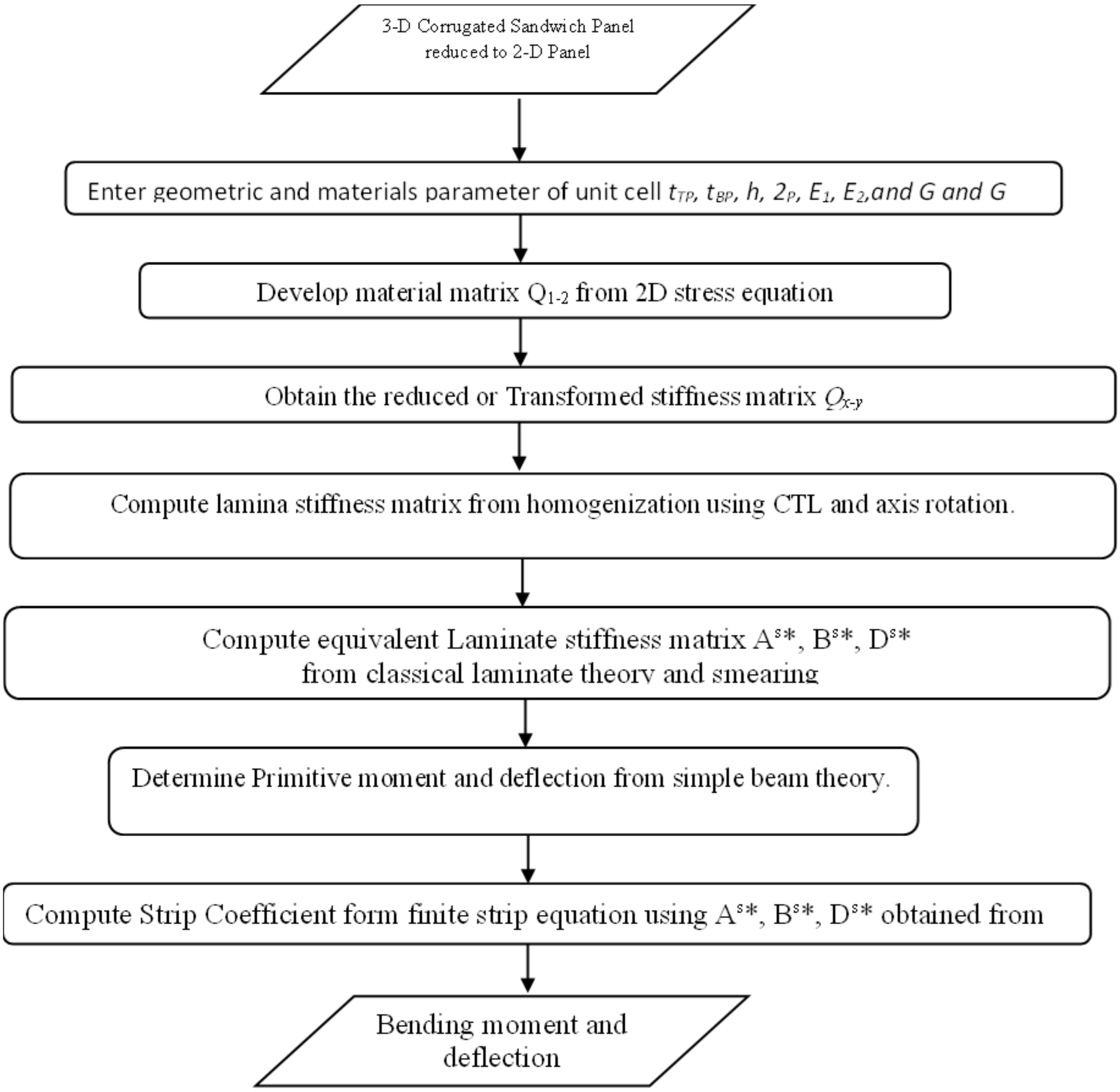


Figure 3: Algorithm of the Sandwich Plate with Corrugated Core

4. Results using Numerical Example

A. Considering the sandwich construction shown in Figure 4, determine, the effect of the variation of the fac thickness t_t and web thickness t_w on the plate stiffness, given that:d= 10.5mm, θ= 45, dc = 9.5mm, 2p = 14, t_w= 1mm, t_b= 1mm, f= 0, E=69 × 10^3 N/mm^2 with $t_t = t_b$

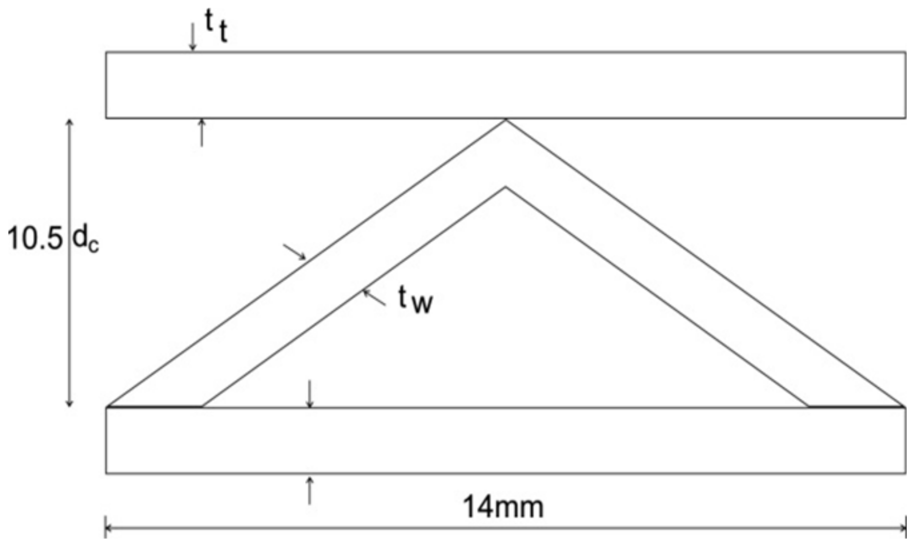


Figure 4: Unit Cell for Sandwich Construction to Sought for Stiffness, Deflection and Bending Moments

In 2011, Magnucki et al, successfully solved this problem and used the finite element model as well as laboratory experiments to verify their results. This problem is repeated here and solved by the equivalent plate model of homogenization. The strength of the sandwich construction with crosswise corrugated core was considered. The geometry of the cross section, flexural stiffness, bending moments and deflection of beam were also found. The results of the evaluation using the equivalent model, Magnucki et al (2011) and the finite element method and laboratory experimentations is presented in Tables 1 to 2 and graphically in Figures 5 to 11.

Table 1: Computed Stiffness Coefficients for Sandwich Panel

$t_t$mm	t_w mm	Ixx mm^4/mm	Stiff.ExactN/mm^2/mm	Stiff.Analytical KN/m^2/mm	Stiff. Magnucki N/mm^2/mm	Stiff.FEM N/mm^2/mm	StiffExp.Nmm^2/mm	%Dif. exact	%Dif.FEM	% DifExp
1.00	0.30	48.07	331,701.19	331.77	331.22	334.16	330.	-0.02	-0.7	-0.5
1.50	0.30	71.03	490,114.09	497.66	530.08	533.47		-1.5		
2.00	0.30	94.36	651,114.09	663.55	763.42	676.16		-1.9		
1.00	0.40	48.88	337,272.69	331.77	339.75	343.35		-0.02		
1.00	0.50	49.63	342,453.57	331.77	348.61	352.61		-0.02		

Table 1, shows that the results from the proposed model deviates from that of Magnucki et al 2011, Finite Element Method and laboratory experiment, with percentage differences of about 0.02, 0.7 and 0.5 respectively for the crosswise corrugated core for t_t = 1mm and t_w = 0.3mm. This result shows good agreement of the model Magnucki et al (2011), FEM and laboratory experiments. It also shows the important role played by the facings.

Table 2: Computed Stiffness Coefficients, Moment and Deflections for Magnucki Sandwich Panel.

$t_w(mm)$	$t_t(mm)$	Stiffness Analytical N/mm^2/mm	Moment in M_X $(N.mm)$	Moment in M_Y $N.mm$	Moment in M_{XY} $N.mm$	Deflection Δ_s mm
0.3	1.00	0.018701601	0.062337526	0.018701601	0.000919729	2.41895 10^{-8}
0.3	1.50	0.028717706	0.062391590	0.018717706	0.000613685	1.1030910^{-8}
0.3	2.00	0.018725769	0.062418657	0.018725769	0.000460463	6.20487 10^{-9}
0.4	1.00	0.018701601	0.062337526	0.018701601	0.000919729	2.41895 10^{-8}
0.5	1.00	0.018701601	0.062337526	0.018701601	0.000919729	2.41895 10^{-8}

Table 2, shows that, the moments in the longitudinal and transverse directions, increases with increase in core thickness and moments in the twisting direction decreases with increase in core thickness, while the deflections increase with decreasing thickness of core. This also shows the important role played by the core thickness.

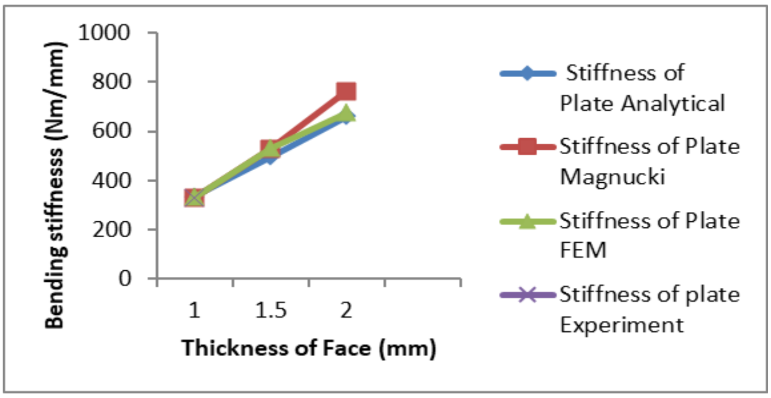


Figure 5: Comparison of Analytical, Magnucki et al (2011), Numerical and Experimental Results for the Crosswise Corrugated Core (Thickness of the Corrugated Core t_w=0.3mm)

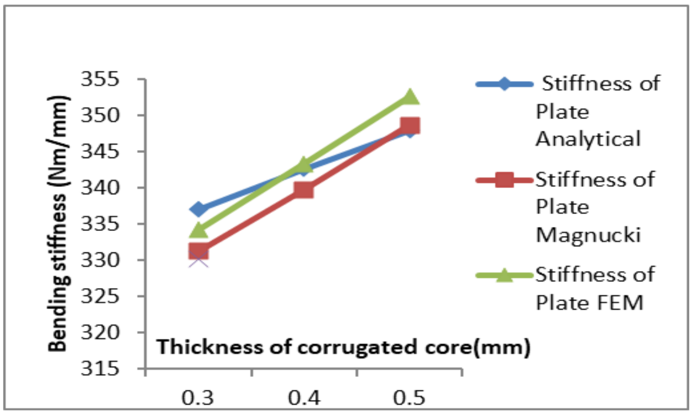


Figure 6: Comparison of Analytical, Magnucki et al (2011), Numerical and Experimental Results for the Crosswise Corrugated Core (Thickness of the Faces t_t =1mm).

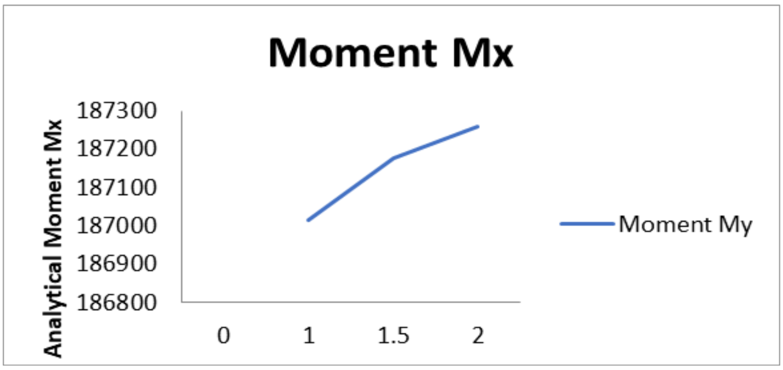


Figure 7: Analytical Moments M_x Vs.Thickness of Facings for the Crosswise Corrugated Core (Thickness of the Webt_b =1mm).

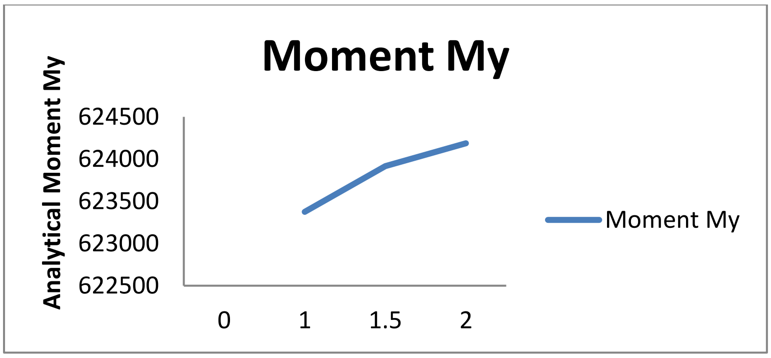


Figure 8: Analytical Moments M_y Vs.Thickness of Facings for the Crosswise Corrugated Core (with Thickness ofWebt_b =1mm).

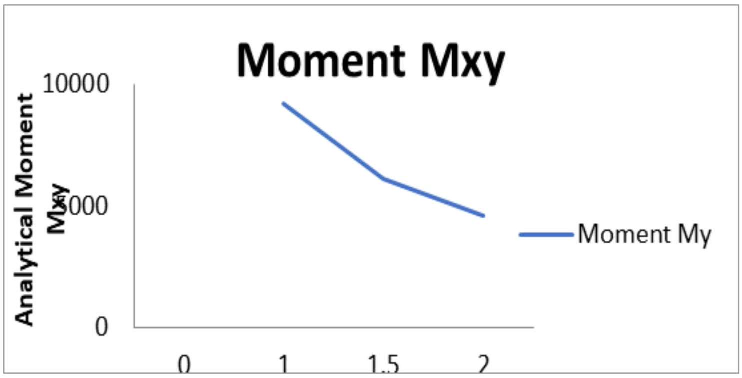


Figure 9: Analytical Moments M_{xy} Vs.Thickness of Facings for the Crosswise Corrugated Core (with Thickness ofWebt_b =1mm).

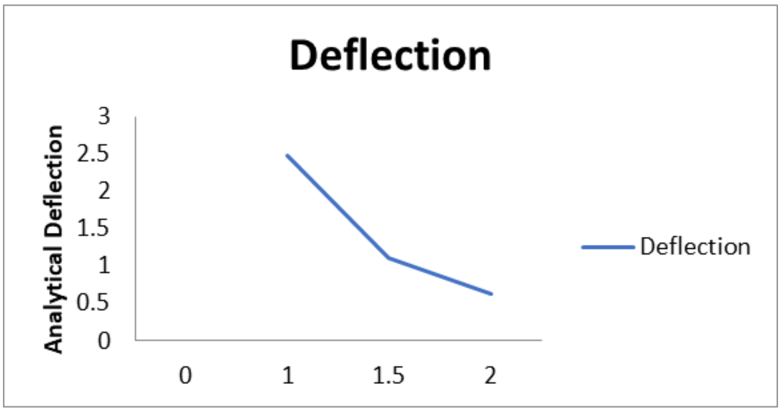


Figure 10: Analytical Deflection Vs. Thickness of Facings for the Crosswise Corrugated Core(With Thickness of Web t_b =1mm).

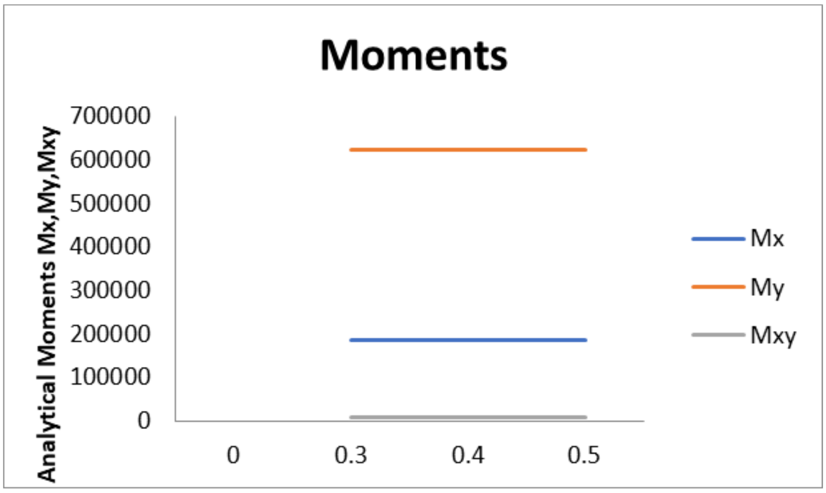


Figure 11: Analytical Moment M_x, M_y and M_{xy} Vs. Thickness of Core for the Crosswise Corrugated Core (with Thickness of Face t_t =1mm).

Figure 5 shows that flexural Stiffness of the sandwich construction increases with increase in the thickness of the facing for the equivalent plate model, Magnucki et al 2011 and the Finite Element method. Figure 6 shows that, the increase in the thickness of core, affects the flexural stiffness of the sandwich construction. Figure 7 and Figure 8, shows that, the moments in longitudinal and transverse directions increases with increase in the facings thickness. In Figure 9 and Figure 10, the moments in the twisting directions and the deflections in the sandwich plate, decreases with increasing facings thickness. Figure 11, shows that the moments in the plates are not significantly affected by the thickness of the web.

B: The Effect of Varying the Depth of Core and Pitch on The Orthotropic Properties of The Sandwich Constructions.

Considering the sandwich plate, simply supported on all four side, under the action of a uniformly distributed load q= 1N/m^2 on its upper face with a stacking sequence $[0/90]s$, determine, the effect of Varying depth of Core (d_c) and pitch (2P) on the maximum deflections. given that l=b=0.64mm, $t_t = t_w = t_b$= 1mm, E_1= 138x10^3 N/mm^2, E_2= 9x10^3 N/mm^2, G= 6.9 x10^3 N/mm^2, v=0.3, ϴ = 75°

This problem was also solved by Rajesh (2014) using minimum potential energy and Martinez (2007) using shear deformation plate theory. The problem. is also sought here using the plate model. For effective comparison $4Pt+\frac{2(d-t)t}{\sin\emptyset}= 478$ is used to obtain varying geometric properties shown in Table 3

Table 3: Varying Values of d_c and 2P

d_c	2P	Dc	2p
29.86	160	69.96	200
49.86	160	69.96	180
69.86	160	69.96	160
89.86	160	69.96	140
109.86	160	69.96	120

The results obtained from the proposed model are presented in Table 4 and Table 5. The graphical representation of the results is found in Figure 12 and 13.

Table 4: The Influence of Depth of Core on Flexural Behavior of Corrugates

d_c mm	2P m	D_{11} Nm. 10^5	D_{22} Nm. 10^5	D_{12} Nm. 10^5	D_{66} Nm. 10^5	Δ_s 10^{-08}	m_x Nm. 10^{-5}	m_y Nm. 10^{-5}	m_{xy} Nm. 10^{-5}
29.86	160	2.064	2.281	0.0842	0.2800	1.743	2201	2322	1901
49.86	160	2.487	2.281	0.0842	0.2800	5.480	2382	2274	1783
69.86	160	2.938	2.282	0.0842	0.2800	1.129	2525	2228	1672
89.86	160	3.429	2.284	0.0842	0.2800	0.346	2714	2185	1566
109.86	160	3.975	2.286	0.0842	0.2800	0.134	2872	2143	1462

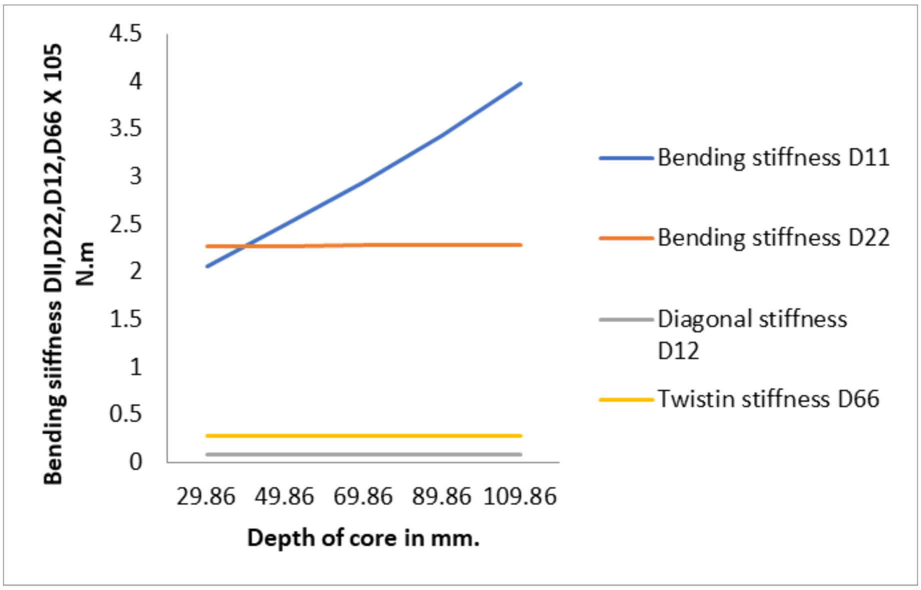


Figure 12: Bending Stiffness D_{11}, D_{22}, D_{12} D_{66}Vs..Depth of Core

Figure 12: shows that the Flexural longitudinal Stiffness D_{11} increases with increase in depth of core d_c whereas the transverse flexural stiffness D_{22}, the diagonal stiffness D_{12} and the twisting stiffness D_{66} are not influence by the depth of core

Table 5: The Influence of Pitch on the Flexural Behaviour of Corrugates

d_c mm	2P Mm	D_{11} Nm. 10^5	D_{22} Nm. 10^5	D_{12} Nm. 10^5	D_{66} Nm. 10^5	Δ_s 10^{-08}	m_x Nm. 10^{-5}	m_y Nm. 10^{-5}	m_{xy} Nm. 10^{-5}
69.86	120	2.664	2.283	0.0842	0.2800	1.339	2541	2256	1737
69.86	140	2.787	2.283	0.0842	0.2800	1.221	2497	2243	1707
69.86	160	2.938	2.282	0.0842	0.2800	1.129	2552	2228	1672
69.86	180	3.134	2.282	0.0842	0.2800	1.085	2619	2210	1628
69.86	200	3.395	2.282	0.0842	0.2800	0.098	2704	2187	1573

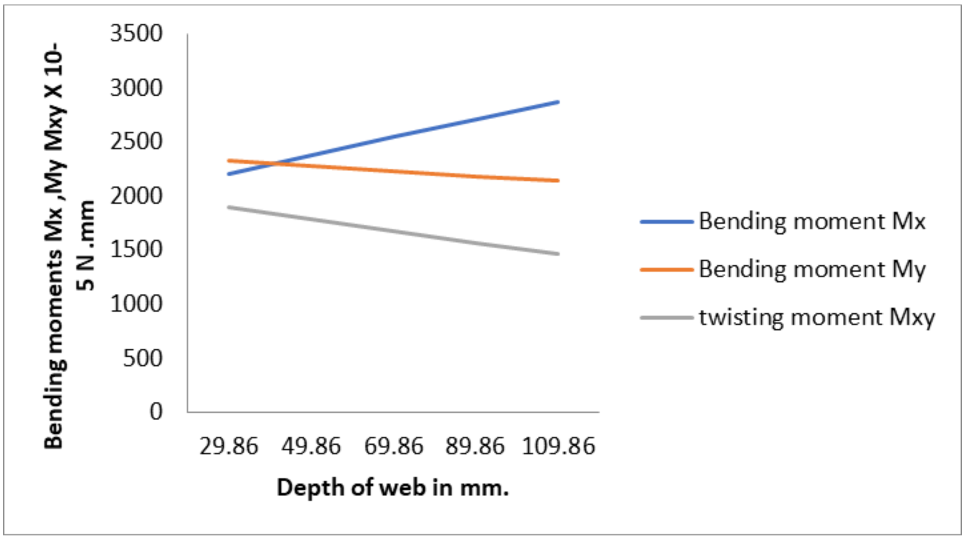


Figure 13: Bending and Twisting Moment Vs. Depth of Core.

Figure 13 shows that the bending moment in the longitudinal direction increases with increase in depth of core. While the bending moment in the transverse direction and in the twisting direction, decreases with increase in the depth of core.

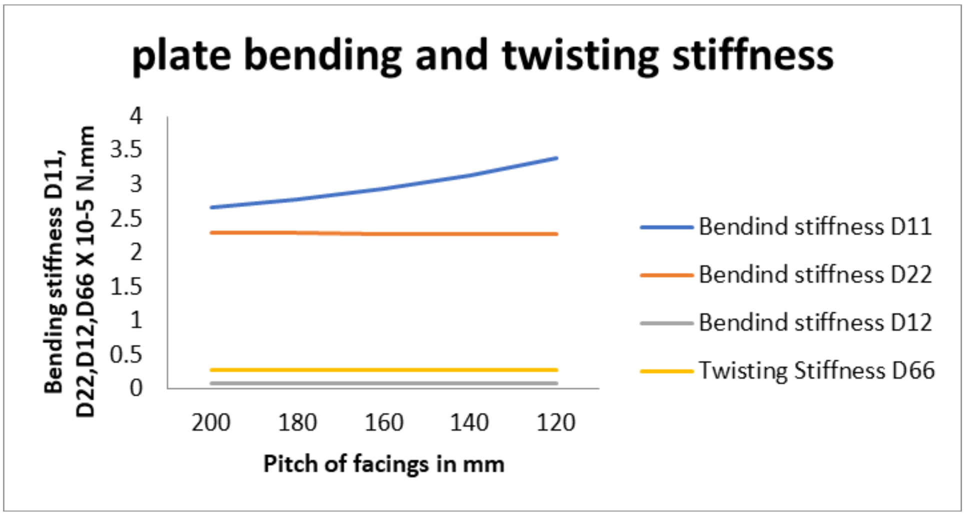


Figure 14: Bending and Twisting Stiffness Vs. Pitch of Facings

Figure 14 show that the Flexural longitudinal Stiffness D_{11} increases with increase in Pitch of facings2p, whereas the transverse flexural stiffness D_{22}, the diagonal stiffness D_{12} and the twisting stiffness D_{66} are not influence by the pitch of facings.

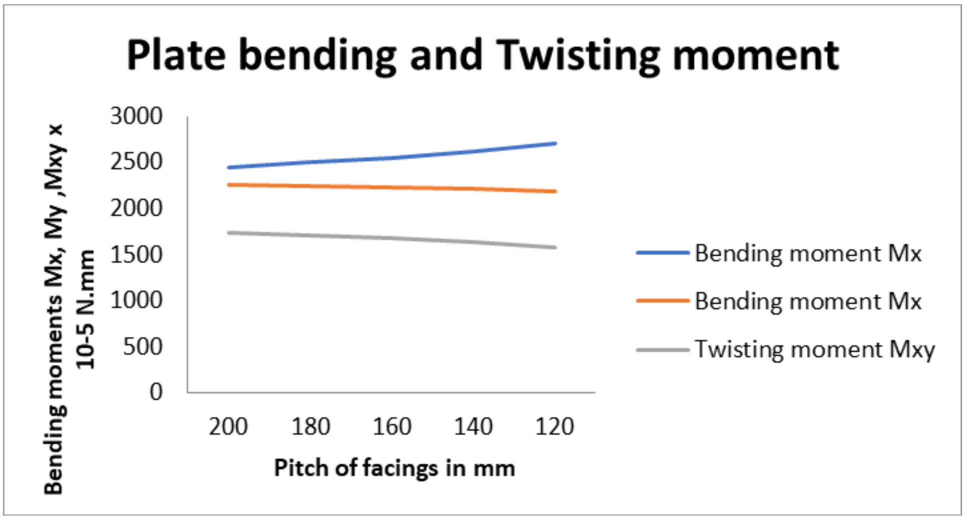


Figure 15: Bending and Twisting Moments Vs. Pitch of Facings.

Figure 15 shows that the bending moment in the X direction, increases with increase in the pitch of facings, while the bending moment in the Y direction and in the twisting direction, decreases with increase in the pitch of facings

5. Conclusion

The complexity of models of composite structural systems, resulting from homogenization approaches, based on the various micromechanics technics, shear deformable theory, minimum potential energy and Euler Bernoulli solutions are recognized. The results from the equivalent plate model of homogenization using the synergy in the classical laminate theory and the finite series expressions agree very closely with various plane plain strain method of analysis and the more refined finite element method for the determination of the mechanical and structural properties of sandwich plate with corrugated cores. The results are valid for the linear elastic behaviour under static loads in any materials.

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