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Mechanical Behaviour of Composite Corrugate Core Sandwich Panels

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Abstract: Aluminium sandwich construction has been recognized as of promising concept for structural design of light weight transportation systems such as aircraft high speed trains and fast ships. The aim of the present study is to investigate strength characteristics of aluminium sandwich panels with aluminium corrugated core experimentally. A series of crushing and bending test is carried out on corrugated core sandwich panel. The comparison of results is done based on the parameters viz. no of layers and patterns of perforated sheets. The structural failure characteristics of corrugated core sandwich panels are discussed. The test data developed are documented.
Keywords: Corrugated core sandwich panels, Crushing strength, Bending strength, perforated sheets.

I. INTRODUCTION

For design and construction of light weight transportation systems such as satellites, aircraft, high-speed trains and fast ferries, structural weight saving is one of the major considerations [1]. To meet this requirement, sandwich construction is frequently used instead of increasing material thickness. This type of construction consists of thin two facing layers separated by a core material. One of the advantages of sandwich structures is that they can have a relatively high fraction of open space, hence a much lower density as compared to the parent material. In nature, cellular materials have evolved to make biological parts more structurally efficient by eliminating unstressed material and providing pathways for the growth of other organic materials [3]. The corrugated core sandwich panel is a progressive evolution of lattice truss structures in which the metal trusses are replaced with metallic wires, which facilitates fabrication due to the continuous nature of the wire-mesh employed as raw material. The corrugations provide the layers with high rigidity and stiffness in the direction perpendicular to the corrugations. Typically, alternate layers of the corrugated core sandwich panels are arranged orthogonally so that the high stiffness provided by the corrugation is available in both directions. Unlike metallic foam, which also has potential for similar application, the CWML offers the advantage of controllable rigidity and strength [3]. The material of the wire mesh, wire diameter, opening width, and corrugation parameters such as the corrugation height and the base angle can be altered to provide a wide range of strength to the laminate structure [5]. In aerospace and mechanical engineering fields, CWML has potential for applications as high strength, low weight, core material in structural sandwich construction [6]. In order to find maximum strength of corrugated core sandwich panel under compressive and bending loading number of experiments can be performed for different combinations of operating parameters and their optimum values can be found out. The idea to analyse the influence of Sandwich panel using perforated sheet is a good way to review the physical properties of material compressive strength, analysis the structure of sandwich panel by application of load.

A sandwich panel is a structure made of three layers low density core inserted in between two relatively thin skin layers. This sandwich setup allows to achieve excellent mechanical performance at minimal weight. The very high rigidity of sandwich panel is achieved thanks to interaction of its components under flexural load applied to the panel. Core takes the shear load and creates distance between the skins which takes the in-plane load stresses, one skin in tension and other in compression. Sandwich structure can be optimized by using various core materials such as honeycomb, foam core and corrugated core. Honeycomb is well-known core used to build sandwich structures. Honeycombs and flex cores are used in many applications, for example chassis of modern cars use honeycomb sandwich structure. The big number of core materials and core configurations have been proposed these days. The most often used core materials are foams and honeycomb. The foam cores are preferably used when the waterproof, sound and heat insulations are required. The stuffing of honeycomb cells with foam can be considered as the enhancement of de-bonding resistance and ability to produce new types of sandwich cores.

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A corrugated-core sandwich structure is embraced of a corrugation sheet between two thin surface sheets. The important feature of this structure is its high strength-to-weight ratio. The corrugated-core keeps the face sheets apart and stabilizes them by resisting vertical deformations, and also enables the whole structure to act as a single thick plate as an asset of its shearing strength. This second feature gives better strength to the sandwich structures. Furthermore, unlike soft honeycomb shaped cores, a corrugated-core opposes bending and twisting as well to vertical shear. Then, corrugated-core sandwich panels, due to their extremely high flexural stiffness-to-weight ratio are usually used in aeronautics, aerospace, civil engineering and other applications, where weight is a significant design issue. This structure approach to form a sandwich plate may be defined as 'structurally composite', since its behaviour characteristics are defined by the composite action of its components [7].

II. DESIGN AND DEVELOPMENT

Work is undertaken into selection of parameters, fabrication of corrugated core sandwich panel and its experimental testing on computerized universal testing machine. In corrugated core sandwich panel several parameters are involved in its configuration such as material and types of the wire mesh, wire diameter, opening width, number of corrugated layers, number of corrugations and corrugation parameters such as the corrugation height and the base angle which can be altered to provide a wide range of stiffness and strength to the laminate structure. These parameters are contributing in the strength of corrugated core sandwich panel, among which some parameters are critical whose effect on strength of structure cannot be predicted directly such as corrugation or base angle, laminates structure, opening width. Hence in order to improve the strength of corrugated core sandwich panel the effect of these parameters on the strength of corrugated core sandwich panel needs to be evaluated. The parameters are selected in this study are types of core and number of layers.

A. Establishment of Objective Function

The main objective of this work is to compare strength of the panel with honeycomb panel on the basis of strength to weight ratio and equivalent core density with various core materials.

B. Geometry Of Corrugated Core

The corrugated-core geometry is defined by a repeating arrangement of unit cells, which are determined by a set of geometric parameters. In this study, the unit cell is based on a triangular profile and the corrugated specimens consist of several repetitions of an identical unit cell. The geometric parameters identified in Fig.3.2 are as follows: θ and β are the internal angles of a unit cell in the corrugated-core sandwich panel; T is the height of the core and HS is the overall height of the sandwich panel; HU and HL are the upper and lower thicknesses of the skins, respectively; H is the average thickness of inclined core member i.e. the wall thickness; x is the length of the core; and w is the width of a sample. For the current mould design, the value of x was 20 mm while θ and β were set to 55^0 and 70^0, respectively. During preparation of the test specimens, the value of the width, w was maintained constant at 100 mm.

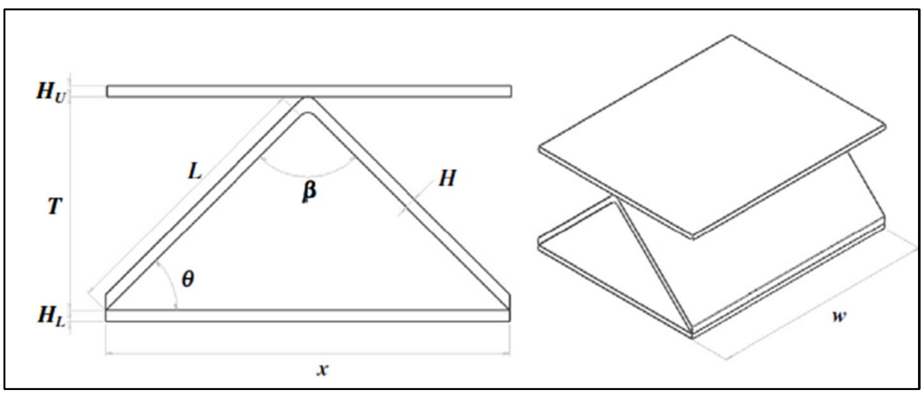

Figure 2.1 Geometry of corrugated core [2]

C. Corrugation Process

Die and punching process is used to make corrugations in the perforated sheets. The die and punch designed and manufactured under this work is shown in Figure 2.2 and Figure 2.3. The pair of die and punch was designed & manufactured with corrugation angle 55°. The length L_x and width L_y (area) of the corrugated wire mesh is (100×100) mm^2. Also the base length L_B is (20mm).

The corrugation height H_c is 14.28mm. The perforated sheet is fed through this pair of die and punches to create corrugations in them. Figure 2.4 show samples of corrugated cores by the above process.

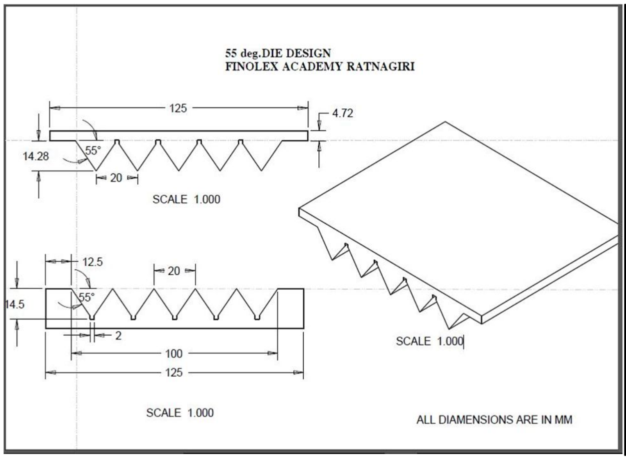

Figure 2.2 Design of Die used for corrugation

Figure 2.3 Manufactured die with corrugation angle of 55°

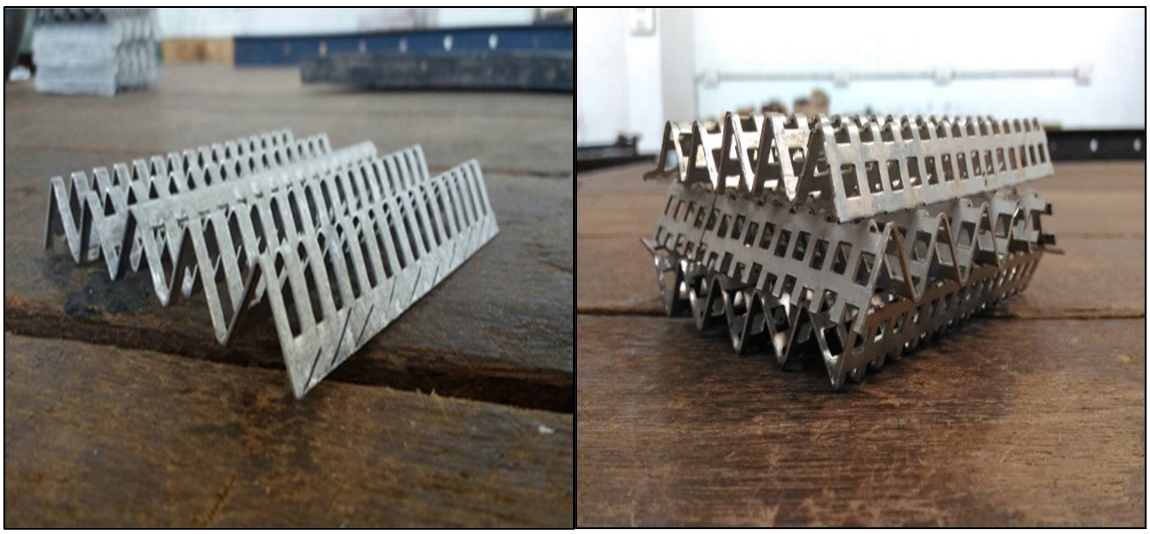

Figure 2.4 Corrugated Perforated sheets

D. Bonding Technique

The bonding technique used in the present work is adhesive bonding with epoxy resin. Epoxy adhesives are two part (resin and hardener) adhesives having large variations in its viscosities. Epoxy adhesives forms tough, rigid thermo set polymers with high strength and good environmental resistance. The bonding material is 'Araldite Standard Epoxy adhesive' produced by Petro Araldite Pvt. Ltd. is selected.

E. Work Material

The wire mesh used in the current study is perforated sheets made of 6061 Aluminium. Al is commonly used as core material or light weight sandwich construction in mechanical, automotive, marine and aerospace engineering. Materials should satisfy the requirements given below:

1) It must have high strength and light in weight
2) It should resist the corrosion
3) It should be durable
4) It should be available easily with reliable cost

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So we have selected aluminium as core material and aluminium composite as face material. The mechanical properties of materials are given in Table 2.1.

Table 2.1 Mechanical properties of materials

Material	Density Kg/m^3	Poisson's Ratio	Elastic Modulus (GPa)	Tensile Strength (Mpa)	Yield Strength (Mpa)
Aluminium	2700	0.3	68.9	310	65
Aluminium composite	1700	--	700	260	44.2

F. Lamination

Then samples for laminations were prepared by applying bonding material (araldite) to the corrugated wire mesh and then assembling the layers over each other one by one according to the laminate structure. All specimens were cured at room temperature for 15 hours. Some samples of corrugated core sandwich panels fabricated using the present technique are shown in figure 2.5.

Figure 2.5 Samples of CWML Sandwich Panels

G. Experimental testing

1) *Crushing Test:* Crushing test of each specimen of corrugated core sandwich panel was conducted at room temperature using computerised universal testing machine having 60 KN maximum load as shown in Figure 2.5.

The test specimen is put on the rigid floor and a rigid plate is pushed down by the dynamic loading actuator which incidentally is part of the same machine used for the three point bending tests above. The lateral crushing load was increased until the corrugated core is completely crushed so that it behaves as a rigid body. The loading speed was kept at 0.05 mm/sec [1]. The figure 2.7 shows the sample after crushing test.

Fig 2.6 Testing Setup

Figure 2.7 Compressed corrugated core sandwich panel

2) *Bending Test:* To investigate the characteristics of bending behaviour of aluminium corrugated sandwich panels three point bending tests are carried out. Figure 2.8 shows the three point bending test set-up. The experiments were carried out in a quasi-static manner with a loading speed of about 0.05mm/second using the computerized universal testing machine. The loading

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Panel No.	Panel Name	Strength (KN)	Weight (KN)	Strength/Weight	Comp. strength
1	S	14.3	0.001395	10250.8	1.43
2	C	7.5	0.00120	6250	0.75
3	W	2.1	0.00095	2210.52	0.21
4	SS	13.1	0.001481	8843.524	1.31
5	SW	8.1	0.001393	5814.705	0.81
6	SC	11	0.001197	9191.023	1.1
7	CC	7.9	0.001373	5752.148	0.79
8	CW	6.1	0.001256	4857.926	0.61
9	WW	4.5	0.001373	3276.54	0.45
10	SSS	18	0.001736	10366.45	1.8
11	CCC	15	0.00155	9677.544	1.5
12	WWW	8	0.001383	5783.648	0.8
13	SCW	16	0.00154	10388.46	1.6
14	SWW	14	0.00154	9089.906	1.4
15	SCC	16	0.001658	9650.821	1.6
16	CWW	9	0.001413	6371.05	0.9
17	CSS	17	0.001736	9790.54	1.7
18	WSS	15	0.001619	9266.982	1.5
19	WCC	12	0.001511	7943.127	1.2

system is controlled by a personal computer. The data sets relating the loads and the mid-span deflection of the panel specimen are automatically detected and directly recorded on to the hard disk of the computer in real time as the stroke of the actuator advances.

Table 2.2 Experimental values for crushing test

Figure 2.8 Bending Test Setup

III. RESULTS AND DISCUSSIONS

A. *Crushing Test Results*

Crushing test is performed on Electronic Universal Testing Machine and Load versus deflection behaviour of each sandwich panel is obtained. This results also gives compressive strength of the panel. The test specimen is put on the rigid floor and a rigid plate is pushed down by the dynamic loading actuator which is part of UTM. The lateral crushing load was increased until the core is completely crushed so that it behaves as a rigid body. Table 2.2 shows experimental values for crushing test. We also got load vs. deflection curve for each sandwich panel. One of them is shown in figure (for SCW panel)

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B. Bending Test Results

To investigate the characteristics of bending behavior of aluminum corrugated core sandwich panels, three point bending test is carried out. Figure 4.3 shows the schematic view of the three point bending test set-up. As indicated in Fig. 4.3, the tip of supports and indenter have a round shape with R=20 mm. The respective load vs. deflection curve is shown in figure

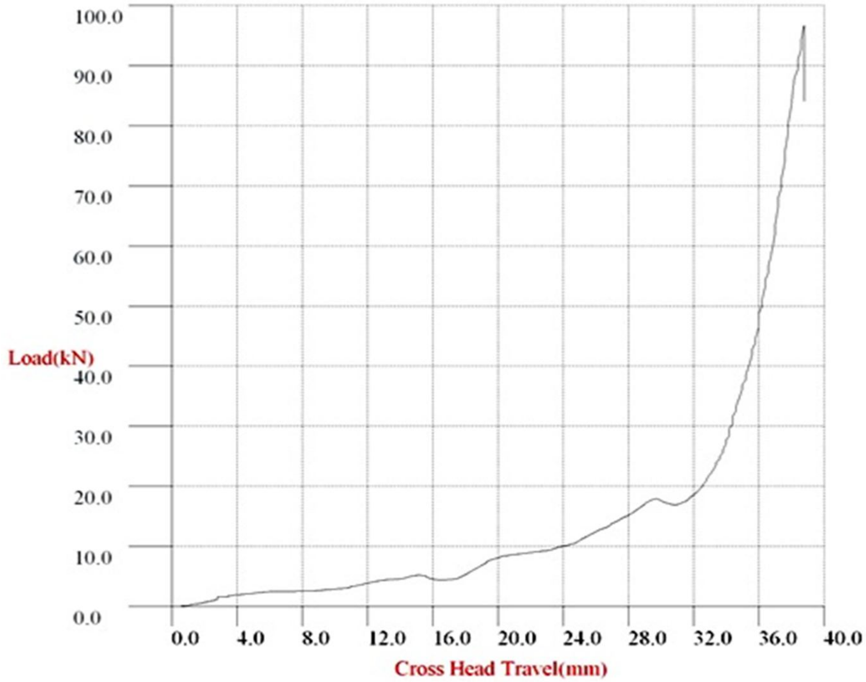
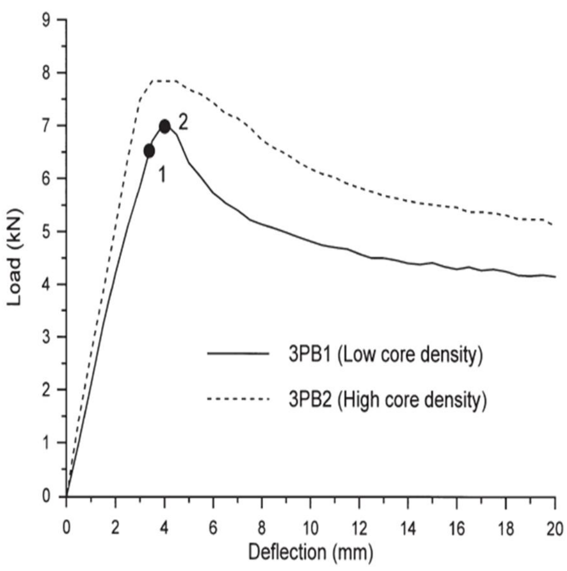


Figure 4.2(m) Behaviour of SCW panel

From the above table it is clear that strength to weight for SCW panel is maximum. So we select this configuration for bending test.



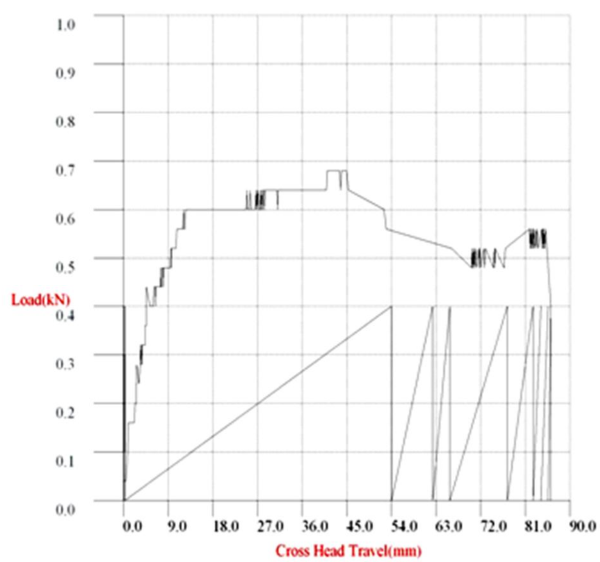


Figure 4.8 Behaviour of honeycomb Panel [2].

Figure 4.9 Results of tested sample.

It has been observed that for same load, deflection is more in second condition. Performance of sandwich panel depends upon various parameters such as number of layers, corrugation angle along with this strength also depends upon bonding type. From above graph it is evident that bending strength varies proportional to deflection in starting phase after some deflection it loses its proportionality and deflection varies largely with respect to load.

C. Comparison Based On Equivalent Core Density

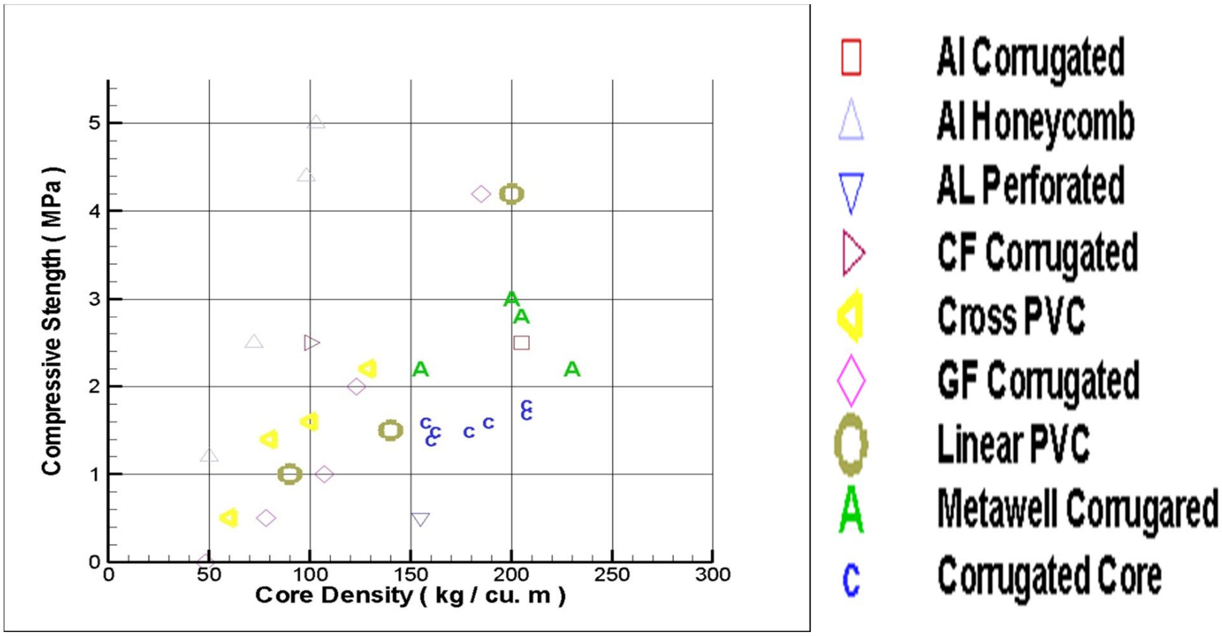


Figure 4.7 Comparison of compression strength of the corrugated-cores with other core types design, as a function of equivalent core density [2].

Core density plays vital role in the strength of the sandwich panels. Hence we have compare the strength of our tested sandwich panel with strength of sandwich panels having various core materials tested before such as AL corrugated, CF corrugated, Cross PVC, GF Corrugated, linear PVC, Metawell Corrugated etc. The mean crushing strength of the honeycomb panel is one of the most important properties on which the energy absorbing capability of the entire structure will depend. For the sandwich, this strength depends on the yield strength of the bare core as well as geometrical dimensions such as cell size and wall thickness. Since the density of the honeycomb is in turn affected by the geometrical dimensions of the honeycomb, the crushing strength also has a strong relationship with the density, as evident from the results of figure 4.7.

III. CONCLUSION

A sandwich construction, which consists of two thin facing layers separated by a thick core, offers various advantages for design of weight critical structures. Depending on the specific mission requirements of the structures, aluminum alloys, high tensile steels, titanium or composites are used as the material of facing skins .Several core shapes and materials may be utilized in the construction of the sandwich. Among them, it has been known that the aluminum honeycomb core has excellent properties with regard to weight savings and fabrication costs. Even if the concept of the sandwich construction is not very new, as so far been applied to the design of light weight structures restrictively. The sandwich panels have primarily been used as non-strength parts of the structures in the last decade. This is due to the fact that there are still various problem areas to be overcome in order to enhance the attractiveness of the sandwich construction, several of which have been or are being solved. The aim of the present study has been to compare the strength of corrugated core sandwich panel with the strength of honeycomb sandwich panel. For that purpose, a series of strength tests, namely three point bending tests and lateral crushing tests were carried out on aluminum corrugated cored sandwich panel specimen. Based on the results presented, the following conclusions can be drawn. From the crushing tests on the corrugated core sandwich panel specimens under lateral crushing loads varying the pattern of perforation and number of layers, it is seen that the number of layer is an influential parameter on the crushing behavior of corrugated core. As would be expected, however, the spacing between the pattern is a critical variable affecting the crushing strength of sandwich panels subject to lateral pressure loads. A substantial increase in crushing strength for the specimen can be obtained by facing skins when compared with the tests for the bare honeycomb core. This would appear to be from the stabilizing effect of the facing skins during the process of crushing. The compressive properties of the corrugated core sandwich panel were compared with those of conventional honeycomb core, composite corrugations and foam material. It was found corrugated core sandwich panel offer properties similar to those exhibited

by more conventional core structures such as linear PVC and Met well corrugations. The compressive properties were not matched well with those of honeycomb core. The reasons why comparison are not matched well and how it can be improved are as follows:
Fabriation of corrugated core sandwich structure is handmade and hence they are not made perfectly.
Also the strong material can be used which can improve the compressive strength of structure.
The bonding of different layers was done by hand. The strength of the structure can be increased by using different bonding technique.
From three point bending test on the aluminum honeycomb core sandwich panel specimen, it was observed that with an increase in the thickness of honeycomb core cell, the start of plastic deformation could be delayed, resulting in increase of ultimate strength. But when we compared the strength of the corrugated core sandwich panel with the strength of honeycomb core panel the deformation for same load comes more due to bonding method. We can improve it by changing the bonding method of sandwich pal.

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