MECHANICAL PERFORMANCE OF CORRUGATED SANDWICH SLABS IN FOUR - POINT BENDING: ANALYTICAL INVESTIGATION

Kavya K, Nithin Mohan

Abstract— In this paper, a new generation of composite sandwich slab was proposed as a solution for the rehabilitation of slabs in old masonry buildings. An innovative solution was developed using Glass Fiber Reinforced Polymer (GFRP) material formed by three components: Top and Bottom GFRP face sheets, GFRP stiffeners. Different types of slabs using different geometric orientation was studied and their behavior was assessed under flexural loading. The results showed that the developed hybrid sandwich slabs accomplish all design requisites and assure a stiffness/dead-weight and load capacity/dead-weight ratios much higher than conventional structural slab systems. And the most effective geometrical parameter for the slab was also found.

Index Terms— Sandwich,Slabs,Structural,GFRP,Flexure loading,Stiffness,Geometry

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1 INTRODUCTION

Sandwich structure consists of stiff, thin face sheets and a light weight core. The face sheet is selected from the materials of high resistance to bending and stretching loads. The front and back face sheets are usually constructed from the same material with the same thickness. However, different face sheet materials or thicknesses may also be used in a single sandwich structure in the presence of specific loading conditions. Core material is considered to be the most critical part, as it greatly affects the overall performance of a sandwich structure. The crushing strength of sandwich structures is directly related to the resistance of the core to the applied loads in through thickness direction. The core structure is also required to withstand transverse loads that can cause core buckling/bending. Cores are usually selected between the lightweight or low-density materials or structures such as balsa wood, metallic and synthetic foams, honeycomb and corrugated structures.

The core and face sheets are bond to each other using a thin layer of adhesive. An additional weight is generally applied to sandwich structure to create an uninterrupted contact between face sheets and core and the whole structure is cured. During curing process, a stiff resin creates a strong bonding between core and face sheets. The selected adhesive has also significant effects on the mechanical performance of sandwich structure. Adhesive material has to be stiff enough to carry bending and shear loads without leading to any separation between sandwich components. A variety of metallic core materials have been investigated, particularly aiming at improving the impact resistance of sandwich structures, including aluminum foams and honeycombs.

Corrugated structures are relatively new groups of materials, which offer overall strength and mechanical performances comparable with those of metal foams and honeycombs.

Corrugated structures can be made of paper , composite and metallic materials .The core between the liners, also called fluting, provides cushioning to the structure to be protected. The processing route for corrugated structures enables them to be manufactured in intricate geometries with relatively homogeneous macro-structures . The most widely investigated topologies include V-type , U-type , X-type (diamond) and Y-type. The schematics of various corrugated topologies including straight, trapezoidal, V-type and curvilinear are shown sequentially in Figures 1.

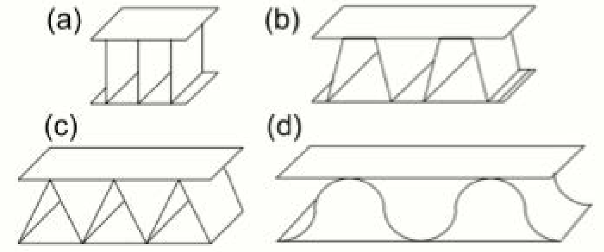

FIG.1.TYPES OF GEOMETRY

2 METHODOLOGY

The innovative hybrid GFRP sandwich slabs proposed in the present paper have a GFRP laminate on the bottom tension skin. Shear stresses in the proposed new hybrid sandwich panel are transferred by both GFRP ribs and foam core, and it was expected that most part of the stress was carried out by the GFRP ribs. Another important aspect related to the sandwich slab is the adhesive bond between the foam and the skin layers. This adhesive bond was introduced for enhancing the transference of shear forces between layers, by contributing in this way for the desired composite action. According to the aforementioned reasons, these structural elements can also be used in other applications like walls or roofs, where a combination of relatively high flexural stiffness and low dead weight justifies the use of constituent materials of higher price than traditional ones.

TABLE 1
DETAILS OF SPECIMEN

Specimen	L (mm)	d (mm)	h (mm)	t_s (mm)	t_w (mm)	V(m^3) $*10^{-4}$
FPB-rect	1000	225	50	3.2	2.0	5.6
FPB-tri	1000	225	50	3.2	2.0	5.6
FPB-trap	1000	225	50	3.2	1.6	5.6
FPB-rect	1000	225	75	3.2	1.6	7.3
FPB-tri	1000	225	75	3.2	2.0	7.3
FPB-trap	1000	225	75	3.2	1.6	7.3
FPB-rect	1000	225	100	3.2	1.6	8.5
FPB-tri	1000	225	100	3.2	2.0	8.5
FPB-trap	1000	225	100	3.2	1.6	8.5

Each component can be considered as relatively weak by itself, but together they provide a strong and lightweight structural system. Furthermore, to ensure proper transfer of stress from the GFRP skin through GFRP rib, the connection zone between GFRP skin and rib was further improved with a rounded transition. The main aim of the present study was to obtain the force-displacement curves of corrugated sandwich panels with different geometry and configuration under flexural loading and thereby propose the innovative hybrid sandwich panels.

2.1 Discription of specimen parameters

In this study, nine specimens were modelled. The GFRP and HS-2101-G100 unsaturated polyester resin were used for face sheets and corrugations.Table 1 lists the geometry of the components forming the sandwich panel developed. All the nine specimens were identical in length, width and face sheet thickness.

TABLE 2
MATERIAL PROPERTIES

Mechanical property	Value
Modulus of elasticity (GPa)	20.9
Poisson's Ratio	0.5
Tensile yield Strength (MPa)	322.9
Compressive yield Strength (MPa)	55.3

2.2 Finite Element Modelling

The corrugated sandwich panels were modelled using the finite element (FE) code ANSYS/WORKBENCH, which allows simulating nonlinear large deformation effectively.

To reduce the complexity of geometry in the finite-element modelling(FEM) simulation, the size of the model was reduced by applying symmetry planes. As a result, a geometrical model with a lower number of elements, which leads to a lower numerical computation and a shorter processing time, was generated. Here, two planes of symmetry were applied to the sandwich panel on the longitudinal and transverse centrelines and divide the model in to four equal sections(FIG). The shaded section shows the quarter model, which was analysed in this study. Fig exemplifies some FE models for different configurations of corrugated sandwich panels.

TABLE 3
DETAILS OF SPECIMEN-VARYING WEB THICKNESS

Specimen	L (mm)	d (mm)	h (mm)	t_s (mm)	t_w (mm)
FPB-rect	1000	225	100	1.6	1.6
FPB-rect	1000	225	100	1.6	2.0
FPB-rect	1000	225	100	1.6	2.4
FPB-tri	1000	225	100	1.6	1.6
FPB-tri	1000	225	100	1.6	2.0
FPB-tri	1000	225	100	1.6	1.6
FPB-trap	1000	225	100	1.6	1.6
FPB-trap	1000	225	100	1.6	2.0
FPB-trap	1000	225	100	1.6	1.6

Both face and core sheets were made of GFRP, which was characterized as a orthotropic material with material properties listed in Table

The core and face sheet were meshed using SHELL 181 element with plane stress condition. Thickness of core was assumed to be normal along its length. This rectangular element with four nodes and 6 degrees of freedom at each node can be used to analyse thin to moderately thick shell structures. Although SHELL 181 is a two-dimensional element, the sheet thickness can be added to the element properties through the real constant feature in ANSYS. The displacement of all nodes located on the symmetry planes were restricted to in-plane movements, and there was no translation perpendicular to the plane of symmetry.

Based on the test setup used by Tan et al. (1989), the sandwich panel is assumed simply supported on all sides. Face and core sheets are prevented from penetrating each other by defining contact areas. Each contact pair, which is considered to be surface to surface, consists of target and contact elements. Element CONTA174 is located on the surface of the shell elements to represent contact and sliding between the target surface and a deformable surface. Contact occurs when the contact element surface penetrates in to one of the target segment elements on a specified target surface. The target surface is discretized by a set of segment elements, TARGE170 and is paired with the associated contact surface.

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3 RESULT

3.1 Failure Mode

The macroscopic failure modes of specimen found can be categorized in to two types,which are :

(1) top face sheet compressive failure
(2) core rib failure.

3.2 Influence of web thickness

The test results are presented along with discussion on the influence on the influence of various parameters on bending behaviour of specimens.The bending load, deformation,and initial bending stiffness are summarized in Table

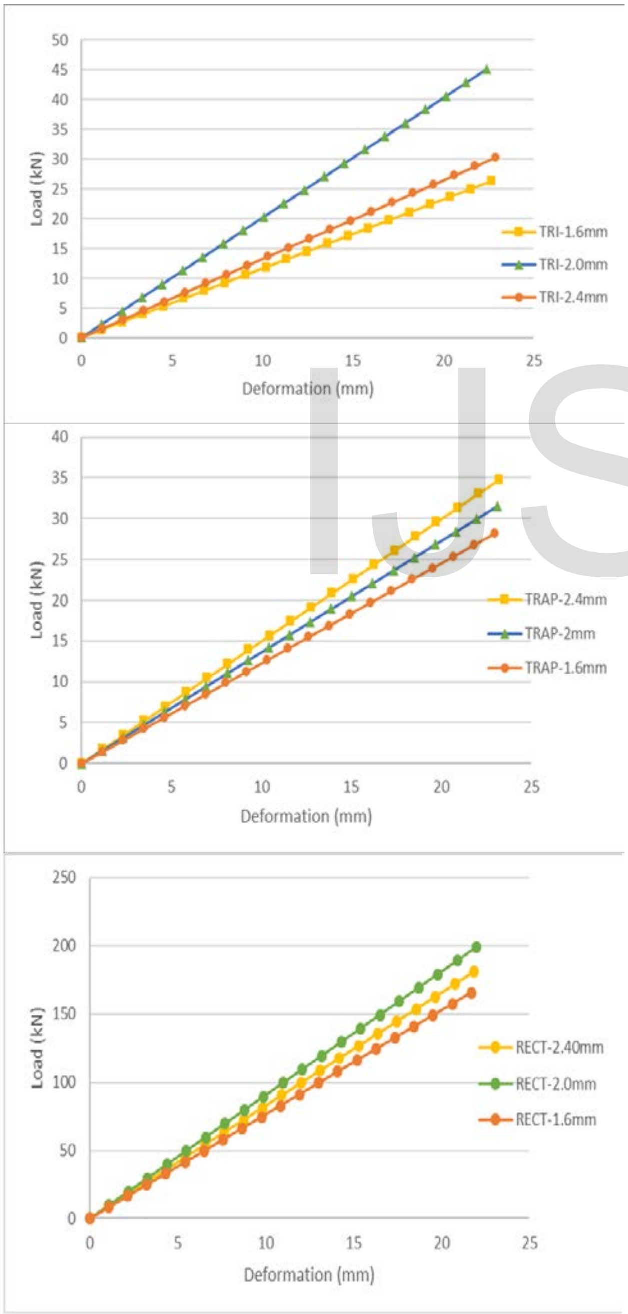

Fig. 2. Influence of web thickness

TABLE 4
STIFFNESS

Specimen	h (mm)	t_w (mm)	Stiffness (kN/mm)
FPB-rect	50	1.6	1.4
FPB-rect	75	1.6	3.14
FPB-rect	100	1.6	3.75
FPB-tri	50	2.0	1.00
FPB-tri	75	2.0	2.40
FPB-tri	100	2.0	4.67
FPB-trap	50	1.6	2.00
FPB-trap	75	1.6	4.57
FPB-trap	100	1.6	6.33

3.3 Influence of web height

Three web heights (50mm,75mm,100mm) were adopted to investigate the influence of web height on bending strength. It can be found that the ultimate bending strength of specimens increased with the increase in web height. Hence it can be concluded that increasing the web height can obtained a larger moment of inertia, then the bending stiffness of a panel can be enhanced.

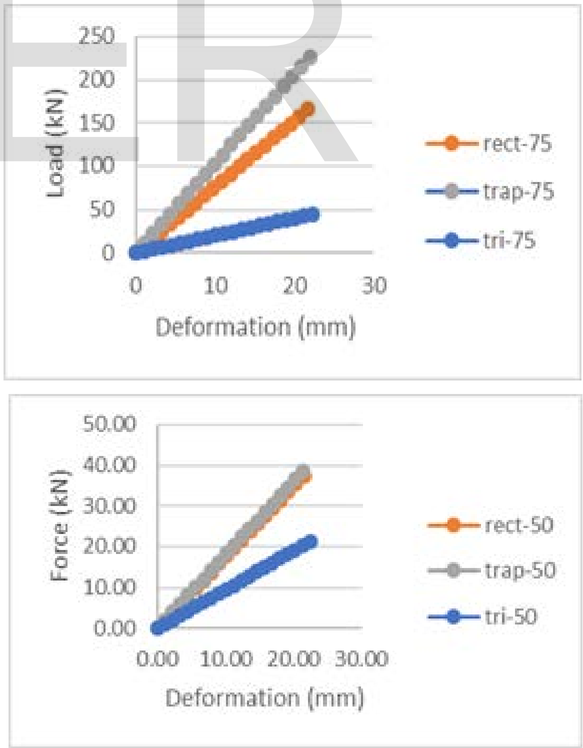

Fig.3.Influence of web height

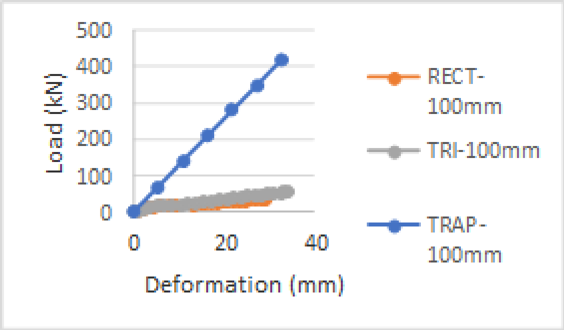

Fig. 4. Influence of web height

3.4 Influence of buckling load and bending load

Buckling and bending load was calculated in order to study,out of the two loads which load was having more influence on the panels. For this the buckling study was performed, where the corresponding deformation at which buckling load was acting was calculated and the result was compared with the bending load and its corresponding deformation.

Obtained result shown in table 5 and the corresponding graph was also drawn. From which it can be concluded that out of the three geometries all of them except the rectangle with web height 100 mm , triangle with web height 100mm showed the effect of buckling.Trapezoidal model had no influence on buckling.

TABLE 5
BUCKLING AND BENDING LOAD LIMIT

Specimen	t_w (mm)	h (mm)	Bending Load (kN)	Buckling Load (kN)
FPB-rect	1.6	50	8	25
	1.6	75	9	22
	1.6	100	14	18
FPB-tri	2.0	50	4	8
	2.0	75	8	13
	2.0	100	15	10
FPB-trap	1.6	50	13	27
	1.6	75	19	24
	1.6	100	16	16

3.5 Influence of web spacing

Fig5 shows the comparison of load-mid span deflection curve of Rectangular Specimen,which were used to evaluate the influence of web spacing on ultimate strength and initial bending stiffness.The yield strength of specimen RECT-2mm-1 and RECT-2mm are 42kN and 40 kN respectively.Their difference can be considered negligible.The reason of this phenomenon was that although the web spacing of specimen Rect-2mm was larger than that of specimen RECT-2mm-1, the thickness,height and number of web was not changed,in other words,the volume ratio of web to the panel was fixed.Hence ultimate bending strength was hardly affected by web spacing.

TABLE 6
INFLUENCE OF SPACING

Specimen	L (mm)	d (mm)	h (mm)	spacing (mm)	t_w (mm)	Vol. Ratio
RECT-2mm-1	1000	225	100	75	2.0	0.5
RECT-2mm	1000	225	100	123	2.0	0.5

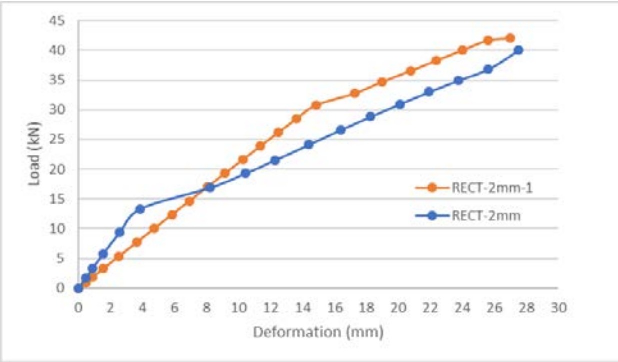

Fig. 5. Influence of web spacing

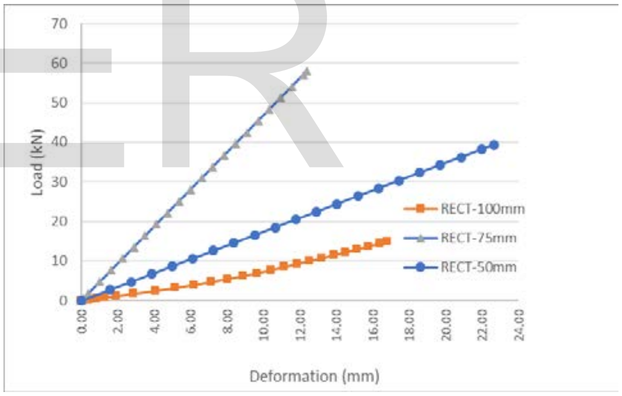

Fig. 6. Influence of web height in triangle specimen

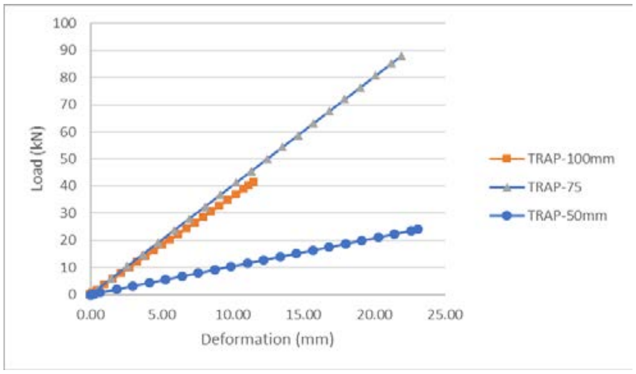

Fig. 7. Influence of web height in trapezoid specimen

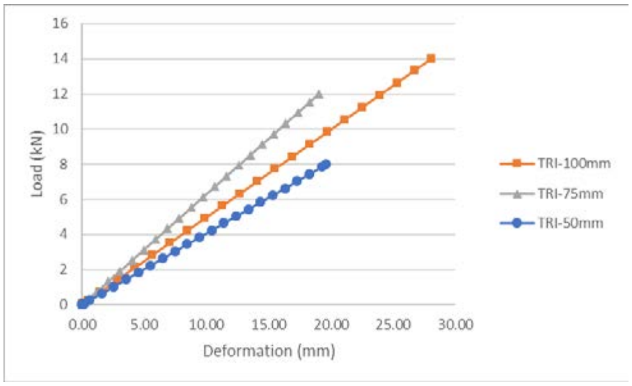

Fig. 8. Influence of web height in triangle specimen

4 DISCUSSION

This new type of sandwich panels with GFRP face sheet and web core is still under development; the corresponding finite element model will be established to investigate the performance of GFRP webs, and minimum weight design procedure will also be provided after conducting more experimental or numerical testing of specimens. In the meantime, although the anti-corrosion ability of GFRP sandwich panels can be enhanced, the flammability of panels should be researched in future because the mechanical performance of GFRP sandwich panels are affected significantly by the high temperature. Moreover, no matter GFRP panels acting as the bridge decks or slabs, the fatigue issue cannot be ignored in future study.

5 CONCLUSION

This paper presents the analytical studies on the sandwich panels with GFRP face sheets and webs loaded in four – point bending. The main findings of this study are summarized as follows:

(1) The mechanical performance of sandwich panels with GFRP face sheets and rib loaded in four – point bending was studied.

(2) These panels had the characteristics of high bending strength and stiffness, simple construction, and cost effectiveness.

(3) Increase in ultimate bending strength of sandwich panels can be achieved due to the presence of webs.

(4) The web thickness and web height have significant effect on the ultimate bending strength of sandwich panels.

(5) The web height of 75 mm was considered to be optimum for all the three geometries.

(6) When web height was fixed for all three geometry better load carrying capacity was shown by Trapezoid stiffeners.

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