Study on the Behaviour of Corrugated Core Panels

[1]Banila K Monachan, [2]Serene Sara Simon
[1]PG Student, [2]Assistant Professor
Department of Civil Engineering,
Amal Jyothi College of Engineering, Kanjirapalli, Kerala, India

Abstract:* *The demand for light weight sandwich panels are becoming increasingly important as multi-functional components in many areas. The tremendous need of these light weight modular structures have application in bridge deck slabs, partition walls, roof slabs etc. Corrugated core sandwich panels can be defined as a sandwiched composite structures in which a corrugated core is sandwiched between a top and bottom face sheets. One of the main characteristics is their high stiffness to mass ratio under bending conditions and also good impact resistance. This study mainly focuses on the analysis of corrugated core sandwich panels, wherein, investigation is performed to determine the effect of geometric parameters on the mechanical behavior of the corrugations on the panel by utilizing different materials. Static, dynamic and buckling analyses of corrugated core panels were conducted and its applicability in bridge deck were presented. The use of different types of core shapes and addition of different material properties results in variation on deformation and shear force of the panels, and also helps to find out performance of panels on different loading condition. Transient analysis were performed on the bridge deck panels to find the effect of moving loads. The results revealed that z core corrugated sandwich panel shows less deformation and more stress compared to other shapes. The studies were performed using ANSYS 16.

***Index Terms* – Corrugated core sandwich panels, bridge deck**

I. INTRODUCTION

The demand for lighter and modular structures is increasing in recent years due to some driving factors in construction projects such as tight scheduling, labour, management and overall cost. For instance, in any construction project, reducing the required man hours on site is highly favourable for construction companies and also more economical. Furthermore, the use of prefabricated modular structures leads to lesser construction workers on site and instead, longer fabrication time in shop which is translated to less cost. Moreover, specifically in bridge construction projects, regarding the renewal of aged and deteriorated bridges, the installation of modular superstructure components definitely helps minimize the disruption to public transportation.

Sandwich panels becoming increasingly important as multifunctional components in many areas. One of the main characteristics is their high stiffness to mass ratio, especially under bending conditions. This property strongly depends upon the properties of the two face sheets. The properties such as thermal, acoustics etc. are governed by the properties and materials used in the core. For this reason several cores are generally available such as foams, honeycombs, cellular, trussed, corrugated etc. Among all these sandwich panels, corrugated core are being increasingly used. There are different types of core shapes adopted including triangular, trapezoidal, circular etc.

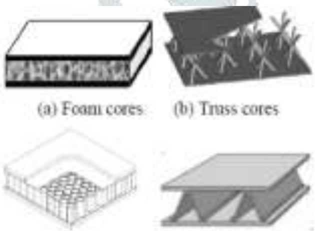


Fig 1.Sandwich panels with different cores

Fig 2 Sandwich panel installation as bridge deck

A. Application of corrugated structures

The wide application of corrugated structures in civil engineering may be classified mainly as: beams with corrugated web, corrugated roofs and walls and corrugated pipes.

1) Beams with corrugated web

The main benefit of applying corrugated web beams in supporting roofs, floors and columns in steel structural buildings are that the corrugated webs increase the beam's stability against buckling. Applying these corrugated web beams in the components of the building results in a very economical design by reducing the required web stiffeners and leads to a significant weight reduction in these beams compared with hot-rolled or welded ones.

2) Corrugated sheets in roof and walls

Corrugated sheets are among the best candidates for application in construction elements, for roofs, claddings and walls, of modern industrial buildings owing to their high strength to weight ratio, much lighter and lower cost than flat isotropic panels of the same strength. Corrugated metal sheets for instance are frequently used as the roof of buildings that have steep slopes to dispose of rainwater quickly. Their combination of high stiffness and underlying building structures.

3) Corrugated tunnel and pipe

Large metal corrugated pipes or arches are frequently used in tunnel structures to transport the aggregate and ore across various points on their properties. The need to maximize the surface area on such sites necessitates the use of tunnels for transporting bulk materials under roadways and processing these materials. The application of corrugated pipes and arcs in these tunnels offers advantages in the design, installation and operation of these projects such as: reducing the design time and related costs; simplicity of construction which leads into the reduction of installation and maintenance costs.

4) Corrugated bridge decks

The weight of the bridge superstructure also plays an important role in the design and construction of bridge substructure such as girders and piers. Specifically, one of the critical challenges in the design process of a bridge construction is the weight of bridge deck in which any design innovation toward the weight reduction is vital. Therefore, design of a deck structure with minimum possible weight would be an important achievement in bridge construction.

II.LITERATURE REVIEW

Sandwich panels are extensively and increasingly used in civil engineering, where weight is an important design criterion. With the variety of faces and cores, the sandwich panels have wide applications in many fields such as acoustic and thermal insulation and fire safety. Therefore, the sandwich panels have been used commercially in exterior walls and internal partition walls in architectural engineering. Sandwich panels are thin walled structures fabricated from two flat sheets, separated by and attach a core. Many studies have been conducted regarding the properties of sandwich panels. A set of analysis regarding the flexural, tensile, shear and compressive strength of corrugated panels by experimental and analytical methods.

A.Types of sandwich panels

Sandwich panels are commonly classified based on the types of core available. Generally available core include foam filled core, honey comb, cellular trussed and corrugated.

An experimental investigations on the response of metallic sandwich panels with stepwise graded aluminum honey comb core under blast loading Shiqiang Li et.al (2016). Sandwich panels are increasingly exploited as blast resistant structures, that's when subjected to impulse loading the core enables large compressive deformation and absorbs large amount of impact energy and hence increase resistance. From the study, the failure modes of sandwich structures mainly depends on geometric parameters. Two specimens of graded group and ungraded group are used in the tests. The main interests are in the effect of core arrangement configuration on the energy dissipation force and stress distribution of blast load sandwich panels of equal mass.results show that graded sandwich panels display a good blast resistance under a weak blast loading.

Sandwich panels with metallic corrugated cores are widely used for various engineering fields. M. Shaban et.al (2017) conducted analysis of corrugated core sandwich panels with trapezoidal shape. A new analytical approach is developed for bending analysis of corrugated sandwich using energy method. The out of plane properties of corrugated core are obtained based on 3D theory of elasticity. The state space method is implemented along the thickness direction to solve the problem analytically. The obtained results are compared with classic plate theory. Results found that elastic modulus in the thickness direction weakens when increasing pitch and height of corrugation and strength when sheet of core becomes thicker. Also thickness distribution of stress and displacement fields are represented and the influences of dimensionless geometrical quantities are investigated.

Tat-Seng Lok et.al (2005) studied investigated about elastic stiffness properties and behavior of truss-core sandwich panel. In this paper, a truss-core sandwich panel is introduced and its elastic properties are presented. Comparisons of deflection between closed-form solution and 3D finite-element results are good across the range of parameters used. Results show that the truss core panel promises greater flexibility in usage and application

B. Materials used in sandwich panels

The materials used in sandwich panels generally depends upon the purpose of its use. Different studies has been conducted with the use of different materials. The same material can be used for core and face sheets. Sometimes different materials are also used.

A parametric study on the mechanical response of corrugated core sandwich panels for bridge decks was conducted by Mehdi Tehrani et.al (2017) .In this study a concrete deck is suggested to replace with corrugated core steel sandwich panels for small bridge deck applications.

Daniel Way et.al (2016) investigates about evaluation of a wood-Strand molded core sandwich panel. The goals of this study were to generate details on structural performance of the product, validate the design, and provide suggestions for future product development. Results indicate that this molded-core panel performs particularly well in flexure while connection properties had the largest scope for improvement. Flexural, in-plane shear, flatwise compression, mechanical connections, and small-scale shear wall properties were investigated. Results suggest that this particular panel design was most efficient when loaded in flexure.

Steel sandwich panels with web-core configuration in which face sheets are attached to the core by the application of laser welding are significantly effective in bending loading in comparison with stiffened plate structure applied in ship manufacturing industry Klanac et.al (2004). The main reason of the high stiff structure is due to the positioning of web-core material far from neutral axis. By the application of the hollow structure sandwich panel as a component in a larger structure, such as a bridge deck, the obtained benefits can be considerably noticeable. The sandwich panels with periodic core geometry have been developed by the use of fabrication techniques such as casting and forming.

An innovative aluminum sandwich panel with sinusoidal corrugated core is investigated by Macro Pierani et.al (2014). In this study elastic equivalent properties of corrugated sandwich panels was studied.

Ganiy Akhmet et.al (2017) discussed about the elastic properties of adhesively bonded corrugated core sandwich panels.Elatisic constants with adhesive layer distortion have been derived and presented in this paper. By submitting these elastic forms in a closed solution. Response of simply supported sandwich panels under uniform load with small deflection is calculated.by submitting these elastic constants in to closed form solution, the response of simply supported sandwich panels under uniform load with small deflection is calculated which agrees well with 3D FEM analysis. Also with the elastic constants, the effects of adhesive layer thickness and its elastic modulus on both transverse shear stiffness with different shapes and dimensions are further studied and discussed.

II. SCOPE AND OVERVIEW

Aim of the study is to analyze the corrugated core sandwich panels and its applicability in bridge deck with different materials.

A.*Objectives*

- To investigate the behavior of different core shapes used in sandwich panels
- To study the maximum deflection and maximum shear force of panels with different materials such as aluminium and CFRP

B. Methodology

- Creating finite element models with different core shapes
- Evaluating the maximum deflection and shear force

- Modelling of bridge deck using the better core shape
- Find maximum deflection and shear force with other material also
- Obtaining final results

III.MODELLING AND ANALYSIS

A.Parametric Study

Modelling using ANSYS software. The flexural properties of the corrugated sandwich panel highly depend on the panel cross-section geometry where several parameters influence its behavior. Based on the application of the sandwich panels, core geometries for the panels can be designed in a variety of forms and shapes. In the present study the corrugated core sandwich panels were modelled to study different parameters which affect the behavior of panel. In this study the parameters such as shape of corrugations, face sheet thickness, length of the panel etc. were studied by static analysis. Static analyses were carried out to find the deformations and shear stresses of panels. Based on the previous studies mainly six types of cell configurations for cores were selected for the study as shown in the fig. below

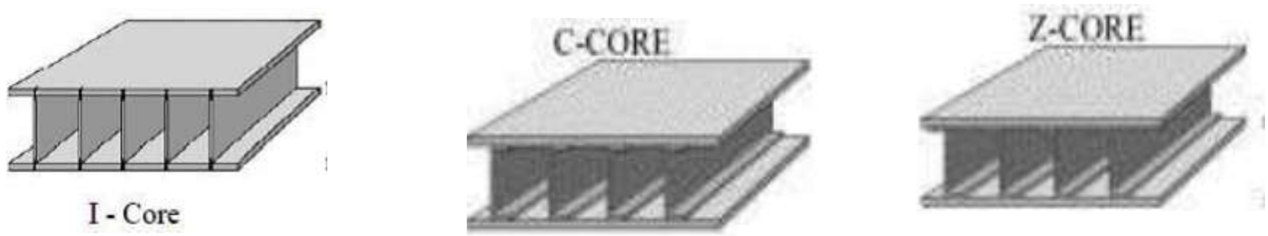


Fig .3 Different Core Shapes

1) Modelling

A typical corrugated core sandwich panel with length 1000mm, width 400mm and height 70 mm modelled in ANSYS 16. In this corrugated core has thickness of 2mm and spaced in 80mm.The face sheet has a thickness of 4mm. Panel with different core geometries were created to study the effect of geometry. In order to study the effect of parameters on the deformation a shear stress of the corrugated core sandwich panels, static analysis of models were carried out. Parameters such as core shape, face sheet thickness, panel length were varied and model were created. The panel was fixed supported. The uniformly distributed load of 10 kN/m^2 was applied.

Table 1.variations in geometry for modelling corrugated panel

Face sheet thickness	4mm	8mm	16mm
Panel length	1m	2m	3m
Core geometry	Z core	I core	C core

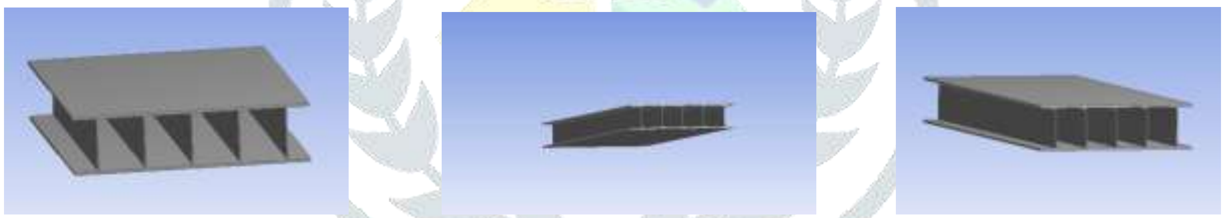


Fig 3.Models with different core shapes

Effect of face sheet thickness

The face sheet thickness of corrugated core sandwich panels is varied as 4mm,8mm,16mm .The panel length are kept constant as 1m . The spacing between cores are kept constant as 80mm and thickness of core as 2mm. Static analysis was done. Deformation and shear stress values are noted

Effect of panel height

The panel height is varied as 1m, 2m, 3m. The face sheet thickness are kept constant as 4mm. The spacing between cores are kept constant as 80mm and thickness of core as 2mm. Static analysis was done. Deformation and shear stress values are noted.

2*) Materials used*

Different types of materials are used for the analysis of sandwich panels. Sandwich panels with different materials are available now a days. Commonly used type is structural steel. Some of the type have same material for face sheets and cores. But for some type materials used should be different for cores. In the present study same type of materials are used for face sheets and cores. The face sheet and core is composed of aluminum. The material properties used for model was given below.

Table 2. Material properties of aluminium

Materials	Properties	
Aluminium	Density (g/cm3)	2.77
	Poisson’s ratio	0.33
	Young’s Modulus(GPa)	71.2
	Shear modulus(GPa)	26.692

B. Corrugated panel as bridge deck

In this section, studies carried out on corrugated core sandwich panels used as deck slab. Corrugated core panels with different core geometry was analyzed in ansys 16 to find out best suitable geometry for bridge deck. Transient and static analyses were carried out to study the behavior of panel. Panel with different material combinations were modelled and analyzed to find out best material for corrugated core panels. Corrugated core sandwich panels with different materials and core geometry were taken for the analysis. In earlier studies steel was used. Hence in this study, carbon fibre reinforced polymer (cfrp) and aluminium were selected as material for modelling the corrugated core panels. The material properties used for the model was

Table 3.Different materials used

Material	CFRP	Aluminium
Density	1.58	2.77
Poisson's ratio	0.25	0.33
Young's Modulus(GPa)	145	71.2
Shear modulus(GPa)	4.8	26.692

1) Loads acting on Bridge decks

The loads imposed on bridge deck include dead load, which includes the self-weight and weight of future surface wearing course, and the live load imposed in the form of wheel load. A uniformly distributed load of 10 kN/m^2 was taken as dead load for future wearing course on the entire panel. These loads should be factored up suitability to account for impact and variation in material properties. The deflection produced by this factored load must be less than the limiting value of deflection. As per IRC 6 recommendation for single lane bridges class A wheel load of 57kN was considered as the live load. The deck panel were loaded to a factored load of 83kN (wheel load of 57kN + 30% of impact factor +DL of future wearing surface). The bridge deck panel was simply supported over short spans and a rectangular patch load that represents IRC class A wheeled vehicle was applied over patch area of 500 mm x250 mm. The analysis was carried out in both static and vehicle moving condition.

In the case of small bridge deck, the load limit was considered based on the light weight vehicles passing over the bridge. The traffic pattern was assumed as single lane at each direction.

2) Geometry of bridge deck

For studying the behavior of corrugated core sandwich panel as bridge deck panel, a panel with width, length and height 2120mm, 6000mm, and 107 mm, respectively was selected. The geometry for the sandwich panel and load limits presented in this study was obtained from the experimental work accomplished by Mehdi Tehrani et al.

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 geometric model with a lower number of elements was generated. This leads to lower numerical computation and a shorter processing time. Here, two planes of symmetry were applied to the sandwich panel on the longitudinal and transverse centerlines and divide the model in to four equal sections. It has a size of width, length and height as 1060mm, 3000 mm, and 107mm respectively. To solve the moving vehicular load on the model, a transient analysis was used. Panels were modelled with different core configuration. A panel with solid core was also modelled and analyzed. Transient analysis was done to find out the effect of moving load on the corrugated core sandwich panels. Also, the time step size in each load step was specified to be 0.1s

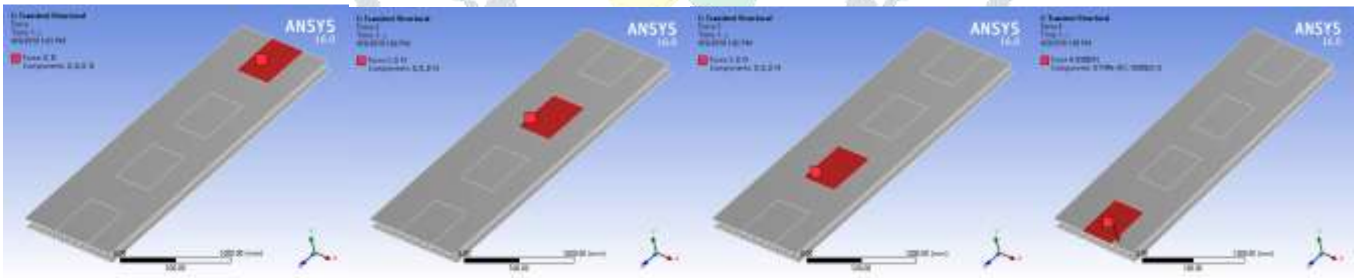


Fig 4. Moving load in deck slab at different time

IV.RESULTS AND DISCUSSIONS

A Parametric study

1) Effect of face sheet thickness

To study the effect of thickness of face sheet thickness on the performance of corrugated core panels, six panels were modelled with different core shapes and the thickness were varied as 4mm, 8mm and 16mm. The obtained results can be tabulated as below,

Table 4 Deformation due to effect of face sheet thickness

Core shapes	Deformation (mm)		
	4mm	8mm	16mm
C core	0.0319	0.0225	0.0072
I core	0.0249	0.0206	0.0073
Z core	0.0350	0.0232	0.00756

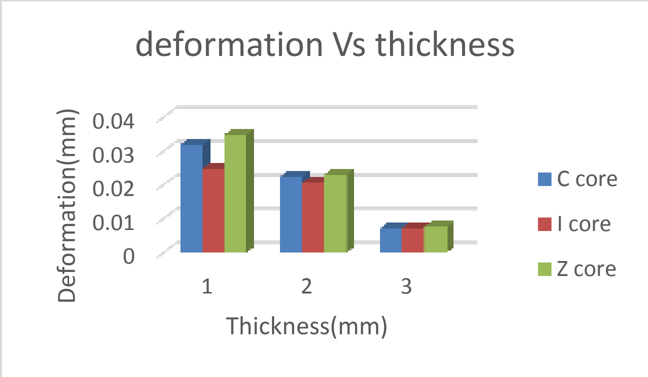


Fig 5. Variation in deformation

Table 5 shear stress due to effect of face sheet thickness

Core shapes	Shear stress(MPa)		
	4mm	8mm	16mm
C core	1.988	1.764	0.795
I core	1.473	1.492	0.740
Z core	1.974	1.745	0.783

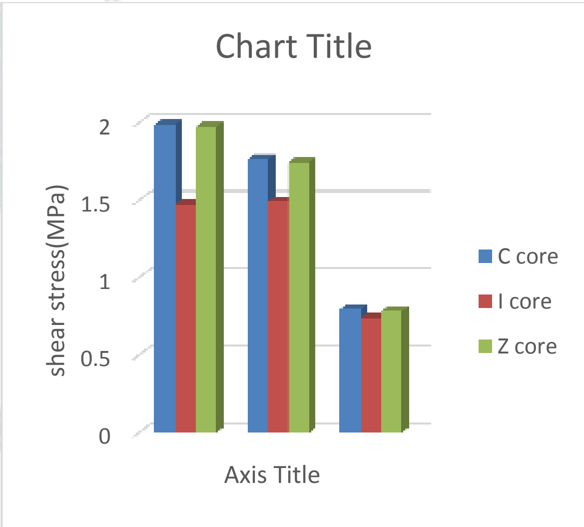


Fig 6 variation in shear stress

B Corrugated Panel as Bridge Deck

In the first part of this study corrugated core sandwich panels with six different cores were analyzed. From the obtained deformation and shear stress it is to be concluded that sandwich panels with z core, c core and I core gives a better performance. Because of this, the three cores were selected for the modelling of bridge deck.

The deformation obtained from static and transient analysis of corrugated core bridge deck panels were compared. Graphical comparison were carried out with deformation obtained using different materials. Corrugated bridge panels with three different core shapes had very less deformation while CFRP used. Aluminium and GFRP shown large deformation

When comparing the shear stress values of corrugated panels with different materials the variation was found little. But the core geometry has great influence on the shear stress values. Z core had more shear stress with less deformation. The comparison of deformation and shear stress of corrugated panels are shown in fig

Table 6 deformation in static and transient analysis

Material	Static structural Deformation(mm)			Transient structural analysis Deformation (mm)		
	Z core	C core	I core	Z core	C core	I core
Aluminium	0.96863	0.96756	1.0331	4.1183	4.010	4.2004
CFRP	0.3399	0.4705	0.5038	1.441	1.5147	2.0492

GFRP	0.9771	1.0887	1.6204	4.1501	5.0337	6.5838
Steel	0.411	0.5601	0.6087	1.651	1.9147	1.4191

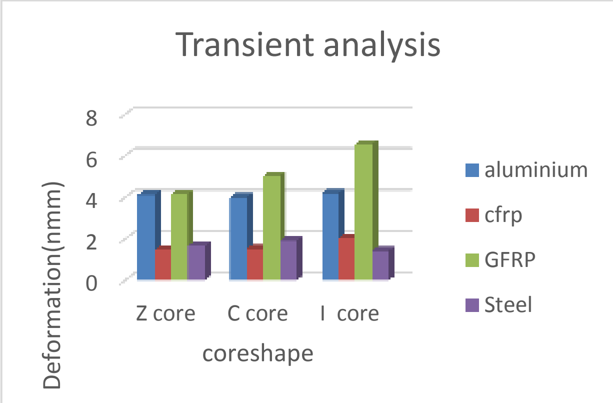
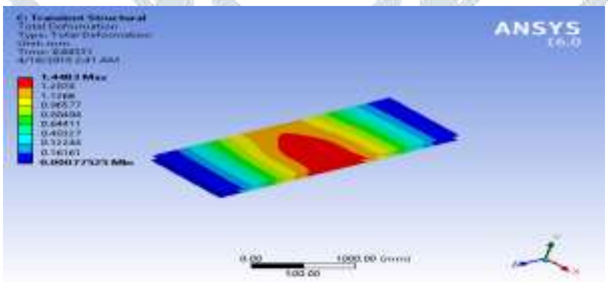
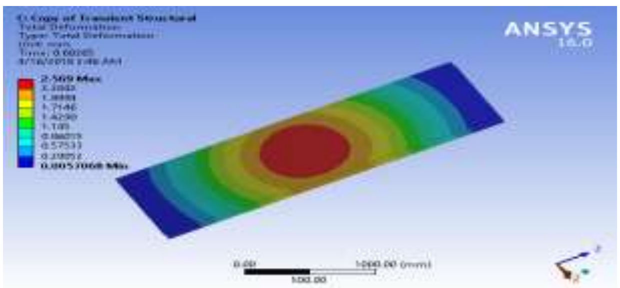


Fig 7:variation in deformation

Table 7 shear stress in transient and structural analysis

Material	Static structural analysis Shear stress (MPa)			Transient structural analysis Shear stress (MPa)		
	Z core	C core	I core	Z core	C core	I core
Aluminium	21.33	19.988	13.27	85.987	77.342	57.68
CFRP	22.482	20.948	13.44	90.677	84.902	58.50
GFRP	22.11	20.62	13.39	89.074	77.414	58.24
Steel	21.693	18.381	13.35	87.387	82.797	58.09





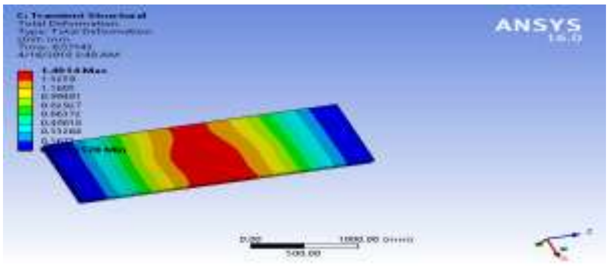


Fig 8 some of deformed models

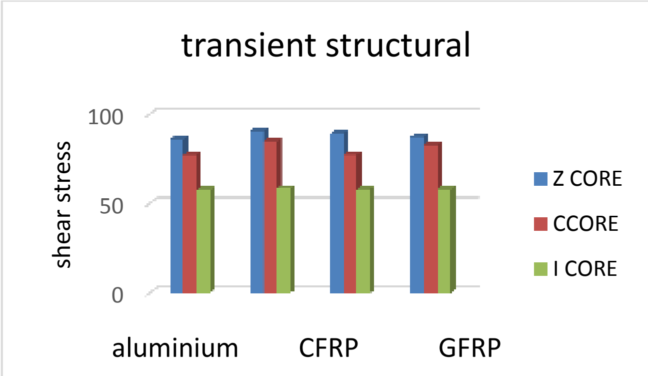


Fig 9:shear stress Vs material types

V CONCLUSIONS

This project work is conducted to investigate the parametric study on the structural behavior of corrugated core sandwich panels and its applicability as bridge deck panel. For the study both static structural and transient structural analysis were carried out with different core shapes. The study which was carried out using ANSYS software was focused on modelled six different core shapes and the static analysis were done by using the properties of aluminum. From this three shapes were selected with better performance and is analyzed for applicability of bridge deck. The following major conclusions were drawn based on the studies carried out under this investigation

- Deformation of the corrugated core sandwich panels decreases with increasing the face sheet thickness and length of the panel.
- The face sheet thickness has not much influence in considering the shear stress.
- From the study it is clear that the z core corrugated sandwich panels have more flexural stiffness and shear strength compared with the others.
- Corrugated core deck panel with CFRP material has high strength among the others due to its material properties.CFRP shows a similar strength and deformation with steel

The study reveals that corrugated core panels structural behavior is mainly dependent on its face sheet thickness, shape of corrugations, gross thickness, length of the panel etc. By increasing the face sheet thickness and core geometry as in a desirable manner, we can improve the stiffness of corrugated core sandwich panels. This panel should be a good option to replace traditional concrete and steel deck panels which has high weight and corrosion.

REFERENCES

1. **Mehdi Tehrani,Farshad Hedayati Dezfuli, M. Shahria Alam, and Abbas S. Milani**(2017) "Parametric Study on Mechanical Responses of Corrugated Core sandwich panles on Bridge Decks*" Journal of Bridge Engineering ,*© ASCE
2. **Jingxi Lui,Wentao He,De Xie,Bo Tao**(2017) " The Effect of impactor shape on the low velocity impact behavior of hybrid corrugated core sandwich structures" *Journal Of composites part b vol: 111 (315-331) Published By Elsevier Ltd.*
3. **Changazia Zhabg,yuansheng Cheng,Pan Zhang,Xinfeng duan,Yong li** (2017) "Numerical Investigations On the Response of I core sandwich panels subjected to combined blast and fragmented loading" *Journal of Engineering structures Vol .151(459-471) Published By Elsevier Ltd.*
4. **M .Shaban,A Alibeigloo** (2017) "Three Dimensional Elasticity solution for Sandwich panels with corrugated coreby using Energy method" *Journal of Thin Walled Structures vol. 119(404-411) Published By Elsevier Ltd.*
5. **Bin Han,Ke-Ke Qin,Qian –Cheng Zhang,Tian Jian Lu,Bing-Heng Lu**(2017) "Free Vibration And Buckling of Foam Filled Composite Corrugated Sandwich Plates Under Thermal Loading" *Journal On Composite Structures Vol :172(173-189)*
6. **Yasser A. Khalifa, Michael J. Tait, Wael W. El-Dakhakhni** (2017) "Out of Plane Behavior of Light Weight Metallic Sandwich Panels" *Journal of Performance of Constructed Facilities © ASCE*
7. **Daniel Way, Arijit Sinha, Frederick A. Kamke, John S. Fujii** (2016) "Evaluation of a Wood-Strand Molded Core Sandwich Panel" *Journal of Materials in Civil Engineering*
8. **Shiquiang Li ,Xin Li,Zhihua Wang,Guiying Wu,Guoxing Lui,Longamo Zhao** (2016) "Finite Element Analysis Of Sandwich Panles With Stepwise Graded Aluminium Honeycomb Cores Under Blast Loading" *Journals On Composites vol :part A 80 pages 1-12*
9. **Krzysztof Magnucki,Ewa Magnucka- Blandzi,Leszek Wittenbeck** (2016) "Elastic bending and buckling of a steel composite beam with corrugated main core and sandwich faces—Theoretical study" *Journal on Applied Mathematical Modelling vol 40 (1276-1286)*
10. **Ehab Hamed**(2016) "Modeling, Analysis, and Behavior of Load-CarryingPrecast Concrete Sandwich Panels" *Journal of Structural Engineering,© ASCE*