Comparative Study on Performance of Precast Structural Insulated Panels with Different Shear Connectors

Ajith M*, Dr. Bharati Raj. J, Dr. Keerthy M Simon

Dept. of Civil Engineering, NSS College of Engineering, Palakkad, Kerala, India

*Corresponding author: aji623@gmail.com

doi: https://doi.org/10.21467/proceedings.112.44

ABSTRACT

Structural insulated panels (SIPs) made by sandwiching an insulating material from both sides have been used in buildings to enhance thermal resistance without loss in structural integrity. New innovations to improve its compositeness are also being explored. One method is to use shear connector made of high thermal resistant and ductile materials. This connects two outer wythes through insulation layer. The outer material can be of any type of high compressive strength concrete. These are usually reinforced with steel or carbon or glass fiber. The use of light weight and high strength materials helps to reduce the overall thickness of the structure. As the material of shear connector acts as a thermal bridge across the outer wythes, materials with low U value (thermal transmittance) are preferred. In this paper, an attempt has been made to carry out a comparative study on the performance of SIPs with shear connectors manufactured using different materials.

Keywords: Structural insulated panels, Shear connectors, Shear tie mechanism, Four-point loading, Non-composite panels, Bonded and unbonded insulation.

1 Introduction

Structural Insulated Panel (SIP) is a composite structural member made by sandwiching an insulating material, by a structural element on both sides. This type of construction has been developed from the early 20th century. The innovation of more efficient materials which could be used as insulation materials, concrete wythes and shear connector led to a new phase in the casting of SIP. This was a good option to enhance thermal resistance without compromising structural integrity. They were constructed in different thickness with most efficient configuration and material of shear connector. Different types of shear connectors, which could be designed as load bearing or non-load bearing structures are readily available in market. Load bearing structures need to be designed to withstand high compressive forces in wythes and shear forces in shear connectors along with flexural forces in the panel. The insulation panels could be un-bonded or bonded to the wythes by means of epoxy resins. They are prefabricated in the factory and should therefore achieve advantages of greater quality control and reduced risk of poor detailing onsite.

Current design guidelines for SIP rely on simplified assumptions for material properties, shear connector engagement and resulting degree of composite action. Materials are selected as per their structural property such as compressive strength, tensile strength, conductivity thermal expansion etc. These properties are available from previous studies and guidelines. The shear connector, connects two concrete wythes through insulation layer. It develops composite action in flexure and provides shear strength. Figure1 shows the cross section of SIP and its main advantages. Table 1 shows the components of SIP.

Proceedings DOI: 10.21467/proceedings.112; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-3-3

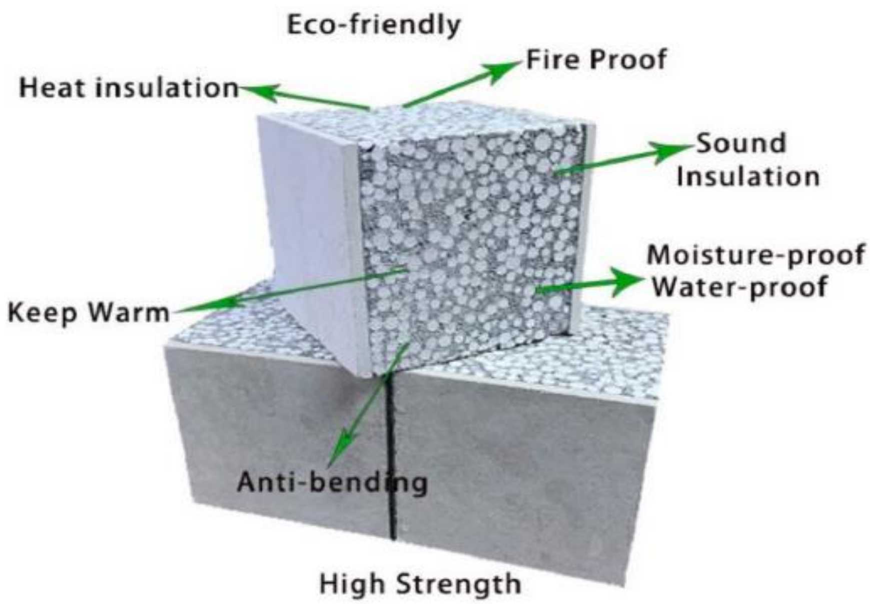

Figure 1: Eco-friendly and waterproof SIP wall [4]

Table 1- Components of Structural Insulated Panel (SIP)

SL NO	OUTER WYTHES	INSULATION	SHEAR CONNECTORS
1	Reinforced Concrete	Expanded polystyrene (EPS)/ Extruded polystyrene (XPS)	Steel
2	Profiled steel faces	Lightweight concrete	Carbon fiber reinforced polymer (CFRP)
3	Reinforced foamed concrete	Mineral wool	Glass fiber reinforced polymer (GFRP)
4	Fiber Reinforced Polymer (FRP)	Polyurethane solid foam	Basalt Fiber Reinforced Polymer. (BFRP)

2 Compositeness of SIP

A composite material is produced from two or more materials of different properties that when merged, create a material with properties unlike the individual elements. In this case, SIP is the combination of different types of structural elements which differ in strength, elasticity and thermal conductivity. The main aim while casting of a panel is to achieve composite action, which indicates that the outer wythe and inner wythe should show equal deformations in all types of loading and minimize the inter wythe slip [7].

Proceedings DOI: 10.21467/proceedings.112
ISBN: 978-81-947843-3-3

Series: AIJR Proceedings
ISSN: 2582-3922

2.1 Composite Panels

In the case of a composite panel, both concrete wythes act together to resist bending. Since shear connector is the main component that determines the compositeness, concrete SIP can achieve full compositeness. Bending moment capacity is calculated by assuming structure as a single section.[7] For full compositeness, the connectors between the two concrete wythes must provide resistance to different types of loads (i.e., axial, eccentric, shear, bending and flexural loads)

2.2 Non-Composite Panels

Two wythes act independently in the case of a non-composite panel to resist the applied loads. Inter wythe slip is high. Bending moment capacity is calculated by assuming the load distribution which is proportionate to the bending stiffness of each wythe.[7]

2.3 Partially composite panels

In actual condition, most of the SIPs fall in the category of partially composite panels. Since compositeness can be achieved by different factors, it is always difficult to reach a state of full compositeness. The degree of compositeness expressed in percentage is calculated by the expression given in Eq (1) [4].

$$K = \frac{I_{exp}+I_{nc}}{I_c+I_{nc}} \qquad \textbf{Eq (1)}$$

K = The level of composite action, %, I_{exp}=Moment of inertia obtained from experimental testing results, I_{nc} = Moment of inertia of non-composite action, I_c = Moment of inertia of composite action.

Eq 2 shows the moment of inertia of a composite section [4]. In the case of non-composite section both wythes are considered as separate structures. Their moment of inertia can be determined separately and added up to total of the structure (Figure 2). The region of insulation panel is not considered since it is an insulation material and do not contribute much to load transfer. In non- composite section, the applied load is transferred to each panel increment of their moment of inertia.

$$I_c = \frac{bt_1^3}{12} + bt_1y_1^2 + \frac{bt_2^3}{12} + bt_2y_2^2 \qquad \textbf{Eq (2)}$$

I_c =Moment of inertia of composite section. b = width of the panel(m), t_1 (m) and t_2 (m) are the thickness of the two wythes. y_1 (m) and y_2 (m) are the distances from the neutral axis (NA) of each individual wythe to the NA of the entire panel.

In composite panels, the total panel behaves as a single structure. Its neutral axis will be in the center of the panel as shown in Figure 3. The structure deflects and deforms in the same rate in both the panels. In the case of strain distribution, the composite panel behaves similar to a reinforced concrete beam. In bending, strain will be maximum at the extreme end from the neutral axis of the section as shown in Figure 4. In non-composite section, the strain plot is separate for both wythes. They both behave as separate beams and have higher strain values at the extreme end of each wythe. The strain in the inner wythe will be maximum in this case. In partially composite section, the strain profile is a combination of both composite and non-composite cases, where the inner wythe slip will be significantly reduced and extreme end strains are similar to the composite section.

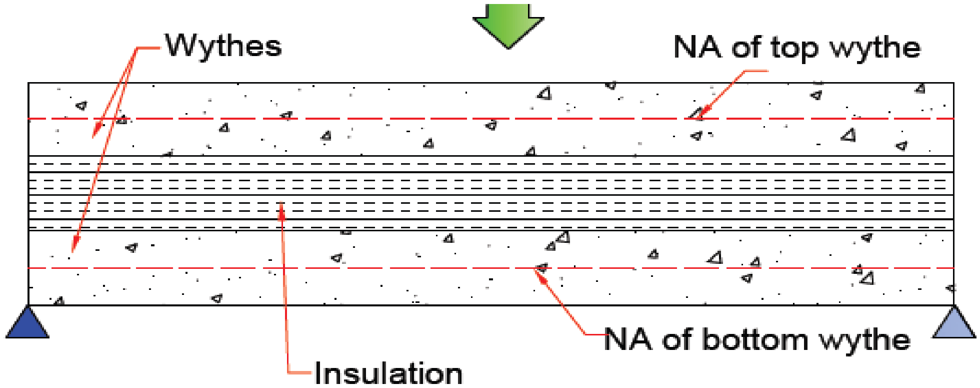

Figure. 2. Neutral axes of a SIP for non-composite cases

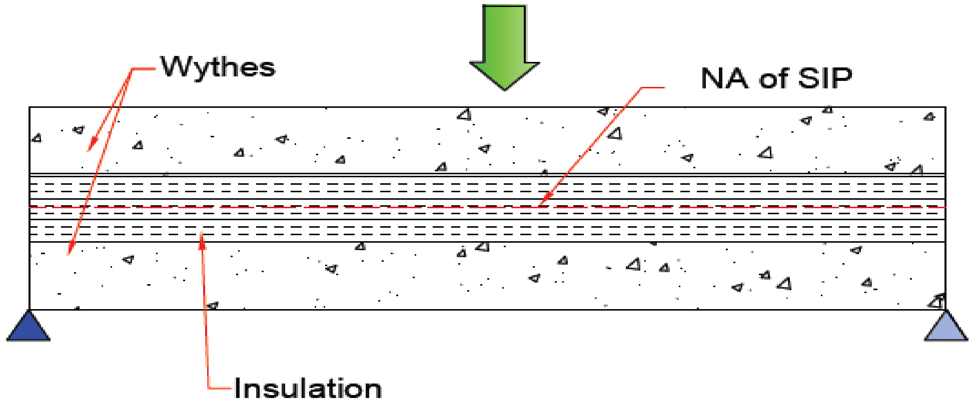

Figure. 3. Neutral axes of a SIP for composite cases

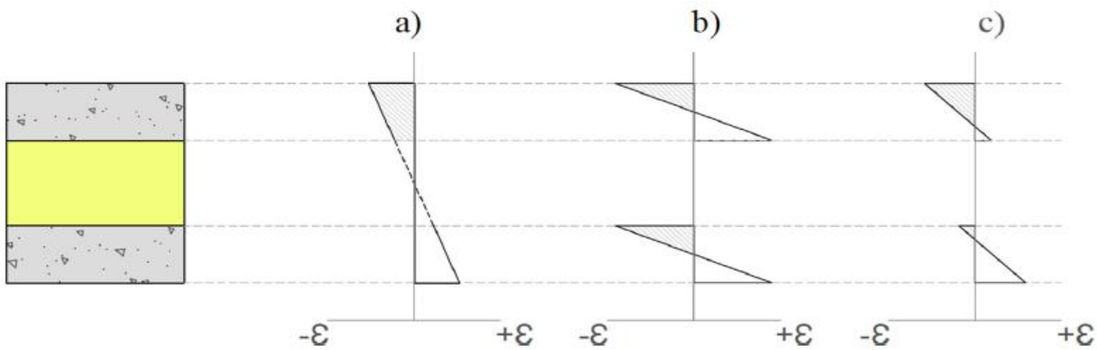

Figure. 4. Degree of composite action displaying approximate strain plots for a) composite b) non-composite and c) partially composite [3]

Figure 5 shows the degree of compositeness of panel configuration 3-2-3 with same wythe material and varying shear connector, insulation and bonding mechanism. It could be noted that the degree of compositeness is 100% for concrete wythe, XPS foam insulation, M ties shear connector and bonded insulation by means of adhesive. Solid concrete shear connector also showed higher compositeness but the thermal transmittance would be high which is less preferable. It was also noted that bonding of insulation to wythes can really increase its performance and also reduce inter wythe slip in case of flexure.

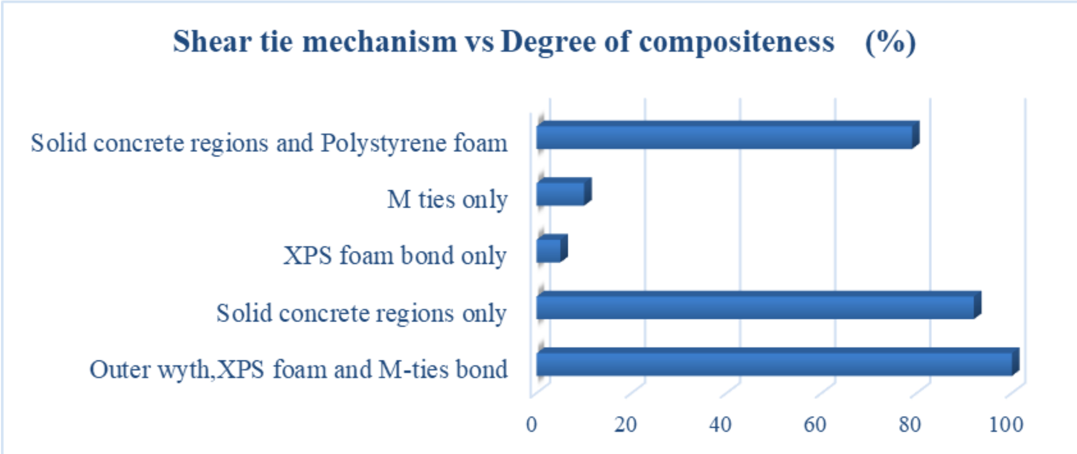

Figure. 5. Degree of compositeness [1][2][3] [4]

3 Material Properties

3.1 Wythe

From Figure 6, it was observed that a maximum compressive strength of 46MPa could be achieved when Self compacting concrete was used. Normal concrete and foamed concrete showed similar results. In recent research, steel was replaced by fiber reinforced polymers, which was found to give more strength thus reducing the sectional thickness.

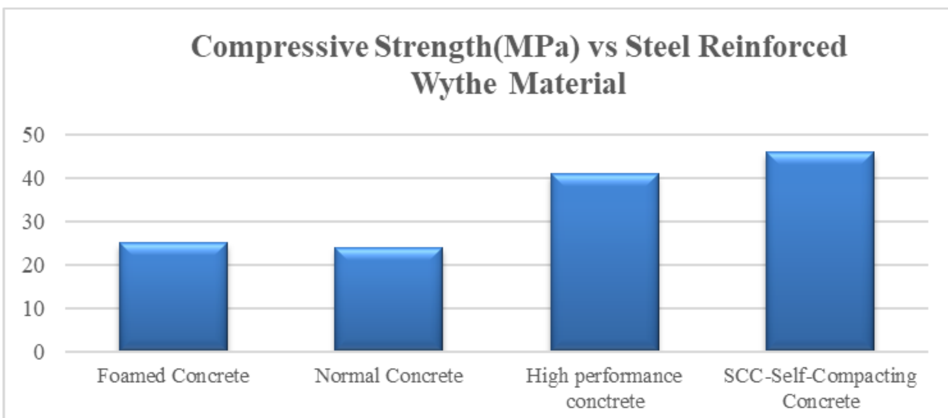

Figure. 6. Compressive strength of different Steel Reinforced Wythe Material [1][2][5][6]

From Figure 7, it could be found that Ultra high-performance concretes (UHPC) with reinforcement as carbon textile or steel fibers yielded good results in compression. All the results were higher than that of concretes reinforced with steel fiber. SCC (Self compacting concrete) and HSC (High strength concrete) with carbon textile as reinforcement exhibited similar results. GRC-Glass Reinforced Concrete, HPFRC-High Performance Fiber Reinforced Concrete, HPC -High Performance Concrete, FRC-Fiber reinforced concrete gave good results which could be used as per availability and cheapness of material. These materials were found to be reliable in reducing thermal conductivity owing to the low U value of fibrous materials when compared to steel. Wythes having high compressive and flexural strength could be used as blast resistant structures [9]. They could be used to protect facades of important structures.

SIPs are also widely used in construction of intelligent homes, which have lesser carbon foot print and greener to the environment [11].

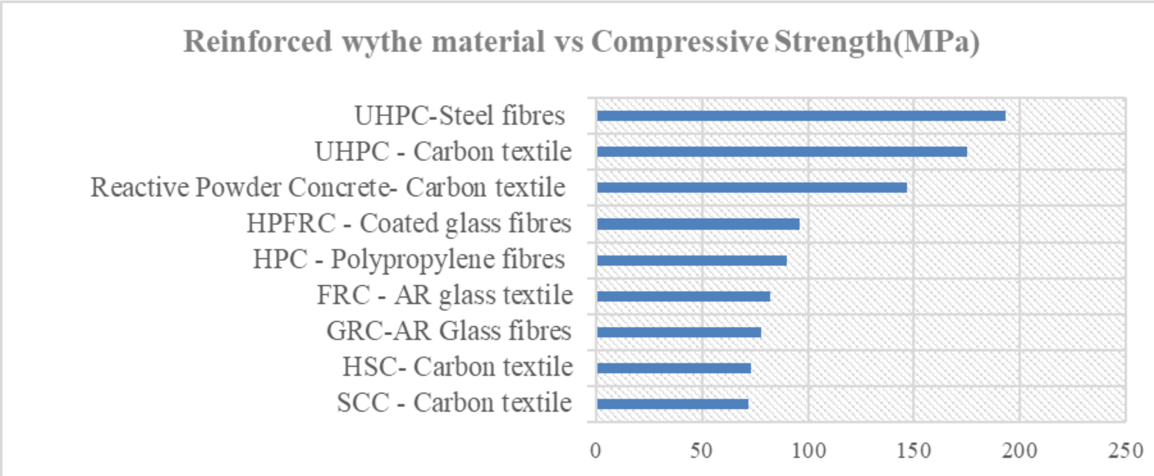

Figure. 7. Variation of compressive strength for special concretes [1][2][5][6]

3.2 Insulation

Materials with low thermal conductivity that can be easily handled with concrete, are preferable as insulation. EPS or XPS are the commonly used insulation material. These are different forms of polystyrene which differ in conductivity and density. For better insulation, materials with lesser conductivity can be used. VIP are highly efficient insulation material which has good resistance to fire. The fire rating of the materials are done as per EN1364-1999 Fire Resistance Tests for Non-Load Bearing Elements. It has a classification from A1(higher ability to withstand fire) to F (poor). The properties of insulation materials are shown in Table 4.

Table 4-Properties of Insulation Materials [4]

SL NO	Insulation type	Conductivity (W/m·K)	Density (kg/m^3)	Fire Rating
1	EPS-Expanded polystyrene	0.034	15	E
2	XPS-Extruded Polystyrene	0.035	38	E
3	PF -Phenolic Foam	0.021	35	B-C
4	PIR -Polyisocyanurate foam	0.025	30	B
5	VIP -Vacuum Insulation Panels	**0.007**	195	**A1**

3.3 Shear Connectors

Shear connectors provide structural shear transfer while minimizing the thermal bridge. The size and material of the connector determines its efficiency. They also determine the compositeness of the panel. They are available in different materials and shapes. Their shape is also a factor which determines the bonding with concrete. Types of shear connectors are concrete connectors, metallic connectors and fibre reinforced polymer connectors [10].

4 Flexural Test Results of Different Panels

Table 5 shows the change in flexural strength of the SIP which are made by the combination of different materials and tested by method of 4-point loading.

Table:5: Flexural Test Results of Different Panels [1]-[6]

<table>
<tr><th rowspan="2">SL. NO</th><th rowspan="2">Overall thickness (mm)</th><th rowspan="2">Wyth material</th><th rowspan="2">Insulation</th><th rowspan="2">Connector</th><th rowspan="2">Reinforcement</th><th rowspan="2">Panel components</th><th colspan="2">Bending moment (kNm /m/width)</th></tr>
<tr><th>at first crack</th><th>at peak load</th></tr>
<tr><td>1</td><td>10-50- 10 (70)</td><td>Textile RC</td><td>None</td><td>Profiled steel sheet</td><td>Alkali resistant-Glass Mesh</td><td></td><td>2.6</td><td>6.3</td></tr>
<tr><td>2</td><td>10-100- 10 (120)</td><td>Textile RC</td><td>EPS</td><td>Insulation bond only</td><td>CFRP</td><td>0.55 m long panel</td><td>2.8</td><td>4.3</td></tr>
<tr><td>3</td><td>25-90- 40 (155)</td><td>UHPC</td><td>EPS</td><td>CFRP grid</td><td>Glass fibers</td><td>155 mm total thickness</td><td>2.7</td><td>7.5</td></tr>
<tr><td>4</td><td>15-150- 15 (180)</td><td>Glass Fiber RC</td><td>PUR</td><td>Pins and steel ties AR- Glass Mesh</td><td>Alkali resistant-Glass Mesh</td><td></td><td>1.7</td><td>12.1</td></tr>
<tr><td>5</td><td>15-150- 15 (180)</td><td>GRC</td><td>PUR</td><td>None</td><td>Alkali resistant-Glass Mesh</td><td>Insulation ϱi = 32 kg·m3</td><td>5</td><td>8</td></tr>
<tr><td>6</td><td>25-150- 25 (200)</td><td>Reactive powdered Concrete</td><td>FC</td><td>GFRP truss</td><td>CFRP</td><td>Single connector</td><td>2.5</td><td>6.7</td></tr>
<tr><td rowspan="5">7</td><td rowspan="5">30-160- 30 (220)</td><td rowspan="5">Textile RC</td><td rowspan="5">XPS, EPS, PUR</td><td rowspan="5">GFRP pins and CFRP grid</td><td rowspan="5">GFRP or CFRP</td><td>EPS low bond</td><td>7</td><td>10.6</td></tr>
<tr><td>EPS high bond</td><td>17.6</td><td>30.8</td></tr>
<tr><td>XPS high bond</td><td>26.4</td><td>48.4</td></tr>
<tr><td>XPS + C-Grid</td><td>28.2</td><td>88</td></tr>
<tr><td>XPS + 2C-Grids</td><td>28.2</td><td>70.4</td></tr>
</table>

Since the panels tested are of different widths for different panels, the bending moment is taken in kNm per m per width. From Table 6, it could be observed that.

- When wythe thickness increases, the bending moment capacity increases.[8]
- High strength concretes as wythe material can yield higher bending moment capacity.
- Higher bonding of insulation contributes to greater bending moment capacity.
- Textile reinforced concrete with GFRP reinforcement, XPS insulation and C-grid shear connector shows higher bending moment capacity.

5 Conclusions

- SIPs are highly thermal efficient and structurally sound material which can replace the concept of brick walls.

- Novel concretes such as ultra-high-performance fiber-reinforced and textile reinforced concretes have enabled thinner sections by replacing solid steel reinforcement bars with non-corrosive alternatives.
- High performance insulation materials, such as vacuum insulation, have also enabled thinner designs – achieving low U values for considerably lower insulation thicknesses.
- Thermal bridging is reduced by using shear connectors of lesser U value materials such as GFRP
- Even the FRP materials are brittle in nature, it exhibits ductile property when inside the SIP.
- In flexural tests most of the panel show greater than 50% strength from first crack to peak load.

How to Cite this Article:

Ajith, M., Raj, B., & Simon, K. M. (2021). Comparative Study on Performance of Precast Structural Insulated Panels with Different Shear Connectors. *AIJR Proceedings*, 367-374.

References

1. Matthew J. Gombeda A, et.al (2020) "*Flexural performance of precast concrete insulated wall panels with various configurations of ductile shear ties* "Journal of Building Engineering Vol:33 Pg. No101574 http://www.elsevier.com/locate/jobe
2. Oliver Kinnanea, et.al (2020) "*Structural shear performance of insulated precast concrete sandwich panels with steel plate connectors*" Journal *of Engineering Structures*, volume 215 -110691 www.elsevier.com/locate/engstruct
3. Richard O'Hegarty, Oliver Kinnane (2020) "*Review of precast concrete sandwich panels and their innovations*" Journal of Construction and Building Materials Volume:233 Pg no:117145 www.elsevier.com/locate/conbuildmat
4. Y.H. Mugahed Amrana,b,et.al (2020) "*Design innovation, efficiency and applications of structural insulated panels: A review*" Institution of Structural Engineers, Structures, volume 27, pg no 1358–1379 www.elsevier.com/locate/structures
5. Richard Hegarty et.al (2020)" *Development of thin precast concrete sandwich panels: Challenges and outcomes*" Journal on Construction and Building materials journal homepage: www.elsevier.com/locate/conbuildmat
6. An Chena, et.al (2020) "*A comparative study of different methods to calculate degrees of composite action for insulated concrete sandwich panels* "Journal on Engineering Structures, vol 212 homepage: www.elsevier.com/locate/engstruct
7. Dong-Hyeon Shin, Hyung-Joon Kim (2020) "*Composite effects of shear connectors used for lightweight-foamed-concrete sandwich wall panels*" Journal of Building Engineering, vol 29 http://www.elsevier.com/locate/jobe
8. Wentao Qiao et.al (2020) "*Experimental study of insulated sandwich concrete wall connections under cyclic loading*" Journal of Structures, vol 28, pg no 2000-2012. www.elsevier.com/locate/structures
9. Omar M. Alawad et.al 2020"*Flexural performance of non-loadbearing blast-resistant precast concrete cladding panels with discrete connections*" Journal of Building Engineering 32 http://www.elsevier.com/locate/jobe
10. Huanzhi Jiang, et.al (2018) *"The Shear Behavior of Precast Concrete Sandwich Panels with W-shaped SGFRP Shear Connectors"* KSCE Journal of Civil Engineering, volume 22, N0;10: Pg No;3961-3971 www.springer.com/12205
11. Choi I, et.al (2015)." *Composite behaviour of insulated concrete sandwich wall panels subjected to wind pressure and suction"* Journal on Materials 2015;8(3):1264–82