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Review

Mechanical and Thermal Properties of Composite Precast Concrete Sandwich Panels: A Review

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Abstract: Precast concrete sandwich panels (PCSPs) are utilized for the external cladding of structures (i.e., residential, and commercial) due to their high thermal efficiency and adequate composite action that resist applied loads. PCSPs are composed of an insulating layer with high thermal resistance that is mechanically connected to the concrete. In the recent decades, PCSPs have been a viable alternative for the fast deployment of structures due to the low fabrication and maintenance cost. Furthermore, the construction of light and thin concrete wythes that can transfer and resist shear loads has been achieved with the utilization of high-performance cementitious composites. As a result, engineers prefer PCSPs for building construction. PCSP design and use have been examined to guarantee that a building is energy efficient, has structural integrity, is sustainable, is comfortable, and is safe. Hence, this paper reviews the expanding knowledge regarding the current development of the mechanical and thermal properties of the PCSPs components; subsequently, future potential research directions are suggested.

Keywords: precast concrete sandwich panel; shear connection; insulation; concrete wythes; load-bearing composite wall

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1. Introduction

Insulated wall panels, also known as precast concrete sandwich panels (PCSPs) or integrally insulated wall panels, are being utilized extensively in structures and building envelope systems. The panels have superior thermal and acoustic insulation and load-bearing capacity [1]. The panels (wythes) are composed of rigid foam insulation sandwiched between two layers of concrete and held together using shear connectors (as illustrated in Figure 1) [2]. The panels can be prefabricated to ensure quality control, elimination of construction delays, and fast deployment [3]. The panels can be fabricated to consist of partial or complete composite action depending on the degree of shear force transmitted and the arrangement of shear connections [4]. Steel, fibre-reinforced polymers (FRPs), and plastics are the most common materials used for shear connectors [4]. However, steel shear connectors are preferred due to their mechanical properties. FRP connectors can provide both structural and thermal performance as they possess low heat conductivity [5]. On the other hand, plastic has a very poor thermal conductivity and consists of weak mechanical properties (i.e., low rigidity) limiting their use in panels [6,7].

In recent years, to enhance the stiffness of the concrete panels, basalt fibre-reinforced polymers (BFRPs) have been used as reinforcement and shear connectors [8–10]. BFRPs have similar strength and thermal conductivity to glass fibre-reinforced polymers (GFRPs) [11,12]. Moreover, BFRPs have a larger stiffness and are more durable than GFRPs [11–13]. Furthermore, BFRPs are easy to manufacture; they are also high thermal insulators that resist freezing and thawing environments [9,12]. In general, BFRPs have a manufacturing cost that is lower than that of carbon fibre-reinforced polymers but higher than that of GFRPs [9,11]. However, the long-term performance of BFRPs in rapid weathering and alkali environments has not been not fully investigated [14]. Researchers have illustrated that BFRPs have outperformed GFRPs and CFRPs in terms of thermal resistance and simplicity of production [15].

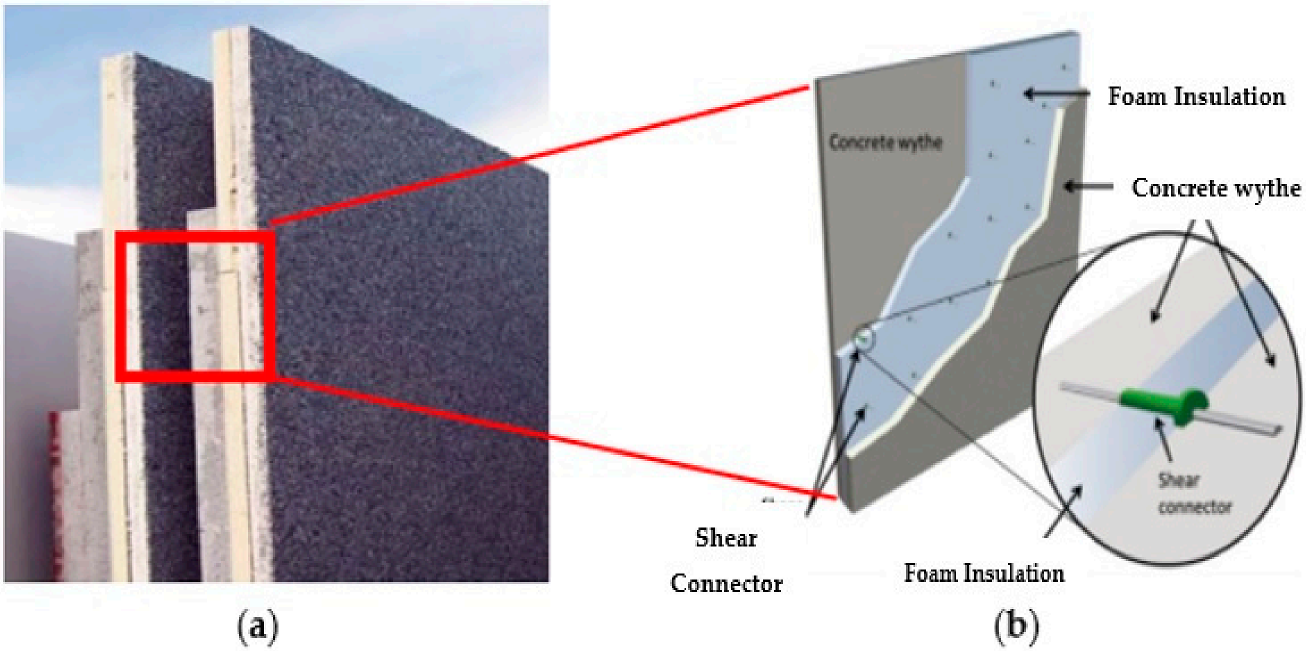


Figure 1. A precast concrete sandwich panel: (**a**) rear view, (**b**) shear connector (edited from [6,7]).

Woltman et al. (2013) illustrated that the panels have good thermal insulation; however, the efficiency is reduced over time [1]. The panels are often restricted to a minimum thickness of 51 mm due to cover and fire resistance requirements. Moreover, an efficient thermal insulation layer can have a thickness ranging between 51 mm and 102 mm [4]. The insulating layer is usually fabricated from extruded polystyrene (XPS) and expanded polystyrene (EPS). The XPS exhibits high shear strength when compared to EPS. This is due to the smoothness of EPS, which results in a low shear strength [4]. Moreover, EPS has a weak bond strength when subjected to freezing and thawing conditions due to their high moisture absorption rate [5].

Researchers are investigating the feasibility of reducing the thickness of PCSPs to save resources and materials and improve efficiency [14–16]. A crucial aspect in reducing the thickness of the panels is maintaining the thermal effectiveness and strength capacity of the cladding components [17]. Therefore, the utilization of partial/full-composite action alongside with anticorrosive reinforcement and shear connectors can be a feasible solution. Several researchers have concluded that a concrete layer with a minimum thickness of 80 mm is required to provide adequate cover for steel reinforcement in a typical concrete wythe [18]. Researchers found that two concrete panels could be attached together to provide composite action in resisting flexural loads [19]. This design mechanism resulted in enhancing the structural capacity while allowing for a small overall composite to be implemented [19]. However, the shear connectors need to be optimized to minimize the impact of thermal transfer (i.e., heat bypass) and structural rigidity [20]. Moreover, to reduce the overall thickness, a smaller cover needs to be implemented. In general, the concrete cover is specified based on the fabrication, transfer, and fire protection requirements and standards [20]. A minimum diameter and development length are required for the bolts used during the deployment of the panels (i.e., the assembling of the panels) [21]. On the other hand, fire protection is provided by the concrete cover in accordance with the design code [22,23]. It is worth noting that the cover requirement for non-structural cladding panels is less than those for structural cladding panels [24].

This review summarizes the expanding knowledge regarding the structural performance of precast concrete sandwich panels (PCSPs). Furthermore, the properties of the components of PCSPs consisting of the concrete wythes, insulation core, and mechanical connectors are discussed.

2. Sandwich Panels Behaviour

Sandwich panels made of precast and prestressed concrete are often utilised for various buildings' outside and interior walls [24]. These panels may be quickly and easily mounted to any structural frame, including ones made of steel, reinforced concrete, pre-engineered metal, and precast or prestressed concrete [25]. The panels are prefabricated in a facility, brought to the project site, and erected by cranes. The panels reach vertically between foundations and floors or roofs to produce permanent walls but may also span horizontally between columns [26]. Sandwich panels are comparable to other precast or post-tensioned concrete members in design, detailing, manufacturing, handling, shipping, and erection [27]. On the other hand, due to an intervening layer of insulation, sandwich panels display behaviours and characteristics distinct from those of other precast or post-tensioned concrete members [28].

The panels can be classified as composite, partially composite, or non-composite. Composite panels are designed so that the two concrete wythes are fully bonded and work cooperatively to withstand the applied load. The usual failure behaviour of a composite panel is the crushing of concrete or the deterioration in steel reinforcement. It is worth noting that composite panels have shear connectors that are designed to withstand higher stresses than concrete or steel can resist. This is to minimize the possibility of a sudden failure in shear connectors. Figure 2 illustrates the linear stress distribution over the thickness of a sandwich panel that is (a) composite, (b) partially-composite, and (c) non-composite. Figure 2d displays the stress distribution of a single panel. A partially composite panel consists of connectors that can only transmit a percentage of the longitudinal shear. For partially composite panels, the failure occurs in the shear connectors.

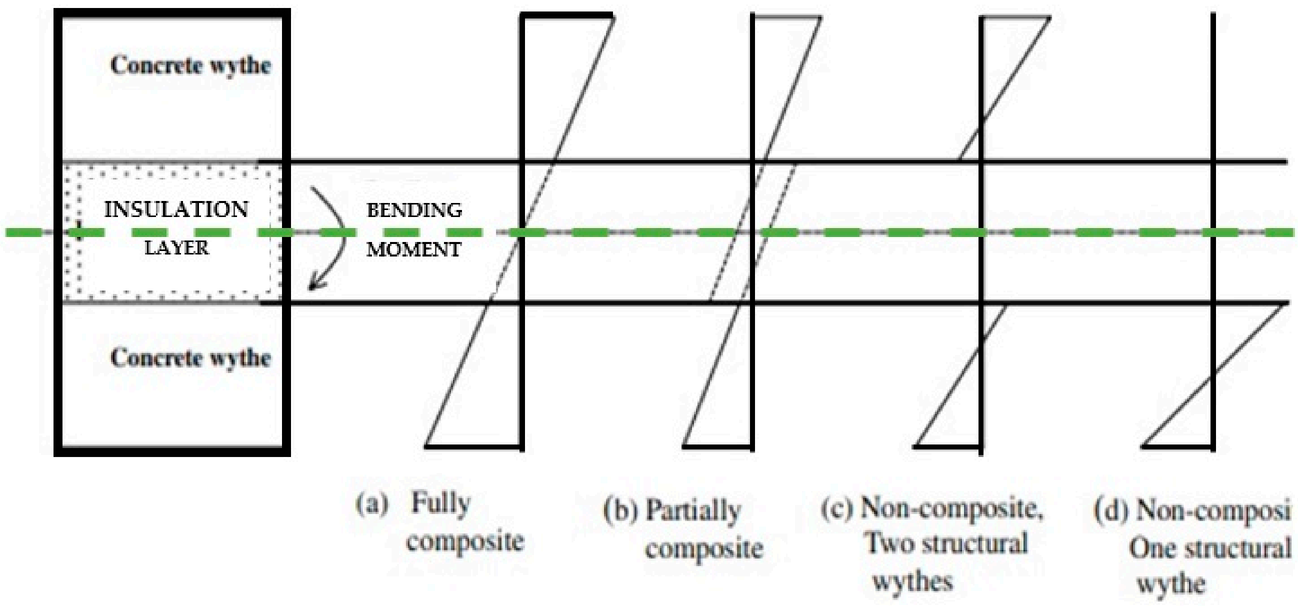


Figure 2. Strain distribution of precast composite sandwich panels [29].

The behaviour of the PCSPs is complex due to its material nonlinearity, the percentage composite action, and the interaction of the components. Researchers have developed models based on experimental results and a fundamental analytical approach. Moreover, the flexural behaviour of the PCSPs has been investigated to understand the effectiveness of the truss shear connectors to assure composite behaviour. However, there is a lack of experimental data due to the expenses associated with conducting full-scale testing and the difficulty associated with developing small-scale models. Furthermore, most manufacturers in North America and Europe do not share detailed information about the panel composition and design as they are protected under proprietary licenses [29].

3. Shear Connectors

Figure 3 illustrates the typical assembly of precast concrete sandwich panels consisting of two outer layers of concrete and a core insulative layer. The layers are bonded using shear connectors. The shear connectors act as a strong bridge between the outer and core layers [30]. The shear connectors should have an adequate diameter (a minimum of 4 mm is used) to improve the system's overall structural integrity. It is critical to ensure that the panels can transfer the applied forces from one outer layer to the other outer layer without causing deterioration to the insulation core. Depending on the intended application and customer need, a shear connection design configuration (i.e., one-way, or two-way direction) and its orientation may vary.

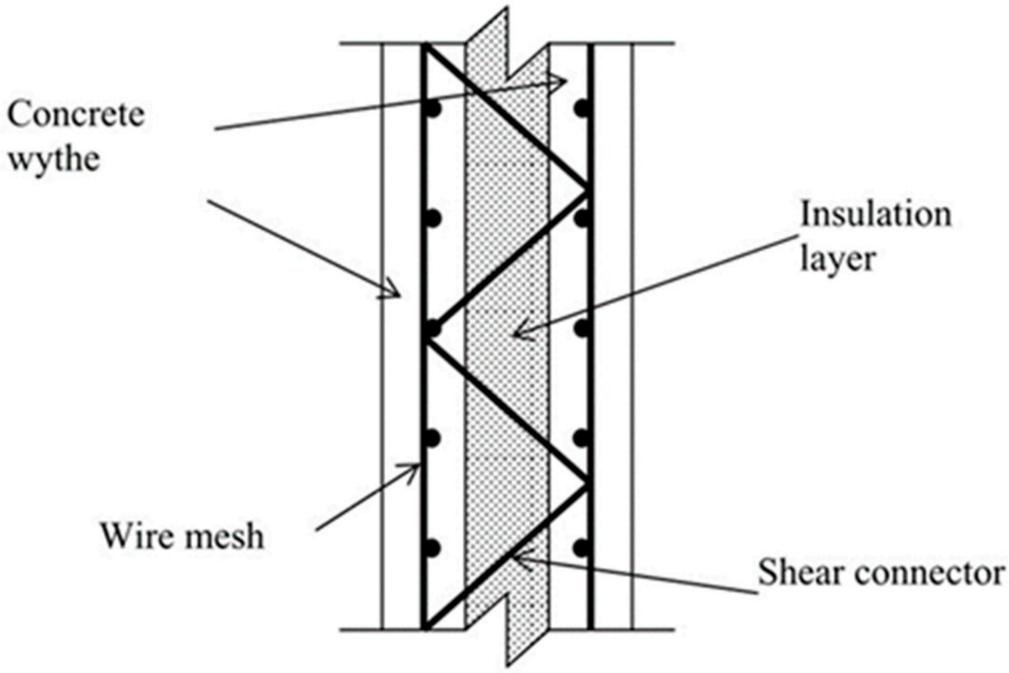
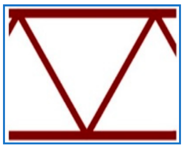
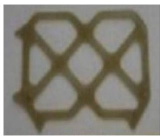
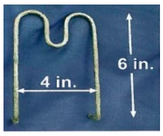
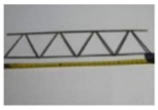
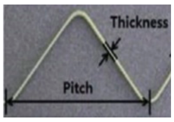


Figure 3. Typical drawing of a precast sandwich panel using a wire mesh as a shear connector [31].

Table 1 presents the various types of shear connectors that have been investigated. Zhang et al. [32] investigated the thermal performance of reinforced precast concrete sandwich panels with three different types of shear connections. Among the shear connectors that have been investigated were steel truss connectors, nominal thermo-mass connectors, and steel-pin connectors. The research illustrated that the nominal shear connectors have a low heat transfer rate and are the most stable under various loading situations. Moreover, truss shear connectors are comparable to the nominal shear connectors. It is worth noting that steel pin connectors do not provide sufficient composite behaviour [32].

Table 1. Typical design of shear connectors and materials used.

Study	Connection Material/Type	Design	Insulative Materials	Thickness (mm)
[33]	Steel Truss-Shaped Shear Connector		XPS	6
[34]	CFRP		XPS, EPS	50, 100, 150
[35]	Lattice Fiberglass Polymer Tie-Connector: FRP		XPS, EPS	75
[27]	Diagonal Anchor			6
[36]	Steel M-Tie		XPS	50
[37]	MC Welded Wire Girder Connector		XPS, EPS	75
[38]	GFRP		EPS	100
[9]	Pin		Foam	50
[34]	FRP: NU-Tie		XPS	75, 150

4. PCSPs Insulation

PCSPs can be categorized as either bulk (i.e., mass) or reflective insulators. The mass insulation can reduce heat transfer by conduction, while reflective insulators reduce the heat transfer by radiation [39].

4.1. Mass Insulation

High thermal mass insulators absorb and retain heat by delaying the rate transfer through conduction. The use of external coatings with low thermal mass and conductivity for structures are helpful in isolating heat transfer in hot climates boosting the insulation efficiency. The efficacy of the mass insulators is dependent on the thickness of the material used and the heat conduction behaviour. Moreover, the effectiveness of the thermal insulator is dependent on the state of the subdivision and the density of the material [28]. Mass insulators are often composed of many small pockets filled with trapped air that significantly decrease the transmission of heat. Therefore, compressing mass insulators have a negative impact on their efficiency to insulate heat [39].

4.2. Reflective Insulation

A reflective (i.e., low emittance) surface provides thermal insulation by reflecting the heat radiation. This results in a reduction in the amount of heat transferred to a building due to solar rays and decreases the indoor temperature while improving the air quality within a structure. The effectiveness of a surface in emitting energy through thermal radiation is defined as emissivity. As the emissivity of a surface increases for a specific wavelength, the energy radiated at that wavelength also increases. Reflective insulators are composed of several low-emittance surfaces that entrap air. They are often employed in residential buildings such as attics, roofing, and wall systems [40,41]. Several researchers have examined the effects of reflective insulators on the thermal performance of the building envelopes [42–45].

5. Classification of Insulators

5.1. Classification Based on Form

The most prevalent forms of insulation include loose-fill spray foam, batts, blankets, and rigid boards. The structure, rehabilitation plan, and building code requirements must all be considered when choosing the insulation material [36,46]. Table 2 provides a summary of the performance characteristics of insulative materials based on their shape.

Table 2. Performance characteristics for common insulators [47–49].

Form	Material	Density (kg/m^3)	Thermal Conductivity (W/m^{-2}K^{-1})	Maximum Service Temp. (°C)	Durability
Blankets: Batts or Rolls	Fiberglass (Sand and Recycled Glass)	12–56	0.04–0.033	−4–260	Compression Reduces R-Value
	Rockwool (Natural Rocks)	40–200	0.037	−240–800	Compression Reduces R-Value
	Polyethylene	35–40	0.041	−40–90	R-Value Decreases with Time
Loose-Fill Blown-in or Poured-in	Open Cell Structure	10–48	0.038–0.030	−4–260	Compression and Moisture Degrade R-Value
	Rockwool (Open Cell Structure)	24–36	0.040	−240–800	Compression and Moisture Degrade R-Value
	Cellulose (Ground-up Wastepaper)	24–36	0.054–0.046	80	Compression and Moisture Degrade R-Value
	Perlite (Natural Glassy Volcanic Rock)	32–176	0.06–0.04	760	Good
	Vermiculite	64–130	0.068–0.063	1315	Good
Rigid Board	Fiberglass (Open Cell Structure)	24–112	0.035–0.032	−4–350	More Rigid Than Batts
	Expanded Polystyrene (Closed Cell Foam)	16–35	0.038–0.037	100	R-Value Decreases with Time
	Extruded Polystyrene (Closed Cell Foam)	26–35	0.032–0.030	100	R-Value Decreases with Time

5.2. Classification Based on Composition

In general, the chemical and physical structure of a material determines the insulation properties. Papadopoulos [50] classified the insulation materials into organic, inorganic, mixed, and innovative technologies as illustrated in Figure 4.

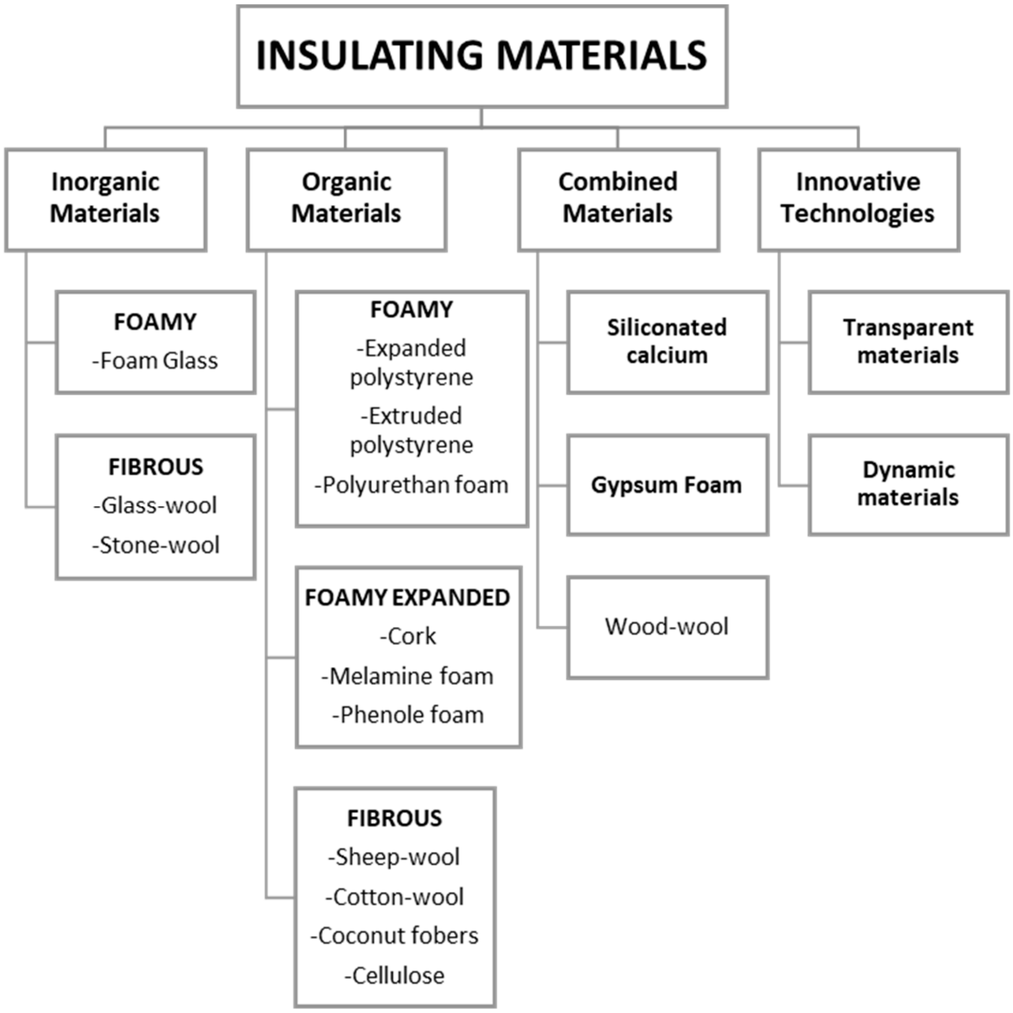


Figure 4. Classification of the commonly used insulative materials [50].

5.2.1. Inorganic and Organic Insulators

Inorganic insulators are composed from non-renewable resources such as mineral wood, perlite, aerated concrete blocks, and foamy glass [51]. Organic insulators are composed of natural flora, wood wool, cellulose, expanded rubber, wood fibre, and sheep wool [52]. Organic insulators have numerous advantages such as being recyclable and nontoxic, along with other environmental benefits. Furthermore, the organic materials use less resources and energy for the manufacturing process compared to the inorganic insulators [53]. However, inorganic insulators are less expensive to utilize and have superior insulation properties [48]. Furthermore, inorganic insulators are resistant to fire and other chemicals compared to organic insulators.

5.2.2. Combined and Innovative Technologies

The utilization of several materials in insulators can improve the overall thermal performance and energy efficiency. Novel thermal insulators such as transparent insulative materials have been developed and have good thermal insulation and solar gathering properties [54]. Moreover, dynamic insulators that actively utilize ventilation systems have been employed to increase insulation efficiency [55]. Currently, insulators are composed of petrochemicals, fiberglass, mineral wool, polyurethane foam, and multiple foils [56]. Additionally, this material can be assembled in several configurations via simple installation techniques. However, these materials are non-renewable, generate waste, and depend on fossil fuels. Table 3 illustrates the material properties of the insulative materials that are currently being used. The selection of insulative material depends on the cost, durability, climatic factors, availability, mode of heat transmission, simplicity of installation, and structure orientation [14]. The following are examples of currently used insulative materials: (1) mineral wool, (2) cellulose, (3) expanded polystyrene (EPS) [57], cork, polyurethane (PUR) [58], extruded polystyrene (XPS) [57], and wood [59].

Table 3. Physical properties of the commonly used insulative materials [31,46].

Physical Property	Polystyrene						Polyurethane	
	EPS			XPS			Unfaced	Faced
Density (kg/m^3)	11.2–14.4	17.6–22.4	28.8	20.8–25.6	28.8–35.2	48	32–96	32–96
Water Absorption (%)	<4.0	<3.0	<2.0		<0.3		<3.0	1.0–2.0
Compressive Strength (kPa)	35–70	90–103	172	103–172	276–414	690	110–345	110
Tensile Strength (kPa)		124–172		172	345	724	310–965	348
Linear Coef. of Expansion 10^{-6} mm/mm/C	45–72						54–108	54–108
Shear Strength (kPa)		138–241		-	241	482	138–690	138–690
Flexural Strength (kPa)	69–172	207–276	345	276–345	414–517	695	345–1448	276–345
Thermal Conductivity Wm/m^2/C	0.043	0.037	0.033		0.029		0.026	0.014–0.022
Maximum Temperature °C	71						118	

6. PCSPs Thermal Performance

Experimental characterization of conventional/typical PCSPs have revealed a thermal transmittance value (U-value) between 1.2 Wm^{-2} K^{-1} and 2.0 Wm^{-2} K^{-1} in panels with just 38 mm of expanded polystyrene (EPS) insulation core. Higher U-values have been observed with panels that consist of closely spaced connections, as thermal bridges are formed across the insulating layer. This results in increasing the number of heat loss pathways. More recently, Zhai et al. developed a PCSP with a novel nylon shear connector; the panel had an insulation core with a 100 mm thickness of polyurethane [60]. The panel had a U-value of 0.66 Wm^{-2} K^{-1}. Zhai et al. also investigated the use of expanded polystyrene with the same configuration and had a U-value of 1.2 Wm^{-2} K^{-1} [60]. Based on the observed results, Zhai et al. concluded that the developed panels were more effective and cost efficient than PCSPs with fibre-reinforced polymer (FRP) connectors that have a U-value of 0.41 Wm^{-2} K^{-1} [60]. Keenehan et al. [61] observed that a PCSP with 120 mm of a phenolic foam (PF) insulative core had a U-value of 0.26 Wm^{-2} K^{-1} when using steel connectors and 0.15 Wm^{-2} K^{-1} when using fiberglass connectors. It is worth noting that the shear connectors were determined based on the mechanical and strength requirements. Woltman et al. [32] investigated panels with discrete 4-mm diameter steel connectors, which had a U-value of 0.36 Wm^{-2} K^{-1}, while the panels with the same number of discrete 9.5mm diameter GFRP connectors and a 150 mm rigid XPS insulative core had a U-value of 0.34 Wm^{-2} K^{-1}. Several researchers have illustrated that PCSPs with significant thicknesses ranging from 250 mm to 390 mm had a U-value less than 1.0 Wm^{-2} K^{-1} [61,62]. Panels with U-values that are much lower than those that have been investigated are necessary for residential and commercial buildings. In Ireland, the construction standard requires panels with a maximum of 0.21 Wm^{-2} K^{-1}, and compliance incentives are given for an additional reduction in the U-value [63].

Vacuum insulation panels (VIPs) are lightweight, flexible and provide a viable solution for achieving thin PCSPs with high thermal resistance [63]. Currently, VIPs have low conductivity ratings compared to other commercially available insulative materials. VIPs are used to safeguard electronic equipment and are constructed of a hardcore using silica fume and covered with aluminium foil to provide an airtight wrap [64]. VIPs have been used for various applications [65]. In a recent publication, it was observed that the U-value was 0.007 $Wm^{-2} K^{-1}$, which is three times lower than the U-value than common foam insulators [66]. VIPs are manufactured in predetermined module sizes to ensure their performance. VIPs that are custom designed have discontinuous layers of vacuum insulation between the two insulation layers. Although the incorporation of VIP into a PCSP is simple [18], there is a likelihood of delamination with the shear connectors (i.e., thermal bridging) [67].

Figure 5 shows the effects of overall panel thickness and insulation thickness on the ultimate load of the panel. In general, insulation thickness has a negative effect on the ultimate load of the panels, as a shorter shear-span between the loadings provides a higher capacity of the shear connector in PCSP.

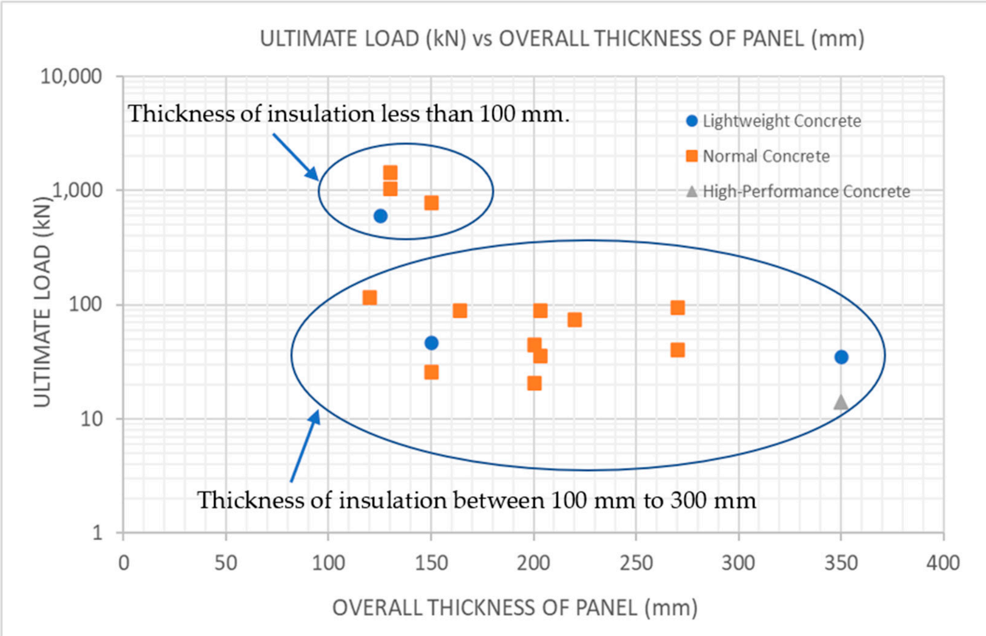


Figure 5. Ultimate load vs. overall thickness of panel with different wythe materials.

Table 4 illustrates the research development that has occurred since 2007 in the area of PCSP in terms of alternative materials for wythes and composite shear connectors. The table presents the ultimate force applied in terms of the axial, bending, and shear characterization. Conventional concrete and steel panels have an ultimate load of 1450 kN, while foamed concrete has an ultimate load of 783 kN. Pantelides et al. observed a maximum bending load of 117.3 kN for PCSPs with GFRP shear connectors in conventional steel and concrete [26]. A maximum bending load of 22 kN to 45 kN was observed for similar PCSPs with glass fibre-reinforced plastic (GFRP) [26].

Table 4. Summary of previous research conducted on PCSPs.

Study	Wythe Material	Shear Connector Type	Shear Connector Shapes	Insulative Materials	Composite Action	Ultimate Load (kN)	Insulation Core Thickness (mm)	# of Layers	Loading Type	Structural System	Overall Thickness (mm)
[68]	Lightweight Concrete	Steel Bar	Non-Continuous	Mineral Hydrated Foamed Material	Full	17.8 to 34.9	150	-	Static Wind and Axial	Wall	350
[21]	Lightweight Concrete	Steel Truss	Continuous	EPS	Full	31.4 to 47.1	30	Single	Axial	Wall	150
[69]	Lightweight Concrete	Steel Truss	Continuous	EPS	Full	250 to 600	40	Single	Axial	Wall	125
[70]	Lightweight Concrete	Steel Truss (6-mm)	Continuous	EPS	Full	188 to 355	-	Double	Axial	Wall	-
[71]	Lightweight Concrete	Steel-Encased Concrete				18 to 44			Flexural	Slab	-
[20]	Lightweight Concrete	CFRP Grid	Continuous	Phenolic Foam	Partial		90		Thermal	Wall	150
[72]	Normal Concrete	Steel Truss	Continuous	EPS	Full	20.04 to 26.00	100	Single	Axial	Wall	150
[73]	Normal Concrete	Steel Bar	Non-Continuous	EPS	Full	-	100	-	Axial	Wall	150
[74]	Normal Concrete	Steel Truss	Continuous	EPS	Full	401 to 783	80	Single	Axial and Flexural	Wall	150
[75]	Normal Concrete	Steel Truss	Continuous	Polystyrene Foam	Full	1250 to 1450	30	Single	Axial	Wall	130
[76]	Normal Concrete	Steel Truss	Continuous	EPS	Full	1050	30	Single	Axial	Wall	130
[69]	Normal Concrete	GFRP Bar	Continuous	EPS, XPS and VIP	Full		100		Flexural	Wall	220
[77]	Normal Concrete	GFRP Shear Grid	Continuous	EPS and XPS Foam	Full	23 to 75	100	Single	Flexural	Wall	220
[78]	Normal Concrete	BFRP Bar	Non-Continuous	EPS	Partial	38 to 41	100		Flexural	Wall	270
[79]	Normal Concrete	GFRP Stud	Non-Continuous	Rigid Foam	Partial	17 to 95	100		Flexural	Wall	270
[80]	Normal Concrete	GFRP Truss	Continuous	XPS		44 to 90	102	Single	Flexural	Slab and Roof	164
[4]	Normal Concrete	GFRP-Grid	Continuous	XPS and EPS	Full	45 to 90	102	Single	Flexural	Wall	203
[26]	Normal Concrete	GFRP Shell	Continuous	EPS	Full	25 to 45	76	Single	Flexural	Wall and Slab	200
[81]	Normal Concrete	Steel M-Tie	Non-Continuous		Partial	30 to 36	50		Flexural	Wall	203
[81]	Normal Concrete	Steel Truss	Continuous	Polystyrene	Full	117.3	40	Single	Flexural	Wall	120
[79]	Normal Concrete	Steel Truss	Continuous	EPS	Full	14 to 21	50	Single	Flexural	Wall	200
[79]	Normal Concrete (Three Layers)	Steel					25 to 50		Flexural	Wall	200
[80]	High-Performance Concrete	BFRP and CFRP Grid	Continuous	EPS, Kingspan Free Rigid Phenolic	Partial	12 to 14	290	Single	Flexural	Beam	350
[82]	Textile-Reinforced Concrete	Pin Connector	Non-Continuous	Polymeric Rigid Foam	Full		160		Flexural	-	280

7. Future Development

According to this review, the vast majority of studies have focused on PCSP with heavy concrete materials. However, the impact of lightweight concrete on PCSP has not been investigated fully. Future research is necessary to develop low cost PCSPs with high thermal insulation and fire resistance. Furthermore, research should be conducted to achieve a high degree of adaptation (i.e., different geometry and sizes) and flexibility to install PCSPs. In addition, it is necessary to emphasize the mechanical strength and to evaluate the environmental impacts of the deployment of building insulators.

8. Conclusions

Initially, PCSPs were developed and manufactured as stressed-skin panels for structures. Rigid polystyrene foams, such as EPS or XPS, were used as the core material, while the outside layers of PCSP were constructed using concrete, plywood, and thin metal laminations (wythes). Concrete sandwich panels consist of two layers of structural concrete sandwiched between two layers of a low-strength and low-density insulative material. Horizontal mechanical shear connectors made of steel, carbon fibre-reinforced plastic, and glass fibre-reinforced plastic link the three layers. The design arrangement of shear connections affects the precast panels' structural efficiency and capacity. The shear connectors and concrete wythes of a structure are typically reinforced with the same materials. The most challenging obstacle researchers must overcome is ensuring a secure connection between the wythes and the core material. PCSPs can be designed as non-composite, partially composite, or fully composite.

The mechanical and thermal behaviour of the sandwich panels depends on the material quality, quantity, diameter, spacing, and arrangement of the horizontal shear connections, the thermal concrete bridges, and the strength of the concrete wythes. Fully-composite panels are PCSPs that have achieved a full integration of strain and displacement compatibility. If a PCSP panel fails due to a shear connector before the concrete crushing and steel reinforcement yielding, then the panel cannot be considered a composite panel. Therefore, a prospective study on sandwich panels may investigate the following topics:

1. Development of PCSP samples using lightweight concrete suitable for use in both wall and flooring systems.
2. Enhancement of composite PCSP by providing more shear connectors in a smaller area while retaining optimum orientation and arrangement.
3. Investigation and development of PCSP specimens with alternative shapes of shear connectors that are functional for walls and floors.

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