Journal of Engineering, Project, and Production Management
2013, 3(1), 2-8

Structural Insulated Panels: Past, Present, and Future

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Engineering Management
Received January 12, 2012; received revisions February 7, 2012; May 1, 2012; accepted May 4, 2012
Available online August 13, 2012

Abstract: Since the emergence of construction technology, construction of affordable and environmentally-sensible home at fast pace has brought dream home within the reach. Structural Insulated Panel (SIP) has become a topic of interest among researchers in the recent years. SIP has the advantages of minimal material wastage and labour-savingness whilst having potential to save house builders' time and money as well as retaining the controlled quality. Nonetheless, it suffers from few drawbacks which should be further explored by researchers in its future design. This study present a brief overview of SIP history and common methods and materials utilised for SIP production. It reviews the recent research in the field of SIP by evaluating its application and drawbacks which enable SIP designers improve on SIP. The review of evaluating SIP application and its drawbacks clearly point to the need for further studies to progress beyond the current SIP to an improved one. It might be achieved by replacement of new material with common material used as skin and core of SIP. Considerably more research will need to be done to obtain SIP universal design standard.

Keywords: Structural insulated panels, thermal insulation, sandwich panel

1. Introduction

Structural Insulated Panel (SIP) is one of the prefabricated home members which has been the topic of interest among researchers in recent years. The idea of SIP was initially introduced in 1935 by Forest Product Laboratory (FPL) researchers in Madison, Wisconsin in United States. SIP is a sandwich panel utilised as structure member such as wall, roof, and floor for concrete and steel frame structures (Smith, 2011). In the last decade, numerous studies have attempted to investigate the behaviour of sandwich panels from different perspectives (Dharmasena et al., 2011; Frostig and Thomsen, 2011; Hoo Fatt and Sirivolu, 2010; Kim and Lee, 2008; Malekzadeh et al., 2006; Wang et al., 2009; Yeoshua, 2009; Zhou and Stronge, 2006). Respite the studies have been done, SIP still needs to be more considered according to the market demand. SIP is usually manufactured with two layers of rigid material as skin and a thicker layer as core. Recent developments in the field of manufactured, modular, and prefab homes have led to a renewed interest in design and application of prefabricated members of building (Anosike and Oyebade, 2011) such as SIP based on their benefits which are neater site, faster project completion, minimal wastage, and labour load reduction. Only residential structures have attributed around 70 percent of SIP applications. SIP can also be utilised for coolers because of its insulation properties (Little et al., 2002; Smith, 2011). Since the existence of SIP technology, several issues have been addressed by researchers for its components and mass production technology. In the rapid development of SIP technology, there are few drawbacks relevant to its core and skin materials, joint connections, repair and retrofit.

Far too little attention has been paid to the size effect on behaviour of SIP with respect to the opening such as door and window. Most of the recent SIP studies focus merely on the materials for its core and skin (Little et al., 2002; Miller et al., 2010; Pardue, 2011; Porter, 2004; Porter, 2009). The range of different SIP prices and its affordability have not been sufficiently explored.

This paper reviews the recent research in the field of SIP by evaluating its application and drawbacks which enable SIP designers improve on SIP. The current research has thrown up many questions in need of further investigation for replacement of new material with common material used in SIP.

2. History of SIP

The idea of structural insulated panel was initially introduced in 1935 at the Forest Product Laboratory (FPL) in Madison, Wisconsin in United States. FPL researchers discovered that hardboard sheathing and plywood were able to bear structural load like a wall. The continuity of the research on SIP has led to the SIP development in its design and materials for almost 30 years. The first commercial SIP was produced by Dow in 1952.

Rigid foam insulation became accessible in the 60s when the affordable SIPs had come on stream. In 1990, Structural Insulation Panel Association (SIPA) was set up as a trade organisation (Akay and Hanna, 1990; Basunbul et al., 1991; Johnson and Sims, 1986; Smith, 2011). In recent years, there is a growing interest in SIP among the researchers. In particular, the types of SIPs which have an inner core and two outer laminate layers have attracted a great attention for their high strength to weight ratio, precise insulation values, and being cost-effective.

3. SIP Components

SIP is a sandwich panel which is utilised as structure member such as wall, roof, and floor for concrete structures. SIP varies in different thicknesses of two layers of rigid material as skin and a thicker layer as core. It can be made of various materials based on its application. The core of SIP is usually non-structural and ridged. It is commonly made of plastic foam such as Extruded Polystyrene and Expanded Polystyrene (EPS) as well as Polyurethanes (PUR) foam such as polyisocyanurate and polyisosyanate as shown in Fig. 1. PUR foam has better performance against fire, flaming, and smoke rating. The SIPs which are made of PUR foam are stronger than the SIPs made of EPS against axial, flexural, and lateral loads (Frostig and Thomsen, 2011; Hoo Fatt and Sirivolu, 2010; Johnson and Sims, 1986; Pardue, 2011; Smith, 2011). Injected PUR foam can be easily adhered to all SIP components such as skin material, cam lock, top plates, and electrical boxes. Thus, it allows durable bond between mating surface and the foam.

Among the accessible types of PUR, HFC-245fa polyurethane foam allows the best insulation protection for moisture transferring and precise adhesion to the OSB skins. Outer layers are commonly flexible skins that are attached to one or both sides of the core. The skins are adhered to the core by the methods of glue bonding and pressing as well as pouring and injecting liquid foam (Medina et al., 2008; Miller et al., 2010; Pardue, 2011; Smith, 2011; Taha, 2011; Wang et al., 2009).

Fig. 1. SIP made of polystyrene and OSB

4. Common Methods Utilised for SIP Production

There are some methods used for SIP production to provide more compatible SIPs based on the code requirements. Cam lock is utilised to provide an excellent tight connection of the panels which can be easily removed without using nails as shown in Fig. 2. However, it is not commonly used due to its high material cost. SIPs are produced with horizontal and vertical chases to accommodate electrical wiring. These chases are located for outlet spacing based on the code requirements and building layout. Other penetrations into the SIP wall, roof, and floor may need to be manufactured to exact specification to fit modular SIP productions (Dharmasena et al., 2011; L.Brown et al., 2011; Porter, 2004; Porter, 2009; Shields, 2011).

Fig. 2. Using cam lock for SIP

5. Common Types of SIP Skin Materials

There is a variety of SIP skin materials suggested by researchers based on their advantages and SIP application such as metal, fibre cement, cement, calcium silicate, gypsum, and oriented strand board (L.Brown et al., 2011; Miller et al., 2010; Porter, 2004; Porter, 2009; Smith, 2011). The SIP skin must be fire-treated to comply with local and national building codes. As an example, according to the International Code Council (ICC), 15-minute thermal barrier from the interior of a building must be obtained by foam plastic insulation (IBC section 2603.4). The advantages and drawbacks of the most common types of SIP skin are summarised in Table 1. In this table, the advantages and drawbacks of SIP skin which confine its application in construction industry are compared together. Among the common SIP skins, OSB is cheaper than the other skin material. However, the drawbacks of OSB confine its application as SIP face sheet. SIP made of OSB can be utilised as partition wall that are not exposed to moisture. However, it has decorative applications such as partition wall in the shops. Aluminum and steel transfer the heat from out of SIP to the core quickly. The rate of heat transferring is very high for these materials. Thus, it confines its application for SIP. The potential flammability of Fiber Reinforced Polymer (FRP) causes serious problem for its application as SIP face sheet, because even using sheetrock does not meet the fire code requirements. Among these types of skins thereof, cement board is more convenient to use as SIP skin. Nevertheless, there is need for future research to improve its brittle failure. The authors have carried out some experiments to improve the brittle failure and maximum load bearing of SIP which is made of cement board using small scale of SIP as shown in Fig. 3 and Fig. 4. The connection of SIP panels should be improved using new material and design to enhance its stability.

Table 1. Advantages and drawbacks of SIP common skins

Type of skin	Advantages	Drawbacks
Oriented Strand Board (OSB)	Cost-effective	Flammable Pervious to insect Vulnerable to moisture Requirement of sheetrock to comply with fire codes
Aluminium and Steel	Non-flammable Lightweight	Unable to insulate the core from heat Requirement of sheetrock to comply with fire codes Requirement of cosmetic finishes
Cement board Calcium silicate board	Fire resistant Able to insulate the core from heat Providing good axial compressive strength	Having brittle failure under compressive load Unavailability with large size panels
Fibre Reinforced Polymer (FRP)	Lightweight Impervious to insect Waterproof	Potential flammability Low compressive strength Unable to insulate the core from heat Requirement of sheetrock to comply with fire codes Lacking of acoustic resistance

Fig. 3. Preparation of small scale SIPs using wood wool and polystyrene as the SIP core

Fig. 4. Uniaxial compressive test for small scale of SIP

6. The State of the Art

In this section the current issues about SIP design are discussed because the new design SIP shall overcome these issues about SIP. The researcher's recommendations about the latest issues of SIP are described according to the patents.

a. The emergence of SIP has driven construction industry in thermal boundary applications. SIPs usually have frame members which are needed to be assembled at their joints. Application of sealant in these joints is necessary to prevent condensation from infiltrating and reduce air leakage and heat loss through the joints (L.Brown et al., 2011). However, application of sealant is sloppy, time-consuming, and it often results different degrees of effectiveness based on the installer expertise. SIP skin is commonly made of wood material because of its low cost and good thermal insulation properties compared to metal frames (L.Brown et al., 2011). The body of SIP does not provide the same thermal insulation in the jointed parts of panel compared to the other parts. Thus, it is necessary to provide SIPs with the improved joint sealing system. In 2011, SIPs with improved thermal insulation performance in regard to the joint insulation was put forward by the researchers (L.Brown et al., 2011). In this design, SIPs are connected together with designed cavity on the sides of panels.

d. A look back at SIP construction technology development, thermal resistance of SIP has been considered as a key factor in its production. However, its design is still not effective enough for some structural applications due to its low thermal resistance. In 2010, SIP with high strength to density ratio and high resistance to combustion was achieved utilising carbon foam as core (Miller et al., 2010). Using carbon foam core in SIP resulted good resistance against both charring and combustion (Miller et al., 2010). Carbon foam as shown in Fig. 5 can also be utilised in different sizes and configurations in SIPs. In addition, using phase-change material (PCM) in SIP section was put forward by researchers to enhance thermal insulation of these wall panels. Based on this study, the average of peak heat flux reductions for PCMSIPs with PCM combination rate of 10% and 20% were 37% and 62% respectively (Medina et al., 2008).

Fig. 5. Carbon foam

c. Current building codes and engineering standards often require a particular wall as a shear-wall. This wall is typically connected to the foundation by using hold-down or tie-down. These two terms are commonly referred to the components systems utilised to secure the wall to foundation. Hold-down, as shown in Fig. 6, usually creates a path to transfer the force from shear wall to other parts of building. To overcome the difficulty for shear wall-foundation connections, SIP with a structural chase or cavity has been recommended by researchers to accommodate the connection between wall panel and anchorage device embedded in foundation (Porter, 2009).

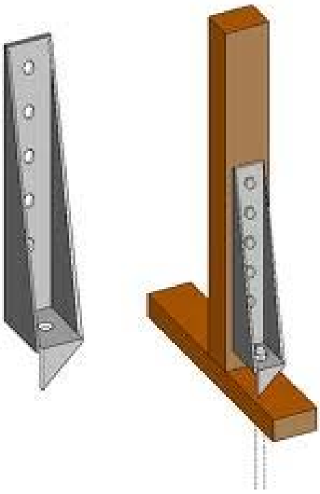

Fig. 6. Typical hold-down

d. Configuration of SIPs with respect to their joint connections to themselves and other structural members in building systems has been an issue among researchers. In 2004, few methods of SIPs configuration have been suggested to build the secure connection in a sealed manner (Porter, 2004). In this configuration, the edges of SIP are connected together with designed cavity as shown in Fig. 7. Plates and adjacent studs are also used to connect the SIP to the windows and doorjamb. The configuration may include a clamp inserted in a core to receive the fastener so that the adjacent panel can be secured (Porter, 2004).

Fig. 7. Typical joint connection of SIP

The above section aims to address the need for a new design of SIP which shall be considered by researchers for further studies.

7. SIP Advantages

This review serves as a base for future studies to overcome the SIP drawbacks. It has gone some way toward enhancing our understanding of SIP drawbacks so that further studies can improve these drawbacks. Thus, the advantages of SIP are briefly discussed in this paper. SIP as a prefabricated member of building has advantages of minimal material wastage, less site material, controlled quality, keeping neater and safer construction site, faster project completion, labour-savingness, and lower total construction costs.

Lower weight of SIP compared to the conventional wall systems lead to the lower total weight of construction. Apart from reducing the seismic load, it also has better insulation values compared to conventional framing and insulation methods (Medina et al., 2008). According to the blower door test, SIP building may have approximately 85% more of air tightness potential than wood-framed building. Based on another study, energy costs can be reduced by 25 to 50 percent per year in SIP constructions (SIPA, 2008).

8. Future Studies Needed to Overcome SIP Drawbacks

Despite the advantages of SIP as discussed in the previous section, SIP suffers from several drawbacks. There are five issues that should be taken into consideration in further studies. These issues are as follows:

8.1. Affordability

As the economy has declined, the market for panel systems has become unaffordable compared to the onsite framers due to the lack of demand and immigrant labours. Recently, panel systems bid have become low. Thus, it is difficult for paneliser to compete for panel systems bids. As an example, Burton lumber company in Salt Lake City has recently stopped working on panel systems due to the low wages of immigrant labours which has caused onsite framing methods more affordable. Nonetheless, SIP production industry has continued to struggle in surviving in the building market where available and low-cost labour helps on-site framing (Porter, 2009; Shields, 2011; Smith, 2011).

8.2. Onsite Unchangeable Design

There cannot be any design changes for SIP building on site. The prospective buyer has to make all decision of the building design and sign off the drawing before the construction starts. The dimension of foundation must be accurately measured and constructed so that it can be fitted perfectly with SIPs (Shields, 2011).

8.3. Insect Nesting

Rodents and insects can nest inside the spaces of SIP, particularly between the joint connections as the insulation is an ideal habitat (Taha, 2011). In some cases, pests can burrow through the panels. Studies have shown that boric acid is an effective insecticide to eliminate the pests (Shields, 2011). However, the application of boric acid has not gained its popularity in the market.

8.4. Breathability

SIP structure, which is almost hermetically sealed, may affect the permeability of the members made of SIP, particularly wall. Thus, mechanical ventilation system is required to ensure environmental performance and indoor air quality (Shields, 2011; Taha, 2011).

8.5. Competitiveness of Custom-Designed Panels

Some prefabricated SIP houses are comparable to other more conventionally framed houses, but these SIP houses come at a cost with custom designed panels (Taha, 2011; Wang et al., 2009).

According to the five drawbacks thereof, the challenges of SIP application such as cost effective, size effect, joint connections, strengthening and retrofitting against axial, flexural, and lateral load require future research to establish an optimum and standardised SIP system. Hence, the authors have undertaken some experiments under Housing Research Centre to evaluate the behaviour of SIP walls considering size effect, axial and lateral loading, as shown in Fig. 3, Fig. 4, Fig. 8, and Fig. 9. Based on the results thereof, it has been found that thermal resistance of SIP particularly with EPS core needs to be enhanced using fire resistant materials.

Fig. 8. SIP wall axial loading

(a) Panorama

(b) Side view

Fig. 9. SIP wall buckling from different view

9.Conclusion

In this paper, the characterisation of SIP is reviewed from the past to the present. The review of evaluating SIP application and its drawbacks clearly point to the need for further studies to progress beyond the current SIP to an improved one. According to this review, conclusions can be drawn as follows:

- Future SIP design shall overcome the current issue related to SIP joint connection in terms of the sealing and thermal insulation.
- Thermal resistance of SIP, particularly with the core which is made of Expanded Polystyrene needs to be enhanced by using cost-effective fire retardant in the further research.
- There is inadequate knowledge about repair and retrofit of SIP structures due to the processes involved.
- Affordability, onsite unchangeable design, insect nesting, breathability, and being uncompetitive with custom designed panels are the major drawbacks of SIPs which are served as a base for future studies.
- The range of different SIP prices and its affordability have not been sufficiently explored.

• However, far too little attention has been paid to the size effect on SIP behaviour with respect to the opening such as window and door.

This review discusses the SIP drawbacks that give direction to the improved further designs. Acknowledging the advantages and drawbacks of SIP, new idea and patents are needed to replace the SIP component with new material for an improved SIP. Therefore, future research shall look ahead at goal to obtain a SIP universal design standard.

Acknowledgements

The authors appreciate Housing Research Centre (HRC) and Naim Company for providing financial support and the requirements for this research. The author 1 is indebted to Taw Ly Wen, from Faculty of Modern Languages & Communications, UPM for her comments.

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