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AN INNOVATIVE STRUCTURAL INSULATED PANEL (SIP): EVALUATION OF DURABILITY PROPERTIES AND STRUCTURAL PERFORMANCE

Muhamad Alias Ghazali Baharudin [1] and Md Azree Othuman Mydin [1]
[1] Cluster of Technology, School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Pulau Pinang, Malaysia
Email: aliasghazali007@gmail.com[1] , azree@usm.my[2]

Abstract:
These days, the buildings we use consume significant quantities of materials and energy to build, and during their operational life. One technology that can improve building performance is structural insulated panel (SIPs) construction. SIPs are a high-performance building system for residential and light commercial construction. Hence this research will explore the idea on the development of this panels consist of an insulating foamcrete as a core sandwiched between two structural facings, by using the fiber cement board & magnesium oxide board. The main objective of this study is to observe and determine the structural performance of foamcrete in-filled fiber cement board and magnesium oxide board. For fiber cement board, there two thickness which is 8mm and 9mm, so do the MgO board which is the 6mm and 9mm thickness. There are 8 sets of each board for every thickness. To fabricate the core sandwich between two structural facings, C-channel steel is used. This metal framing channel is cold formed on modern rolling machines from low carbon steel manufactured. A continuous slot provides the ability to make attachments at any point. Then this C-channel are being placed at both sides if the board. After that, the 2 inches loose self-drill fiber cement screws are used to make sure all this member been held together. The spacing of the screw is 100mm with the 50mm start point from the top. The densities of the infill material are 1000kg/m^3 and 1400kg/m^3. The results have illustrated that SIPs perform as an effective composite material possessing considerable strength and stiffness necessary to sustain required design loads. The creep effects under a series of axial compression loads (much higher than the normal intended loading) are negligible and the panel recovered after load removal. Also, there was no de-bonding or bulging of the boards.

Keywords: Magnesium oxide, Composite walling, Foamed concrete, Sandwich panel, Structural insulated panel

1.0 INTRODUCTION

Although foamcrete has low mechanical properties compared to normal weight concrete, there is a possibility of using this material as partition or load-bearing wall in low-rise residential construction (Mydin et. al, 2015). Foamcrete is defined as a cementitious material having a minimum of 20 per cent by volume of mechanically entrained foam in the mortar slurry in which air-pores are entrapped in the matrix by means of a suitable foaming agent (Jones & McCarthy, 2005). The emergence of structural insulated panel (SIPs) has driven construction industry in thermal boundary applications (Costa et. al, 2008). SIPs usually have frame members which are needed to be assembled at their joints (Cooke, 2000). Application of sealant in these joints is necessary to prevent condensation from infiltrating and reduce air leakage and heat loss through the joints (Alison, 2014). However, application of sealant is sloppy, time-consuming, and it often results different degrees of effectiveness based on the installer expertise (Soleimanzadeh & Mydin, 2013). SIP skin is commonly made of wood material because of its low cost and good thermal insulation properties compared to metal frames. 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 regarding the joint insulation was put forward by the researchers. In this design, SIPs are connected with designed cavity on the sides of panels.

2.0 LITERATURE REVIEW

There is a variety of SIP skin materials suggested by researchers based on their advantages and SIP application such as metal, fiber cement, cement, calcium silicate, gypsum, and oriented strand board. 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). Among the common SIP skins, OSB (Oriented Strand Board) 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 utilized as partition wall that are not exposed to moisture (Alison, 2014).

In order to using a fibre cement board, there are some studied assessment of the durability of a fibre-cement board in wet and dry conditioning, freeze and thaw, and soak and 4 dry cycles has been done. Wet conditioning resulted in an increase in the toughness and ductility of fibre-cement boards and a decrease in the ability to resist flexure; Soaking, drying, and exposure to warm water tests resulted in the reduction of toughness by 25, 35, and 15%, respectively; Soaking, drying, and exposure to warm water tests resulted in the reduction of ductility of the specimens by 26, 32, and 22%, respectively; Soaking, drying, and warm water tests had no significant effects on flexural resistance and the MOR of the fibre-cement specimens; Freezing and thawing have minor effects on the flexural behavior in both longitudinal and cross-sectional directions of specimens especially after 25 cycles; and Ductility and toughness should be included in the assessment of the durability performance of fibre-cement sheets (Cooke, 2000).

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 utilizing carbon foam as core (Miller et al., 2010). 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 (Costa et. al, 2008).

3.0 METHODOLOGY

Portland cement type 1 was used which comply to BS 12:1996 standard. Fine sand was used which was supplied by a local distributor. Protein based foaming agent namely, Noraite PA-1 was chosen to be used in this study due to its stable and smaller bubbles and its stronger bonding structure of the bubbles in comparison to the synthetic based surfactant (Li et. al, 2012). The ratio between surfactant and water used is 1:32 (Amran et. al, 2015). In turn to create a stable foam, 1 liter of protein surfactant was diluted into 32 liters of water. Portafoam TM-2 foam generator was used to produce stable foam which has volume weight approximately 2 gram/liter. Water to cement ratio that been used for this research is 0.45 as it had achieved reasonable workability of foamed mortar (Mydin & Wang, 2012).

The main objective of this study is to observe and determine the structural performance of foamcrete in-filled fiber cement board and magnesium oxide board. For fiber cement board, there two thickness which is 8mm and 9mm, so do the MgO board which is the 6mm and 9mm thickness. There are 8 sets of each board for every thickness. To makes a core sandwiched between two structural facings, C-channel steel is used. This metal framing channel is cold formed on modern rolling machines from low carbon steel manufactured. A continuous slot provides the ability to make attachments at any point. Then this C-channel are been placed at both sides if the board. After that, the 2 inches loose self-drill fiber cement screws are used to make sure all this member been held together. The spacing of the screw is 100mm with the 50mm start point from the top. The densities of the infill material are 1000kg/m^3 and 1400kg/m^3. Figure 1 shows the preparation of outer skins of SIPs. On the other hand, Figure 2 demonstrates preparation of SIPs with foamcrete core.

Figure 1: Preparation of outer skins of SIPs

Figure 2: Filling the panel with foamcrete core

4.0 RESULTS AND DISCUSSION

Table 1 shows the results obtained from structural test to determine the maximum

Table 1: Structural test results

Types of panel	Outer skins	Load Carrying Capacity (N/mm^2)
Plain 1000 kg/m^3	-	2.64
Plain 1400 kg/m^3	-	5.01
Plain 1000 kg/m^3 + 0.3% coir fibre	-	3.48
Plain 1400 kg/m^3 + coir 0.3% fibre	-	6.61
1000 kg/m^3	9mm MgO Board	6.74
	8mm Cement Board	5.56
	9mm Cement Board	8.81
1400 kg/m^3	9mm MgO Board	9.57
	8mm Cement Board	8.27
	9mm Cement Board	10.95
1000 kg/m^3 + 0.3% coir fibre	9mm MgO Board	7.95
	8mm Cement Board	6.44
	9mm Cement Board	9.12
1400 kg/m^3 + 0.3% coir fibre	9mm MgO Board	11.56
	8mm Cement Board	10.02
	9mm Cement Board	12.88

Figure 3 shows the mode of failures for plain foamcrete of 1000 kg/m^3 density. Primarily the cracks occurred near in the side surface of the panel. Then the shear stress along the diagonal of the samples was clearly formed at ultimate stage. Failure mode was brittle failure (brittle fracture) due to low stiffness and high ultimate (yield) strain. Plain panel experience high elastic deformation, abrupt collapse and complete densification

Figure 3: Failure mode of plain foamcrete of 1000 kg/m^3 density

Figure 4 demonstrates the failure mode of structural insulated panel of 1000 kg/m^3 density core and 8mm fiber cement board outer skins. Failure of the panel was initiated by buckling of the cement board, followed by crushing of the foamcrete core. Although the cement board outer skin provided some ductility to the panel, the 8mm cement boards were not able to provide much confinement effect to the foamcrete core. The line of mechanical connectors (screw@100mm) should not be a problem. The cement board buckled & the screw stopped that.

Figure 4: Failure mode of plain foamcrete of 1000 kg/m^3 density core and 8mm fiber cement board outer skins

On the other hand, Figure 5 demonstrates the failure mode of structural insulated panel of 1000 kg/m^3 density core and 9mm fiber cement board outer skins. The 9mm outer skin cement boards were able to offer better ductility compared to 8mm outer skin and were able to provide some confinement effect to the foamcrete core. Mode of failure was buckling of the cement board, followed by crushing of the foamcrete core. No separation of cement board from the foamcrete core until near failure, indicating that the mechanical fasteners (screw) could hold the board & the foamcrete core together to enable them to resist the applied load in composite action.

Figure 5: Failure mode of plain foamcrete of 1000 kg/m^3 density core and 9mm fiber cement board outer skins

Figure 6 demonstrates the failure mode of structural insulated panel of 1000 kg/m^3 density core and 9mm MgO board outer skins. The 9mm outer skin MgO boards not able to offer much ductility compared to cement board. The MgO board tends to break easily. Mode of failure was separation & buckling of MgO board outer skin, followed by crushing of the foamcrete core. There was separation of MgO from the foamcrete core until near failure, indicating that the mechanical fasteners (screw) were not able to hold the MgO board and the foamcrete core

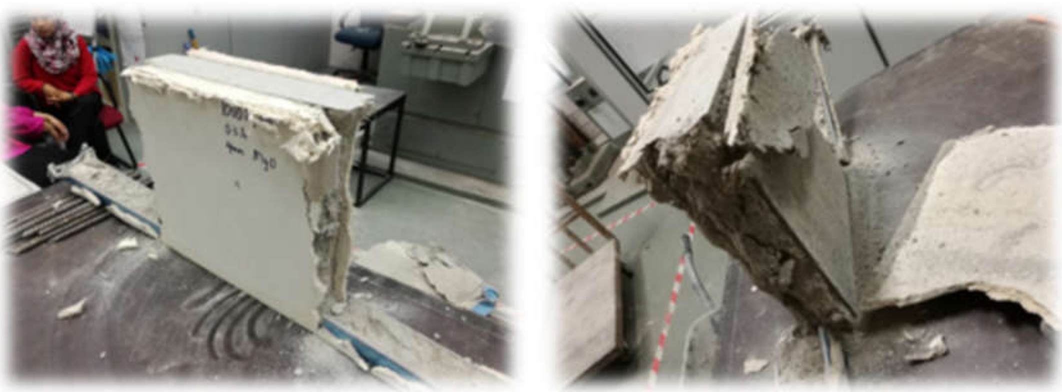

Figure 6: Failure mode of plain foamcrete of 1000 kg/m^3 density core and 9mm MgO board outer skins

5.0 CONCLUSION

This research explores the idea on the development of structural insulated panel (SIPs) this panels consist of an insulating foamcrete as a core sandwiched between two structural facings, by using the fiber cement board & magnesium oxide board. The main objective of this study is to observe and determine the structural performance of foamcrete in-filled fiber cement board and magnesium oxide board. For fiber cement board, there two thickness which is 8mm and 9mm, so do the MgO board which is the 6mm and 9mm thickness. There are 8 sets of each board for every thickness. To makes a core sandwiched between two structural facings, C-channel steel is used. This metal framing channel is cold formed on modern rolling machines from low carbon steel manufactured. A continuous slot provides the ability to make attachments at any point. Then this C-channel are being placed at both sides if the board. After that, the 2 inches loose self-drill fiber cement screws are used to make sure all this member been held together. The spacing of the screw is 100mm with the 50mm start point from the top. The densities of the infill material are 1000kg/m^3 and 1400kg/m^3. The results have illustrated that SIPs perform as an effective composite material possessing considerable strength and stiffness necessary to sustain required design loads. For plain foamcrete panel (without outer skin), failure mode of panel was brittle failure which was due to low stiffness and high ultimate (yield) strain. 9mm outer skin cement board with foamcrete core SIP achieved highest load carrying capacity for both densities. The 9mm cement boards were able to offer better ductility compared to 8mm outer skin and were able to provide some confinement effect to the foamcrete core. MgO of 9mm thickness not really suitable to be used as outer skin for SIP as it tends to break easily under axial compression. If MgO outer skins want to be used, we might need thicker size (15mm to 20mm). There is a potential to utilize this SIP panel in Malaysia but there is a need to perform more research on its structural behavior and thermal conductivity if this panel to be used as external wall in construction.

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