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Effects of Insulation Types on In-Plane Shear Behavior of Insulated Concrete Sandwich Wall Panels with GFRP Shear Connector

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Abstract

This paper describes the in-plane shear behavior of insulated concrete sandwich wall panels (CSWP) reinforced with corrugated glass fiber-reinforced polymer (GFRP) shear connector. The study included testing 8 insulated CSWP specimens with different types of insulation and corrugated shear connector. All specimens were loaded in direct shear. The test variables were embedment depth of shear connector and removal of adhesive stress between insulation and concrete. Test results indicated that the reinforcement of corrugated GFRP shear connector significantly increased in-plane shear strength. And dispersion reinforcement will be more effective in the case of expanded polystyrene (EPS) insulation. Meanwhile, reinforcement at a degree close to 45° will be more effective in the case of extruded polystyrene with surface treatment (XPSS) insulation. Increase of embedment depth of shear connectors was able to restrain pull-out phenomenon of shear connectors. And removal of adhesive force of insulation tended to decrease in-plane shear strength.

Keywords: Insulated concrete sandwich wall panels, Glass fiber-reinforced polymer, Shear connector, In-plane shear

1 Introduction

To ensure zero-carbon emission buildings, it is essential to minimize heat loss through the building envelope. The inside insulation system, which is used for most of the existing apartment houses in Korea built in the 1980's, attaches insulation to the inside of walls. Despite the simple and economical nature of this method, it causes heat bridges due to the gaps in insulation at the joint areas of slabs and inner walls [1]. The outside insulation system, which was proposed to compensate for this weakness, attaches insulation to the outside of walls. This method offers the benefit of minimized gaps in insulation and high thermal performance. However, installation and maintenance of insulation are difficult when this method is applied to high-rise buildings. The insulated concrete sandwich wall panels (CSWP) system inserts insulation between the inner and the outer concrete wall. With precast panels or cast-in-place materials, this method compensates for the weakness of difficult installation and maintenance of the existing outside insulation method. Unlike the existing insulated CSWP system, which used to cause the problem of condensation at inner and local surface due to gaps in insulation, which is installed inside the space between building blocks and outer walls, this method provides a high insulation performance by minimizing discontinuous space.

According to a report by PCI (1997, 2011)[2-4] regarding precast and pre-stressed insulated CSWP, insulated CSWP can be classified into non-composite walls, complete-composite walls, and partial-composite walls according to the composite behavior of the inner/outer concrete against load. The level of composite behavior is decided based on the adhesive stress between concrete and insulation, and the shear transfer capability of shear connectors. In addition, different design methods are proposed subject to the level of composition. As it is difficult to clearly define the level of composite behavior for partial-composite walls, insulated CSWP is generally designed with non-composite walls.

For improving the structural performance of insulated CSWP, studies were conducted on reinforcing concrete with metal truss, bent-type shear connectors, or shear connectors which feature bored cores in insulation. In addition, studies on the behavioral characteristics and design methods of walls have been actively carried out [5]. While the introduction of shear connectors has been proven to improve the structural performance of insulated CSWP, it has exposed the problem of diminished insulation performance, which is caused by partial heat bridge phenomenon created by the high thermal conductivity of steel materials and concrete.

Recently, studies have been actively conducted to find out the methods of satisfying not only the structural performance but also insulation performance of insulated CSWP by adopting fiber-reinforced polymer (FRP) [6], which has lower thermal conductivity than steel and concrete, as shear connectors. This study, as part of the study of insulated CSWP system development conducted by the Korea Institute of Construction Technology, was conducted for the following purposes: to verify the structural performance of the glass fiber-reinforced polymer (GFRP) shear connector, which has been independently developed in Korea; to analyze their impacts on variables that affect bending behavior of insulated CSWP; and to provide experimental data and test results that can be utilized as basic data for future studies on flexural behavior of insulated CSWP.

2 Experimental Program

For the investigation of in-plane shear behavior of insulated CSWP reinforced with corrugated GFRP shear connectors, experimental programs were planned as shown in Table 1. The insulated CSWP specimens were categorized into two experiment groups, based on the types of EPS (expanded polystyrene) and XPSS (extruded polystyrene with surface treatment). The experiments were conducted with the variables of surface condition of insulation, and type of GFRP wave-form shear connectors. For shear connectors with 12 mm and 18 mm width, tests were conducted for embedment depths of 35 mm and 40 mm. Thickness of insulation was basically arranged to be 100 mm pursuant to the standard of insulation performance test in Korea, and experiments were conducted with reduced thickness to set the embedment depth as a variable.

2.1 Test specimens

To evaluate the structure performance of insulated CSWP, it is needed to identify the flexural and shear behavior under wind load through bending test on walls. However, in consideration of miniature modeling, experiment costs, limitations of locations, and the uncertainty of unverified shear connectors, which are characteristics of bending test, direct shear tests were conducted on insulated CSWP. The ICC Evaluation Service proposes [7] to prepare direct shear test specimens for verifying shear connectors reinforcing walls of insulated CSWP as

Table 1. Summaries of insulated CSWP specimens

Specimen	Type of insulation	Shear connector width-pitch [mm]	Embedment depth [mm]	Thickness of insulation [mm]
EPS 12-30	EPS insulation	12-200	30	100
EPS 18-30		18-300		
XPSS 12-30	XPSS insulation	12-200	30	100
XPSS 12-35			35	90
XPSS 18-30		18-300	30	100
XPSS 18-40			40	80
Non-bond 12-35		12-200	35	90
Non-bond 18-40		18-300	40	80

shown in Fig. 1. Based on the relevant standards, this study was conducted with specimens that have 600 mm width and 1,200 mm height. Even though the actual insulated CSWP is composed of 2 concrete walls and insulation layer, double-surface direct shear test specimens, which are composed of 4 unit panels that are 300 × 1,200 mm in size, were prepared to form the load-bearing area and supporting area for the direct shear test. Shear connectors are placed at the center of the unit panel, and a pair of shear connectors was placed in the case of wave-form shear connectors. All specimens were vertically constructed and in fabricating specimens, insulation was cut, shear connectors were reinforced and fixed to the form, and concrete was casted into the form. In fabricating specimens of non-bond insulation, specimens were made by attaching laminating film and paper on the surface of insulation, and reinforcing shear connectors.

2.2 Material properties

Conventional ready-mixed concrete with coarse aggregates with a maximum size of 25 mm, specific concrete compressive strength of 30 MPa, and slump value of 150 mm were used in this study. The compressive test was conducted with 28 day-aged concrete specimens prepared in the form of a cylinder that is Ø100 × 200 mm in size, and with the compressive test specified in the standard of ASTM C 39[8] using 2,000 kN capacity universal testing machine. The compressive test resulted in an average compressive strength of 34 MPa for 3 specimens.

In a previous study [1], in the case of existing XPS insulation, adhesive stress between concrete and insulation has been remarkably decreased to cause some separation between the concrete and insulation during transportation. In addition, the test results of the in-plane shear force showed lower adhesive stress compared with that of EPS insulation, resulting in rapid separation and breakdown of the adhesion surface between the concrete wall and the XPS insulation. Accordingly, for this study, XPSS insulation was prepared by treatment of rough surface and 10 mm square grooves on XPS insulation for improving its mechanical adhesion.

The shapes and reinforcement details of the corrugated GFRP shear connectors used in this study are shown in Fig. 1. The shear connectors were equally set to be 160 mm high and 5 mm thick, and their pitches were fabricated with 200 and 300 mm in size. To analyze the impact of pitches, shear connectors were arranged to have 300 mm width compared with 200 mm pitch so that sectional area of reinforcement for the corrugated GFRP shear connector per unit can have the same value. The tensile strength test resulted in 417 MPa (standard deviation: 6.35) of average tensile force for the connectors having 200mm pitch, and 430 MPa (standard deviation: 13.47) for connectors having 300 mm pitch.

2.3 Test set-up for CSWP specimens

As shown in Fig. 1, load was applied by the displacement control method with hydraulic jack load equipment having 1,000 kN capacity fixed on the reaction frame. For measuring relative slip, which occurs on the adhesion surface of concrete walls and insulation, an aluminum frame was installed on both walls, anchors were installed

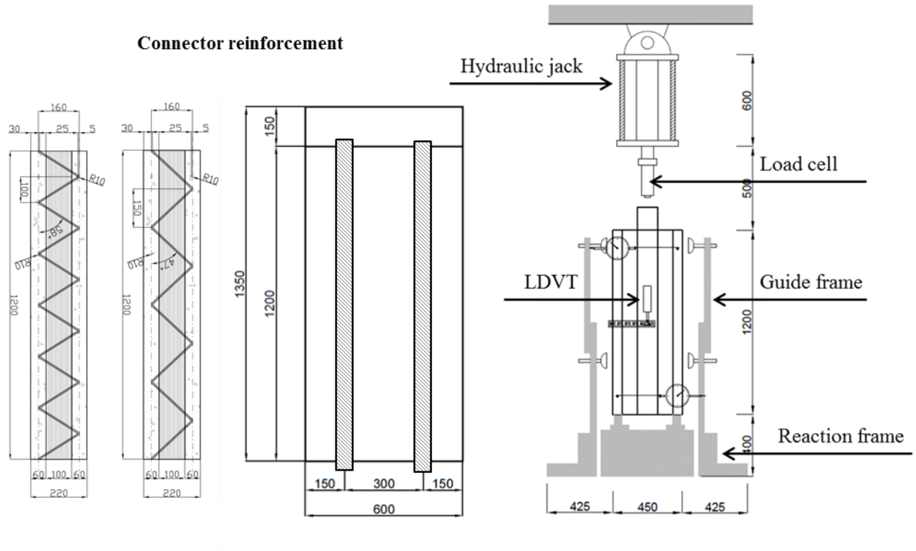


Figure 1 Reinforcement details of specimen and test set-up

on the central area of the wall, and the inter-wall slip was measured with SDT (strain displacement transducer) attached on the front and the rear of the wall. To prevent overturning of the specimens, a guide frame was installed. And the measuring was conducted until the point at which further application of load to the specimens was not possible as fracture concentrated on one side of the shear section after the maximum load.

3 Test results and discussion

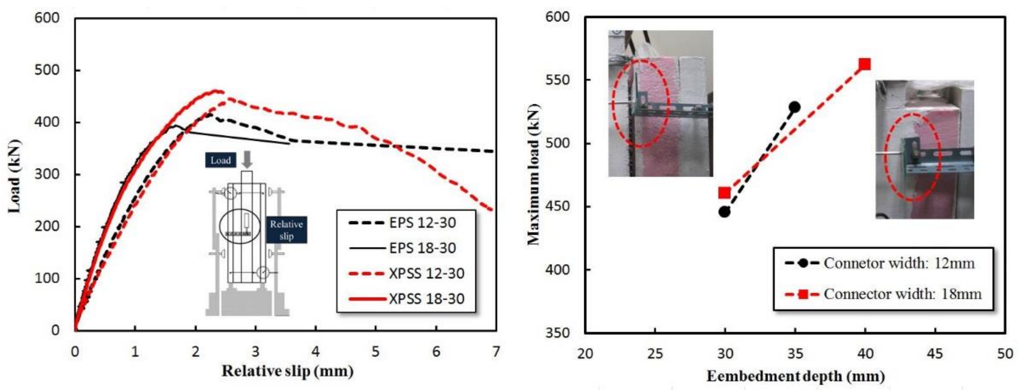
3.1 Effects of insulation type and shear connector pitch

In case of EPS insulated CSWP, shear cracking of insulation was followed by expansion of the cracks on the adhesion surface of concrete and insulation, which led to fracture of the adhesion surface. Also residue of insulation existed on the concrete wall after the completion of the test. On the other hand, when XPSS insulation was used, no shear crack occurred in the insulation, but some slight fractures were observed due to the slip phenomenon on the adhesion surface. This concludes that, in the case of EPS insulated CSWP, as the shear resistance of the insulation was strong between concrete and insulation, it caused fracture of insulation due to the shear resistance occurred by the complete adhesion of insulation. And in the case of XPSS with relatively high shear resistance, it can be concluded that its adhesive stress is weaker than the shear force, and that the higher adhesion will improve in-plane shear strength of insulated CSWP. Fig. 2 (a) shows the effects of insulation type and GFRP shear connector pitch on in-plane shear behavior of insulated CSWP specimens. As shown in the figure, the XPSS insulated CSWP showed higher in-plane shear strength, and higher fracture load of GFRP shear connectors. It is remarkable that such result was caused by the high shear resistance of XPSS insulation.

The EPS12-30 specimen showed higher in-plane shear strength than the EPS 18-30 specimen. On the other hand, the XPSS12-30 specimen showed smaller in-plane shear strength than the XPSS 18-30 specimen, which was different from the cases of EPS insulation. It is deemed that the physical characteristics of insulation affect the reinforcing method of shear connectors. Therefore, it can be concluded that dispersion reinforcement will be more effective in the case of EPS insulation, while shear surface having better mechanical properties. And, reinforcement with corrugated GFRP connector at a degree close to 45° will be more effective in the case of XPSS insulation. And increase of pitch with the same reinforcement section area tended to show minute increase in the relative slip at peak load.

3.2 Effects of embedment depth of shear connector

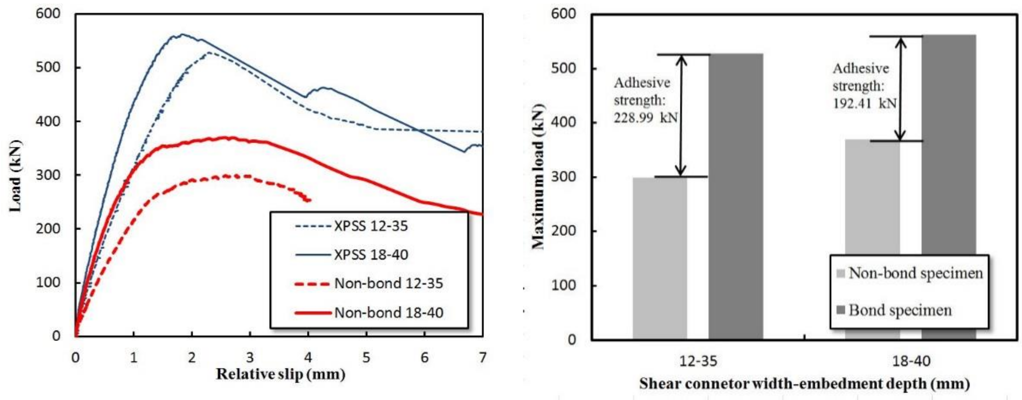
Fig. 2(b) shows the effects of embedment depths on the maximum in-plane shear strength of insulated CSWP. Increase of embedment depth tended to increase in-plane shear strength. It is deemed that decrease of insulation thickness caused decrease of bending moment that is applied to the shear connector. Therefore, relative slip at peak load decreases according to the increase in embedment depth. Also increase of embedment depth delayed pull-out phenomena of shear connectors. It can be concluded that this phenomenon affects the facture behavior of insulated CSWP after the peak in-plane shear load. The pull-out phenomenon occurred a lot on the upper area of specimens, but did not occur as much in the lower area. In the case of specimens reinforced with 12 and 18 mm width corrugated GFRP shear connectors, pull-out phenomenon occurred on non-fractured shear connectors at the embedment depth of 30 mm, but it did not occur in the case of specimens with 12 mm width at the embedment depth of 35 mm and 18mm width at the 40 mm embedment depth.



(a) Effects of insulation and shear connector pitch

(b) Effects of shear connector embedment depth

Figure 2 In-plane shear behavior of insulated CSWP specimens



(a) In-plane shear behavior of specimens

(b) Adhesive strength of specimens

Figure 3 Effects of adhesive stress on in-plane shear strength of insulated CSWP specimens

3.3 Effects adhesive stress on in-plane shear strength of insulated CSWP

Removal of adhesive stress tended to decrease in-plane shear strength insulated CSWP, and Fig. 3(a) shows the effects of adhesive stress between insulation and concrete on relationship of the load-relative slip of insulated CSWP specimens. The adhesive stress of between insulation and concrete was related with the relative slip at peak load, was calculated through the experiment results. Fig. 3(b) shows the effects of adhesive stress on in-plain shear strength. The insulation adhesive strengths for XPSS12-35 and XPSS18-40 were 228.99 and 192.41 kN, respectively.

4 Conclusion

The conclusion of the experiment is summarized as follows:

1) XPSS insulation, which was prepared by applying treatment of rough surface and 10mm groove, showed higher adhesive stress than EPS insulation and existing XPS insulation. It is deemed that the higher adhesion stress will improve in-plane shear strength of insulated CSWP.

2) In terms of impact of pitch, even though it was expected that the specimens with 300 mm pitch, according to the mechanical properties, would show higher in-plane shear strength than the specimens with 200 mm pitch the specimens with 200 mm pitch were found to show higher in-plane shear strength in the case of EPS insulated CSWP. It is considered that dispersed reinforcement of the in-plane shear strength of EPS insulation would be better. Therefore, in applying shear connectors, the properties of insulation must be identified.

3) Increase of embedment depth of shear connectors also increased in-plane shear strength. However, it is deemed that such result was observed since the decrease of insulation thickness caused decrease of the bending moment applied on the shear

connectors, not because the insertion depth directly affected in-plane shear strength. With sufficient insertion depth, it was possible to restrain pull-out phenomenon of shear connectors, and to achieve stable fracture shape.
4) Removal of adhesive stress of insulation and concrete tended to decrease in-plane shear strength. In addition, different relative slips of shear connectors showed different contribution portions of adhesive stress.

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