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Thermal performance of precast concrete sandwich walls with a novel hybrid connector

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A B S T R A C T

This paper presents the experimental and numerical studies on the thermal responses of precast concrete sandwich (PCS) walls with a novel hybrid connector. The hybrid connector is wrapped with nylon, which is shown to reduce the thermal bridge and improve the thermal performance of PCS wall. In the first part of this work, four PCS walls were fabricated for the experimental studies and the effects of hybrid connector, insulation layer thickness and insulation material on the thermal performances of PCS walls were experimentally evaluated. Then, the finite element (FE) method was adopted to conduct the heat transfer analyses on PCS walls. The accuracies of the FE models were verified via comparing the temperature and thermal transmittance versus time of PCS walls obtained from experiments and FE analyses. The FE models were subsequently used to investigate the effects of wrapped nylon, thermal conductivity, connector spacing, central rebar diameter and insulation layer thickness on the thermal performance of PCS walls. It was found that the thermal performance of PCS wall could be improved via wrapping the connector with nylon, reducing the materials' thermal conductivities, increasing connector spacing and insulation layer thickness as well as reducing central rebar diameter.

1. Introduction

Energy shortage problem has become increasingly serious for recent decades and up to 30% of total energy consumption is via the operation of buildings in China [1]. Since the energy loss is mainly through the exterior wall of a building, it is of significance to introduce the exterior wall with high thermal resistance to reduce the energy losing. On the other hand, precast concrete walls are increasingly adopted for the building constructions, which can further reduce the energy consumption during the construction stage. In this work, a precast concrete sandwich (PCS) wall (shown in Fig. 2), which consists of inner wall, insulation layer, outer wall and a novel hybrid connector, was proposed and its thermal performance was experimentally and numerically studied.

The PCS wall usually consists of two (or three) concrete layers and one (or two) insulation layers and shows good thermal performance, thus attracting a considerable amount of interest [2-8]. The incorporation of hollow-core into the thermal resistance design of a building can be an effective way to improve the thermal performance [9,10]. Hence, the Building-Integrated Thermal Energy Storage (BITES) approach was proposed by combing the active thermal energy storage of hollow-core masonry block walls and precast concrete slabs [10], which could offer a significant amount of effective mass for relatively fast thermal energy storage and release and therefore significantly improve buildings' thermal performance. As for the precast two-wythe sandwich walls with two concrete wythes and one insulation layer, the thermal bridge effect could be significant due to the interruption of the continuous insulation layer by wythe connectors [8,11]. Hence, Lee and Pessiki [5,6] developed several PCS walls with three wythes and two insulation layers and the thermal performance of precast concrete three-wythe sandwich wall could be improved as compared to the two-wythe wall via comparison of thermal resistance (*R*-value). This was because the three-wythe wall could stagger the connections between successive concrete wyhtes and extend the total thermal path length through the concrete, which weakened thermal bridge effect [6]. Another potential approach to reduce thermal bridge effect of precast concrete two-wythe sandwich wall was to replace the concrete wythe connectors with metal connectors which had significantly less cross area [7,8]. It was found by Kim and Allard that the shape of the connectors could significantly affect the thermal efficiency of the sandwich system in cold region

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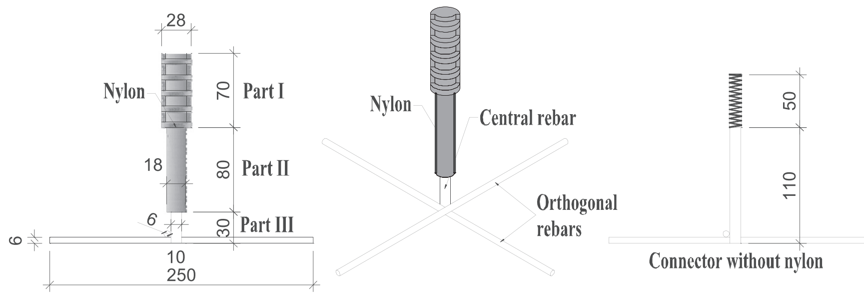

Fig. 1. Dimensions of proposed hybrid connector.

environment and increasing connector spacing could also improve the thermal resistance [8]. In this work, a novel hybrid connector wrapped with nylon was proposed to further reduce the thermal bridge effect and therefore the thermal performance of PCS wall could be improved. Besides, the mechanical performance of the hybrid connector under in-plane shear and out-of-plane tension force were also experimentally studied and good mechanical connection of the hybrid connector was demonstrated [12,13]. Both the research works on the mechanical behavior (in Ref. [12] and [13]) and thermal performance of hybrid connector presented in this paper can promote its application in precast concrete structures.

In the first part of this work, the thermal performances of four PCS walls with novel hybrid connectors were experimentally evaluated via comparing the thermal resistance and thermal transmittance. In the second part of this work, the finite element (FE) method, which was usually used to conduct the heat transfer analysis [14-21], was also employed herein to study the thermal performances of PCS walls. In addition, the effects of wrapped nylon, materials' thermal conductivities, connector spacing, central rebar diameter and insulation layer thickness on the thermal performances of PCS walls were also investigated.

2. Experimental study

2.1. Hybrid connector introduction

The hybrid connector is a vital component to assure the integration of PCS wall via connecting the inner wall, insulation layer and outer wall. As illustrated in Fig. 1, the proposed hybrid connector consists of three parts which are integrated by a central rebar with diameter of 10 mm. Part I of the connector (100 mm in length) is wrapped with grooved nylon and embedded into inner wall. Part II of the connector with length of 80 mm (or 100 mm) is wrapped with plain nylon and passes through the insulation layer. The length of part II can be adjusted according to the thickness of insulation layer. The rest part (Part III) of the connector with length of 30 mm is embedded into outer wall. Two rebars with length and diameter of 250 mm and 6 mm, respectively, are orthogonally welded to the end of central rebar in Part III in order to enhance the bonding between Part III and outer wall. Both Part I and Part II of the connector are wrapped with nylon in order to reduce thermal bridge effect and protect the central rebar from corrosion.

2.2. Design of specimens

Four PCS walls were fabricated for the thermal performance test. The varying parameters of PCS wall include insulation material, insulation layer thickness and hybrid connector. All the four walls have the same dimension of 1500 mm × 1500 mm and the thicknesses of inner wall and outer wall are 200 mm and 50 mm, respectively. Two materials are adopted for the insulation layer, including polyurethane (PU) and expanded polystyrene (EPS). In addition, two insulation layer thicknesses of 80 mm and 100 mm are also employed for the wall fabrication. The dimensions of the PCS walls are shown in Fig. 2 and the details are summarized in Table 1. As shown in Fig. 2, the hybrid connector at the center of the wall is removed for wall PU-80-N to stand for the case without hybrid connector. Hence, the effects of hybrid connector, insulation layer thickness and insulation material on the thermal performances of PCS walls can be evaluated by comparing PU-80-Y and PU-80-N, PU-80-Y and PU-100-Y, as well as PU-100-Y and EPS-100-Y. The casting steps of PCS wall are shown in Fig. 3 and described as follows: (1) placement of mold and rebars of outer wall shown in Fig. 3(a), (2) casting the 50 mm thick outer wall shown in Fig. 3(b), (3) placement of insulation layer shown in Fig. 3(c), (4) placement of rebars of inner wall shown in Fig. 3(d) and (5) casting the 200 mm thick inner wall.

2.3. Experimental setup and instrumentation

In order to evaluate the steady-state thermal performances of the PCS walls, the BES-DL hot box and cold box (shown in Fig. 4(a)) were placed at two sides of the PCS wall with the hot box on the inner wall and cold box on the outer wall. During the whole test, the temperature was specified as 40 °C and −10 °C for the hot box and cold box, respectively. This test approach can provide a steady heat transfer scenario. The power of the BES-DL hot box and cold box was supplied by a power supplier in Fig. 4(b). Four heat flux meters were glued to the inner wall at the center as shown in Fig. 4(c) to measure the heat flux. Eight thermocouples were employed to measure the temperature with four thermocouples glued to the inner wall at the center and the rest glued to the outer wall. The four thermocouples on the outer wall are shown in Fig. 4(d). The four heat flux meters and eight thermocouples can be divided into four measure groups and each measure group includes one heat flux meter and two thermocouples with one glued to the inner wall and the other glued to the outer wall. The data from one of the measure group was recorded by the BES-Aa data logger in Fig. 4(e) and the data from the rest three measure groups were recorded by the BES-GT data logger in Fig. 4(f). The measured data were automatically logged at interval of 10 min. It should be mentioned that the data recorded by the BES-Aa data logger is only used for real-time monitoring and the data from the BES-GT date logger is used to evaluate the thermal performances of the PCS walls.

The dimensions of the hot and cold box are 1000 mm × 1000 mm and 1200 mm × 1000 mm, respectively, both of which are smaller than the dimension of PCS wall (1500 mm × 1500 mm). In order to impede the heat loss from the perimeters of PCS wall, the hot box, cold box and PCS wall were tightly clamped together with their centers aligned, as shown in