Thermal Resistance of Two Layers Precast Concrete Sandwich Panels

Abdul Aziz Farah N. A., Sani Mohammed Bida, Abu Bakar Nabilah, Mohd Saleh Jaafar, and Farzad Hejazi

***Abstract*—The main difference between normal precast wall and precast sandwich wall panel (PCSP) is the thermal insulation layer which is introduced not only to reduce the weight of the panel but more importantly is to improve the thermal resistance of the panel. Besides the type of insulation material, thermal performance of the sandwich wall panel is also influenced by the arrangement of the shear connector and the contact area between the concrete layers. This approach eliminates the direct transmission path between the two concrete layers at the same time. Hence, this study is conducted to determine the influence of shear connector spacing to the thermal path of PCSPs. A total of four specimens and each size of 500 mm x 500 mm by 150 mm thickness was prepared for the Hot Box Test. The staggered shear connector is spaced at 200 mm, 300mm, 400mm for P2, P3 and P4 specimen, respectively. While the control (P0) have steady shear connector at 200mm spacing. Based on the results, the control specimen achieved the highest thermal conductivity and the lowest is achieved by P4, a panel with shear connector at 400 mm spacing. Hopefully this two layers PCSP will provide to the industry a lighter weight and higher thermal resistance load bearing wall panel in the near future**

***Index Terms*—Precast concrete, two layers sandwich panel, shear connection, thermal performance.**

I. Introduction

Industrialised Building System (IBS) or Precast Concrete System is described as a building system that requires prefabrication of precast components in factory or at site which are brought together to form a complete structure with minimum in-situ activities. This approach provides sustainable solution to overcome problems such as shortage of workers, increased cost of labour and inadequate concrete quality. It provides shorter construction time coupled with high quality control advantages of high strength, durability, thermal comfort and labour savings. IBS construction can be implemented in two stages, (a) productions of modular parts in a yard/factory, and (b) assemble for erection at the construction site. Therefore, very little finishing works are required at in-situ position saving both delivery time and cost of labour.

In modern architecture, one of the main emphasis is on sustainability through minimization of thermal transfer between outside and inner parts of buildings that can be achieved through the provision of insulation layer between the building components, thus, leading to the paradigm shift to precast concrete sandwich panel (PCSP) systems [1]. This is agreed by Gervásio *et.al.* [2], who highlighted the material efficiency and energy efficiency as two main factors contributing to the building's sustainability. The earlier is refers to the use of environmental-friendly materials and the minimization of construction waste both during construction and at the demolition stage of the building. While the latter is defined as the optimization of energy used during the building's service period for heating, cooling, lighting, etc. Introducing an insulation material to the building is one way of improving the energy efficiency of the building. Thus, PCSP system have gained popularity in civil engineering applications due to its thermal performance [3], [4].

PCSP offers better thermal efficiency than other traditional masonry or solid wall building construction methods due to the insulation layer created between the concrete layers. The two concrete layers are separated through the insulation layer and are connected by the shear connector to ensure the two concrete layers act as one panel. Therefore, types of insulation and shear connector materials are important because they significantly affects the PCSP behaviour in terms of strength. Also, connection points between the layers that referred to as thermal bridges are the main contributor to the thermal transfer from one side of the panel to another [5]-[8]. Hence this paper presents the thermal bridge approach by using different thermal path length to study the heat transfer between the two surfaces of PCSP.

II. Experimental Program

A. Materials

Grade 40 concrete was designed for the two layers and a connection area. Only granules of less than 10mm diameter was used as coarse aggregates in the mix together with sand and cement. The ratio of water to cement was 0.4. The concrete layers are reinforced by 6mm diameter steel wire mesh at 100mm spacing in both directions. The wire mesh is a mild steel with yield strength of 250 MPa while the longitudinal bars is a high strength steel with yield strength of 500 MPa. The shear connector was made of 10mm high strength steel in '∩' shape and tied to the steel wire mash on both legs. All the polystyrene materials were glued to the dry surfaces of the precast concrete panels after curing using

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polystyrene friendly adhesives.

B. Specimen Details

The two layers precast concrete sandwich panel (PCSP) is a composite panel consists of two numbers of 40mm thick concrete layers and an insulation layer of 70mm polystyrene. The overall size of each specimen was 500 x 500 x 150 mm. The two concrete layers were connected through a shear connector and two longitudinal steel reinforcement of 10mm diameter each. Fig. 1 shows staggered shear connectors positions on both concrete layers. The shear connectors wee placed as such in order to prevent direct thermal bridges. The spacing between the shear connectors are 200, 300, and 400 mm centre to centre. This area is known as connection area and were made of 45mm x 150mm wide concrete and 25mm insulation layer as in Fig. 2. Specimens were designated as P2, P3, P4 and P0 for shear connectors spaced at 200mm, 300mm, 400mm and the control respectively. The control specimen was made with shear connectors at 200mm spacing spaced equally to allow direct thermal bridge on both concrete layers.

Fig. 1. Staggered shear connectors positioned on both concrete layers.

Fig. 2. Sample photo.

C. Casting Procedure

All dry materials were mixed in a portable mixer with 0.5m3 capacity until all material blended together. After that the water was poured gradually until the acceptable workability was achieved (measured from the slump flow) then the concrete was poured into the mould. After 7 days, the concrete layers were demoulded and the polystyrene are placed as in Fig. 1. Finally the longitudinal bars were placed inside the connection area and casted. This different procedure of casting is made with an intention of reducing the weight of PPCSP and to make transportation easier. The specimens were left to dry for 14 days before the test can be conducted.

D. Hot Box Test Procedure

A steady state thermal conductivity test was conducted in accordance to ASTM C1363 [9] known as hot box test method. The test is measured the thermal conductivity, transmittance and thermal resistance of the two layers PCSP. The set up comprises of hot chamber and climatic chamber i.e test room for hot and environment temperature, respectively as shown in Fig. 3. The hot chamber comprises of two compartments. The specimen was placed in the first compartment and the heating elements i.e. five (5) red bulbs were placed in the other. Hot air was transferred to the surface of the specimen through two (2) fans which represents the heat radiation and force convection respectively as in Fig. 4. Inside the hot chamber, temperature was made steady at 70-75oC, while the room temperature was controlled at 18-20oC by the air conditioner to represent the environment temperature. One thermocouple in each chamber was placed to ensure the steady state was reached during test.

The specimen was placed in an opening of 500x 500 x 150mm as shown in Fig. 3. The specimen's surface facing the inside the hot chamber was referred as hot side (H) and the surface facing the room is represents the cold side (C). Each face of the specimen was mounted with five (5) numbers of surface thermocouple to measure the temperature on the surfaces of the specimen. Also, two (2) heat flux sensors were attached onto the hot concrete surface (H) to measure the heat flow rate as shown in Fig. 5. The devices were attached to the data logger and computer, both are configured before commencement of the experiment. The operating condition inside the hot chamber was 3.7 m/s for wind speed, 63% humidity and 65oC average temperature at steady state. The experiment was carried out for a period of 25 hours. Data was recorded every minute until steady state was reached.

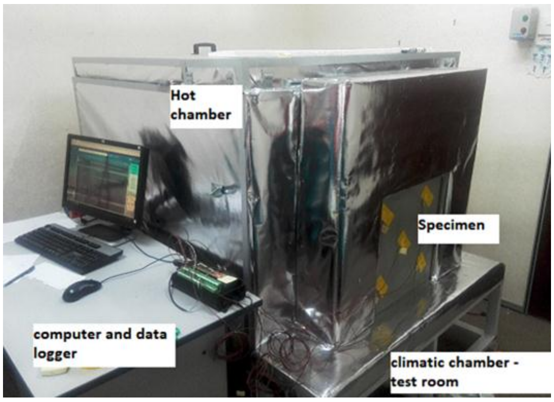

Fig. 3. Hot box apparatus

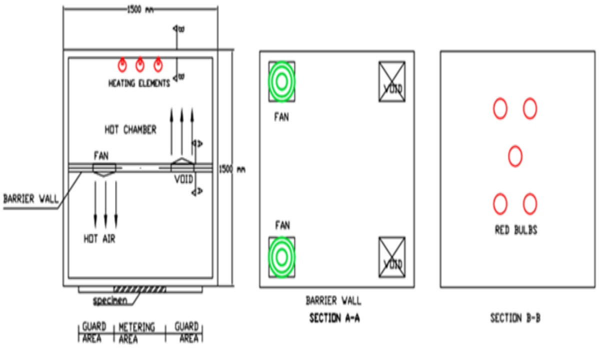

Fig. 4. Plan and x-section view of the Hot box.

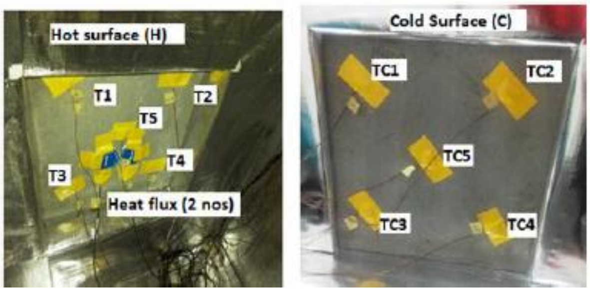

Fig. 5. Instrument's positions.

III. Results and Discussion

Temperature in the hot and climatic chambers were measured during the test to ensure that the change in temperature was negligible or attained steady state conditions. The recorded temperature is shown in Fig. 6, which shows temperatures in both chambers started to show stable profile at 600 minutes. The climate chamber reached approximately 19-200C and in hot chamber was 70-750C.

Similar pattern of temperature profile were observed on all specimen's surfaces as in Fig. 7. It was detected that the temperature falls between 23-650C which is within the limits provided in the ASTM C1363 of between -40 to 850C [9]. The control sample, P0 attained the lowest temperature differences showing large heat transferred between the two surfaces. This prove that direct thermal bridge allow faster heat transferred through the shear connectors to both concrete layers. On the other hand, specimens with staggered shear connectors shown higher temperature differences. The highest temperature difference was attained by P4 and the lowest was by P2, explaining that the thermal transfer have linear relation to the spacing of the shear connectors. The reduction in the surface temperature on these specimens were due the thermal path design. Thermal path which is design in parallel to the ambient surface receiving the heat energy, which transmitted slower heat than the perpendicular path [10].

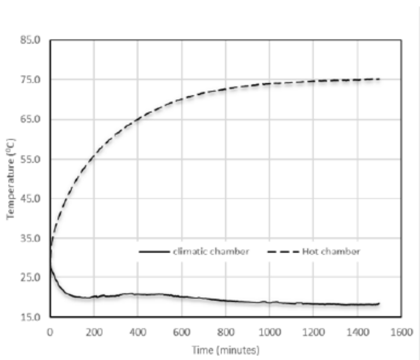

Fig. 6. Hot and climatic chambers air temperature.

Heat flux is defined as the heat transferred per unit metering area measured in watts per meter squared. In this experiment, heat flux sensor were attached to the hot surface (H) of the specimen with the aid of thermal paste to determine the quantity of heat absorbed by the samples. Fig. 8 shows the heat transferred vs time of P0, P2, P3 and P4 specimens. It can be observed that the highest quantity of heat that flow through was measured by the control sample (P0) and least was by P3 and P4 specimens. This shows that the surface with high surface temperature at the cold side (C) would absorb more heat energy causing higher thermal transfer. Furthermore, P0 recorded almost constant heat transferred after 400 minutes while other specimens start to transfer less heat. Thus, it could be inferred that the heat energy passes through the control sample through the thermal bridge with no obstruction until it reached the steady condition. Oppositely, for the two layers PCSP specimens, heat energy passes steadily through the outer layers until it reaches the insulation which broke the transmission, thus less heat transferred was measured. At 1600 minutes, the heat flux of 276 W/m2, 174 W/m2, 128 W/m2 and 127 W/m2 were recorded for control sample, P2, P3 and P4 respectively. This indicates that the control absorbed more energy than P2, P3 and P4 by 58.6%, 115.6% and 117.3% respectively. Thus it can be concluded that the magnitude of the heat transmission decreases when the travel distance increased up to 300 mm (P3), however when it increased to 400mm (P4) an insignificant reduction was observed.

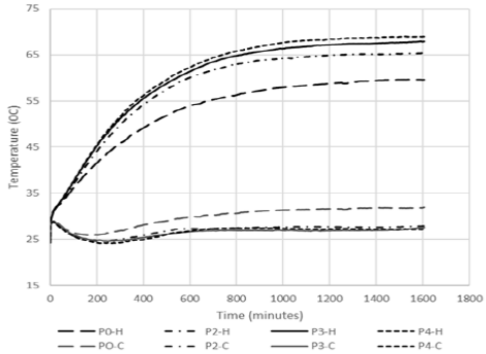

Fig. 7. Hot and cold surfaces temperature of all specimens.

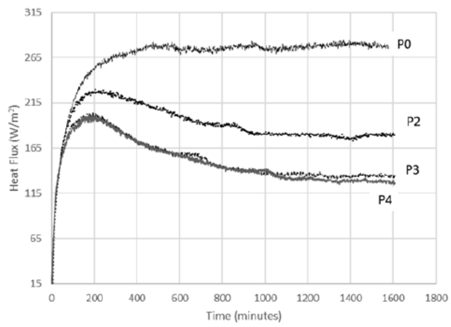

Fig. 8. Heat flux reading of all specimens.

TABLE I: The Thermal Properties of Specimens

Specimen	Thermal Transmittance U (W/m^2K)	Thermal Resistance R (m^2K/W)	Thermal Conductivity K (W/mK)
P0	1.43	0.70	0.21
P2	0.66	1.52	0.10
P3	0.47	2.15	0.07
P4	0.43	2.35	0.06

Based on the data measured and discussed above, the thermal transmission properties of these specimens are calculated and tabulated in Table I. The measurements are taken only after a steady-state condition has been established. It was found that specimen P0 which allows direct heat transfer attained the highest thermal conductivity. On the other hand, although the thermal path are different by 100mm, P3 and P4 show insignificant different on this property. The most benefit of thermal path was shown by P2 with approximately half and P3 with three quarter reductions of thermal conductivity than P0.

IV. Conclusions

This experiment was carried out to determine the thermal performance of an insulated PCSPs using hot box method under constant temperature refer to as steady-state conditions. Based on the results obtained and subsequent analysis, it was found that the thermal transmission across the specimen is directly proportional to the length of the thermal path and particularly economical for spacing of 200mm and 300mm. Thus, by having staggered shear connector better thermal transmittance could be achieved. Also, the time lag for heat transfer depends on the direction of the thermal path, either parallel or perpendicular to the ambient surface of the panel system. The heat transmittance is slower for thermal path parallel to the ambient surface of the wall system making it more efficient. Industy should benefit from this research in terms of designing the thermal resistance system of their sandwich products.

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