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Protection and Heat Insulation Performance Comparison using Insulation Formwork in Winter

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Abstract

Concrete pouring in winter is critical to both concrete manufacturers and end users owing to the possibility of concrete damage due to cold weather. In this context, various methods have been used to prevent frost damage to concrete in winter, including adjusting the concrete mix using a chemical admixture and heat-curing with tents. Of these methods, the insulated-gang-form approach does not require concrete-mix adjustment via a chemical-admixture addition. Furthermore, its positive effect on the initial quality of concrete during concrete construction in winter has previously been confirmed. In this study, the power consumption of the conventional gang form was compared with that of the insulated gang form to evaluate the efficiency of the two protection methods. A thermal vision camera was used to examine the surface heat loss of the gang forms after concrete pouring. The insulated gang form significantly outperformed the conventional one through its significantly reduced power consumption and reduced surface heat loss. These findings can contribute to the standardization of insulated gang form application to concrete protection in cold-weather conditions.

Keywords Insulated gang form, Cold-weather construction, Concrete protection in winter, Insulation performance

1 Introduction

Reinforced concrete (RC) has become the most widely used construction material over the past few decades (Huang et al., 2004) because it offers the advantages of strength, durability, longevity, and resilience. In the past, steel frame structures were used to reduce the duration of construction. In recent years, the use of RC structures has become widespread owing to significant advances in formwork methods and materials. The resulting construction duration has also been significantly reduced (Shin et al., 2012).

Among the several methods used in concrete construction, formwork construction is widely employed for applying RC structures and significantly reducing the duration of construction (Ferguson, 1999; Proverbs et al., 1999; Kang et al., 2005). Therefore, the selection of an appropriate formwork method at RC-structure-based construction sites is necessary for successful construction management (Hanna, 2005; Won et al., 2016).

Currently, formwork methods for high-rise building construction do not follow a consistent process owing to the lack of formwork-related data that are available to construction companies and the lack of information sharing among them. In addition, few studies have focused on formwork-related evaluations and procedures (Kim et al., 2007). However, gang forms have been commonly

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used for constructing office buildings and apartments in many countries (Koo et al., 2012). The gang form offers the following benefits over existing formwork systems: (1) the assembly time can be reduced; (2) Manpower can be reduced because formwork is standardized; (3) The use of modularized systems in gang-form-based construction can reduce material loss and provide excellent repeatability owing to high durability; (4) The high formwork stiffness of gang forms enables the increased safety of concrete work; and (5) The resulting excellent formwork surfaces facilitate subsequent processes (Huang et al., 2004). Thus, gang forms have become an important aspect of modern building construction.

Meanwhile, with the prevalence of year-round construction, several studies have focused on cold-weather construction with consideration of the possibility of concrete damage due to cold temperatures. Consequently, concrete quality management during cold-weather conditions has become an active research topic (Han et al., 2004). During the cold-weather concrete-application period, which the American Concrete Institute refers to as "the period in which the daily average temperature is expected to be 4.5 °C (40 °F) or lower for three or more consecutive days and the period in which the temperature is 10 °C (50 °F) or lower for more than one half of any arbitrary 24-h period." Thus, caution should be exercised to prevent reduction in the heat of hydration and frost damage in fresh concrete. In most countries with cold climates, considerable costs are incurred each year in the facilitation of concrete pouring in cold weather and extending the pouring period (Polat et al,. 2014).

The cold-weather conditions in winter adversely affect the performance of Portland cement, particularly in the manufacturing, transporting, pouring, and curing processes. Thus, understanding the effects of cold weather on these processes is crucial to both concrete manufacturers and end users (Ortiz et al., 2005). For example, it was observed that, in the absence of protection, Portland cement does not harden at the freezing point. Moreover, concrete can be subjected to frost damage and deterioration if it is not protected in cold-weather conditions.

Current protection methods include increasing the concrete temperature to 5 °C or higher from a material perspective or using insulation materials and tent protection from a management perspective (Korhonen, 1999). With respect to the material approach, many researchers have focused on using chemical admixtures, such as accelerators, corrosion inhibitors, and anti-freeze agents, for concrete protection. The appropriate selection of such admixtures can provide strength early in the process similar to that of ordinary concrete. However, the adjustment of the concrete mix may cause insufficient on-site perception, changes in material properties, and a reduction in long-term strength (Nmai, 1998). In terms of the management-based approaches, insulation materials can be affixed to the surface of the formwork. Alternatively, a tent can be used to cover the structure and the air inside the tent can be heated with fossil fuels. Nevertheless, these management-based strategies suffer from the problems of increased protection costs, environmental pollution, and accidents such as the suffocation deaths of workers.

Studies related to concrete protection in winter are scarce. A previous study on addressing the above problems has demonstrated that the use of insulated gang forms positively influences the quality of concrete in winter (Won et al., 2016). However, most studies on concrete usage in winter have focused on the concrete temperature, compressive strength, chemical admixture, and durability from the material perspective. In addition, owing to the variety of concrete protection methods adopted in different countries, it is difficult to provide practical definitions with comprehensive consideration of these differences.

Therefore, the present study analyzed concrete protection methods during winter from the perspective of the insulated gang form construction-site manager. To this end, the usage of hot-air blowers and lignite for concrete protection was converted into electrical energy (in kilowatt-hours), and the power consumption of the insulated gang form was compared with that of the conventional gang form. In addition, the surface calorific values of the conventional and insulated gang forms into which concrete was poured were measured using a thermal vision camera to investigate the insulation performance of the two gang forms. We then compared and strived to understand the electrical energy consumption of the insulating gang form as well as the economic efficiency of the insulating gang form under extreme environmental conditions in winter.

2 Materials and Methods

2.1 Experimental Design

2.1.1 Power-Consumption Comparison Experiments

Table 1 lists the experimental design parameters used in measuring power consumption. Table 2 lists the concrete-mix specifications used in these experiments. The power-consumption experiments were performed by employing an insulated gang form in which a rigid urethane board was affixed to the outside surface with adhesives, as shown in Fig. 1. The detailed structure of the insulating gang form was based on the general gang form. A 30-mm hard urethane board was attached to the outside of the gang form. The thermal conductivity of the hard urethane board was 0.018 W/m·k, and the density was 35 kg/m^3. Each experimental member was fabricated

Table 1 Experimental design parameters used for power-consumption experiments

Experimental parameter	Number of experiments	Experimental level
Water/binder ratio	1	0.585
Curing-chamber temperature (℃)	1	− 10
Temperature inside the member (℃)	1	15
Specimen type	2	Gang form and insulated gang form
Hardened concrete	2	Power consumption by age and total power consumption

Table 2 Concrete mix applied for power-consumption experiments

Water/binder	w (kg/m^3)	Mass per unit volume (kg/m^3)					
		C	BS	FA	S	G	SP
0.585	172	185	65	44	903	931	1.62

BS: blast furnace slag; FA: fly ash; S: fine aggregate; G: coarse aggregate; SP: superplasticiser

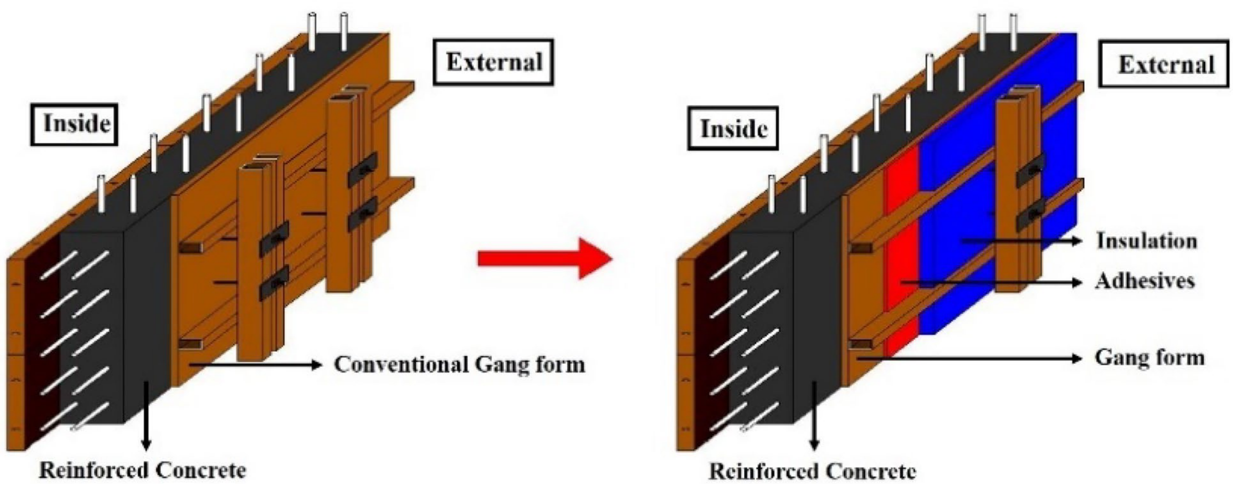

Fig. 1 Conceptual diagrams of the conventional and insulated gang forms

as a four-side closed-type member, and concrete was poured inside each gang form, as shown in Fig. 2. The power consumed during the protection process was compared between the conventional and insulated gang forms. To ensure accurate temperature settings and data measurement, the experiments were performed in a chamber with a constant temperature and humidity at the residential performance research institute of a company. The water/binder (w/b) ratio was set to 0.586, and the curing conditions after pouring were determined to be 3-day curing at − 10 °C. The ready-mixed concrete strength of 21 MPa, which is the typical strength used in construction sites, was employed. The admixture replacement ratio was not specifically lowered or otherwise adjusted for the experiment.

2.1.2 Calorific-Value Measurement Experiments

The changes in the surface calorific value of the insulated gang form were measured using a thermal vision camera to evaluate the insulation performance. Table 3 lists the experimental design parameters and Table 4 lists the concrete-mix specifications used for these experiments. For the experimental members, a gang form and an insulated gang form were fabricated by using square walls with a width and height of 1–200 mm and a thickness of 200 mm. The experimental members were not fabricated as four-side closed-type ones as in the case

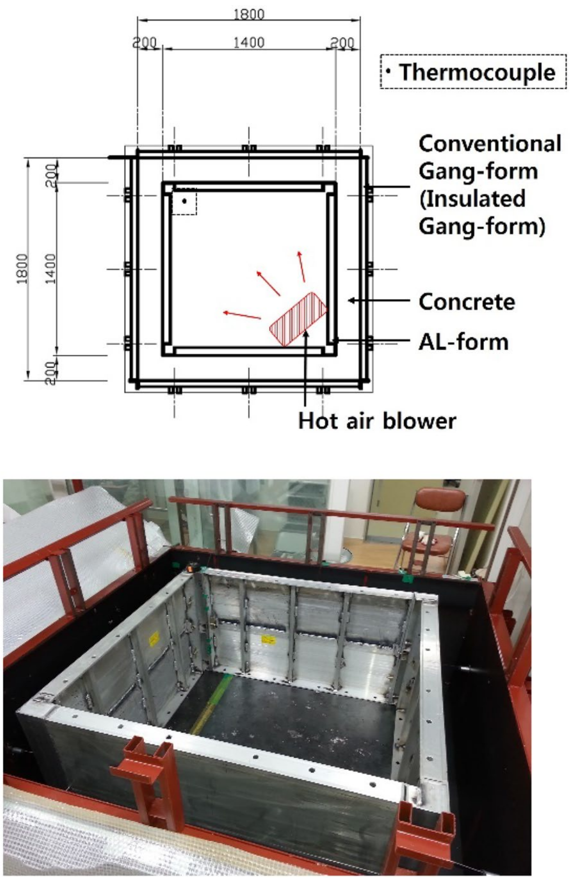

Fig. 2 Plan of members and experimental method

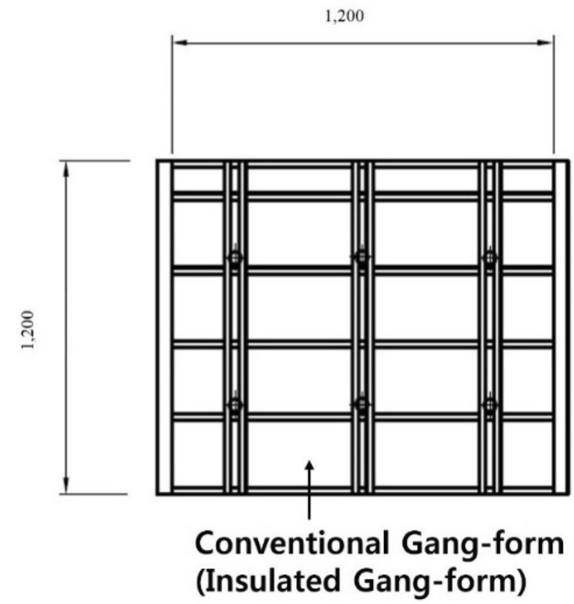

Fig. 3 Elevation of members

Table 3 Experimental design parameters used for calorific-value measurements

Experimental item	Number of experiments	Experimental level
Water/binder	1	0.463
Outside air minimum/maximum temperature	2	− 5 ℃/6 ℃
Specimen type	2	Gang form and Insulated Gang form
Hardened concrete	2	Power consumption and gang-form calorific value

Table 4 Concrete-mix specifications applied for calorific-value measurements

Water/binder	w (kg/m^3)	Mass per unit volume (kg/m^3)			
		C	S	G	SP
0.463	165	356	862	911	2.49

of the power-consumption experiments. Instead, they were fabricated as shown in Fig. 3 to enable assessment of the changes in the heat of hydration in the concrete according to the gang-form type by fabricating walls that excluded the space-heating condition by a hot-air blower. Air curing was performed in the temperature range of − 5 °C to 6 °C at the end of February. The thermal imaging camera used in the experiment was an FLIR E96 product with a resolution of 640 × 480.

2.2 Experimental Method

2.2.1 Power-Consumption Comparison Experiments

For the power-consumption comparison experiments, we fabricated four-side closed-type members using the conventional and insulated gang forms. To measure the power consumption of the two types of members, we set the internal temperature of each member to 15 °C using a hot-air blower. The hot-air blower operation was stopped when the internal temperature of the member exceeded 15 °C (Fig. 2a) and resumed when it became lower than 15 °C. The power consumption by age and the total power consumption after concrete pouring were measured by using the power-consumption measurement device shown in Fig. 4. The temperature of the chamber with a constant temperature and humidity (b) was set to − 10 °C. Fig. 5 shows the installation locations of the hot-air blower and thermocouple after concrete pouring.

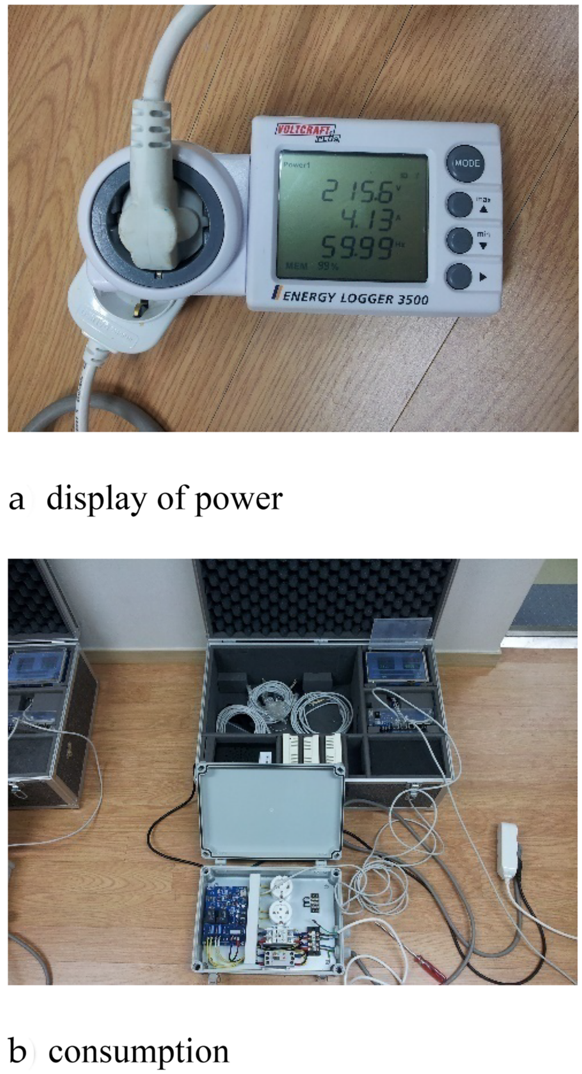

Fig. 4 Power consumption measuring device—measuring device

Fig. 5 View of arrangement of members

Fig. 6 View of arrangement of members

Fig. 7 Thermal vision camera

2.2.2 Calorific-Value Measurement Experiments

The calorific-value measurement experiments comparatively analyzed the insulation performance of the conventional gang form and the insulated gang form. They did not involve comparative analysis of calorific values from differences in concrete protection methods. The two types of concrete members of identical sizes were positioned at a single location, as shown in Figs. 6 and 7. The change in calorific values on the gang form surface were measured immediately after the completion of concrete pouring, as well as at 6, 12, 18, 24, 48, and 72 h (3 days of age, immediately after the removal of the formwork) to evaluate the insulated gang form performance. The measurement distance between the thermal vision camera and the member was 5 m.

3 Experimental Results

3.1 Fresh-Concrete Experimental Results

Table 5 lists the slump and air content of the fresh concrete poured in the power-consumption comparison and

Table 5 Fresh-concrete experiment results

Category	Water/binder	Slump (mm)	Air (%)
1) Power-consumption measurement experiments	0.585	165	5.8
2) Calorific-value measurement experiments	0.463	163	5.6

calorific-value measurement experiments. The slump and air content in the power consumption measurement experiments were 165 mm and 5.8%, respectively, and those for calorific-value measurement experiments were 163 mm and 5.6%, respectively. The experimental slump and air content values satisfied both the target slump and air content ranges of 150 ± 25 mm and 4.5 ± 1.5%, respectively, for the given concrete.

3.2 Power-Consumption Comparison

Fig. 8 illustrates the power consumption by age after concrete pouring in the conventional and insulated gang forms. Table 6 lists the total power consumption of the conventional and insulated gang forms over 3 days. The table indicates that, at 1 day of age, the conventional gang form consumed approximately 11 kW h, whereas the insulated gang form consumed scarcely any electrical energy. This finding indicates that, under the curing-chamber temperature of − 10 °C, required for the internal space of the conventional gang form to maintain the same temperature as the internal space of the insulated gang form, the power consumption of 11 kwh is required. For concrete, it is crucial to prevent early frost damage in the early years of age.

To this end, protection costs are incurred for application of various protection methods in winter. In this regard, the heat of hydration in the concrete is conserved in the insulated gang form, and the conventional gang form requires initial heating owing to the large difference in the material heat loss of the internal space. At 2 days of age, power consumption for the conventional gang form was 29.43 kwh and 13.29 kwh for the insulated gang form. On the second day, power consumption occurred in both members. The main reason for this difference from the first day is the fact that the temperature of the curing chamber was − 10 °C. However, it was also partly due to the fact that, after the concrete temperature reached its peak, the concrete temperature was gradually lowered, leading to the reduced heat release from the concrete. The conventional gang form showed higher power consumption than the insulated gang form because the hot-air blower was turned on several times to maintain the target temperature of 15 °C inside the tent. For this reason, it was apparent that the insulated gang form protection system had a structure suitable for maintaining the temperature of the internal space. However, with the conventional gang form, the protection area and volume were large owing to the tent installation. Moreover, since it involved circulation through both the interior and exterior of the formwork, excessive power input occurred in the process as well as considerable heat loss. Furthermore, the conventional gang form required three power-consumption interventions for the initial 12 h after concrete pouring, whereas the insulated gang form required no power consumption for the first 21 h after concrete pouring. This finding indicates that the insulated gang form is superior to the conventional gang form in terms of initial protection, considering that the 24-h period after concrete pouring is important for curing.

In addition, the total power consumption of the conventional gang form was found to be 3.7 times that of the insulated gang form, indicating that the insulated gang form is more effective for concrete protection in winter. As can be observed from these results, with on-site application of the insulated gang form, the protection cost incurred at early stage of concrete pouring can be drastically reduced. As a result, it is possible to reduce both labor costs and the risk of accidents by nighttime (late night) temperature management.

3.3 Calorific-Value Measurements

In this study, the surface temperature and ambient temperature of two structures were simultaneously measured using a thermal vision camera. Accordingly, the extent of the difference in insulation performance of the insulated gang form was examined through thermal images comparing its insulation performance to that of the conventional gang form. For evaluating the insulation performance of the insulated gang form relative to the conventional gang form, Figs. 9, 10, 11, 12, 13, 14, 15 show the measured changes in the calorific value on the surfaces of the gang forms over time.

For both members, the gang-form surface exhibits temperatures below zero immediately after concrete pouring because of the low outside air temperature. In addition, the surface calorific value is not large. For the conventional gang form, the calorific value on the gang-form surface is large between 6 and 12 h after concrete pouring, which implies high heat loss from the gang-form surface at subzero temperatures. The calorific value begins to decrease owing to the surface heat loss after 18 h. It shows a tendency similar to that of the surrounding bottom structures after 24 h. In addition, as depicted in Fig. 13, the outside air temperature immediately after pouring is − 2 °C; however, after 24 h, the outside air temperature is 5 °C. Nevertheless,

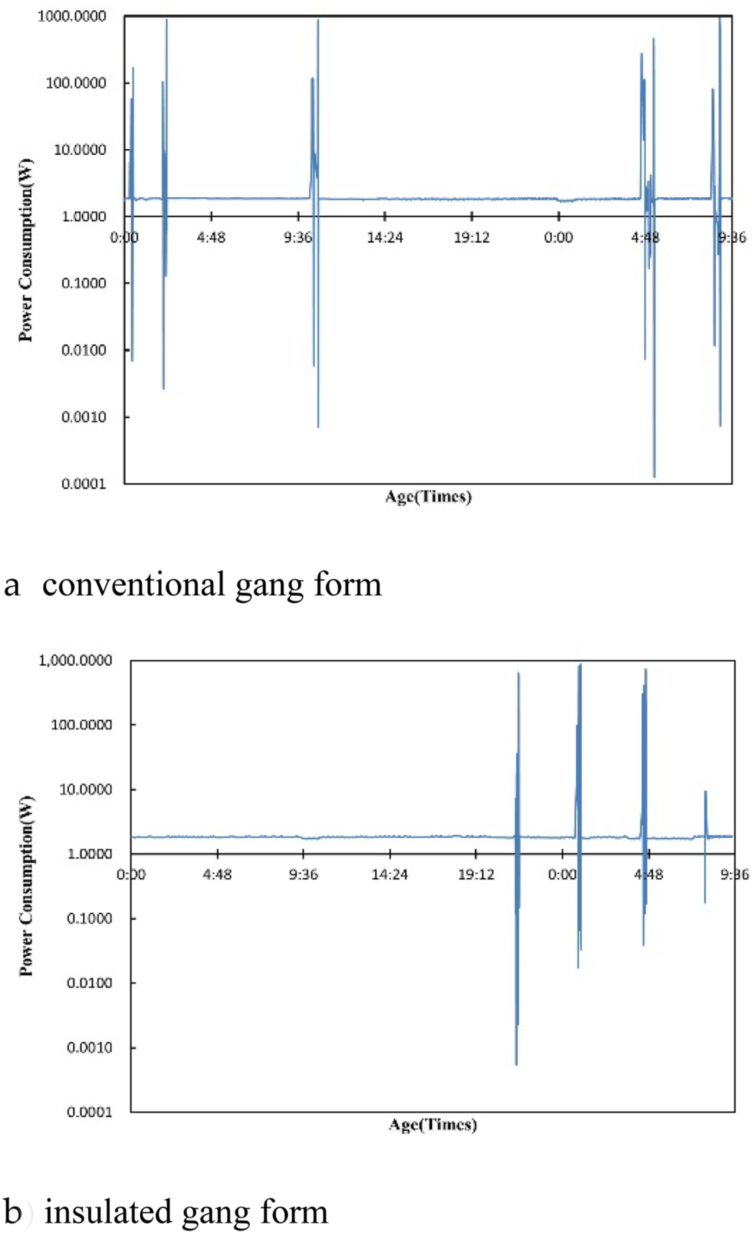

Fig. 8 Power consumption by age

Table 6 Results of power-consumption comparison experiments

Category	At 1 day of age (kW·h)	At 2 days of age (kW·h)	At 3 days of age (kW·h)	Total (1–3 days of age) (kW·h)
Gang form	10.63	29.43	10.63	50.69
Insulated gang form	0.14	13.29	0.14	13.57

the surface temperature of the conventional gang form immediately after pouring shows the opposite pattern compared to the outside air temperature result illustrated in Fig. 16. Although the outside air temperature has increased, the surface temperature of the conventional gang form has decreased after 24 h of pouring, as shown in Figs. 9a and 13a. This result can be confirmed through the fact that the outside air temperature and conventional gang-form concrete temperature are almost the same after 24 h of concrete pouring, as shown in Fig. 13. Moreover, from 24 h onwards, the

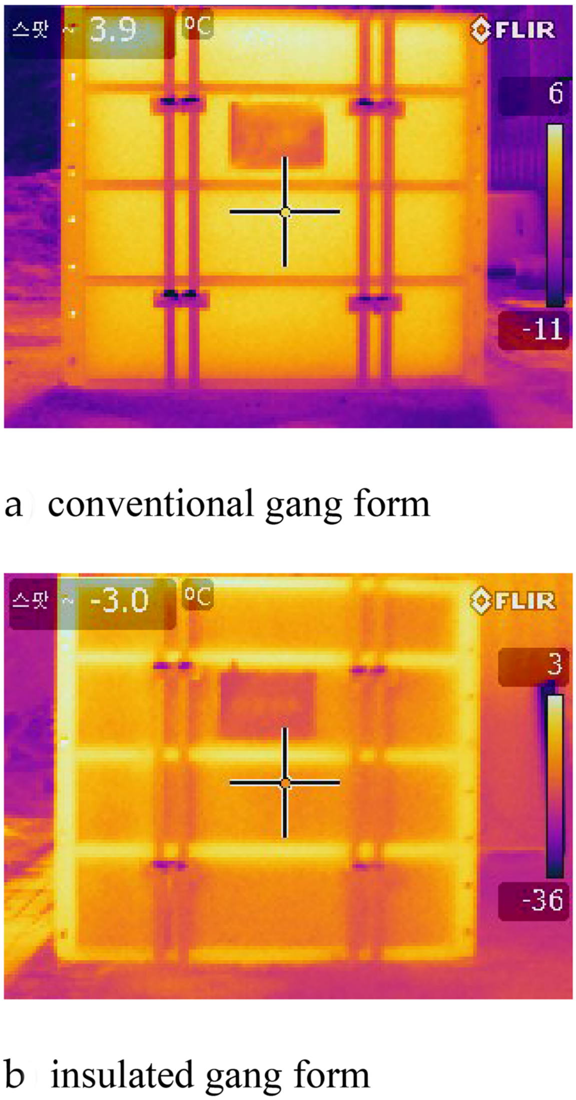

Fig. 9 Measured calorific values over time

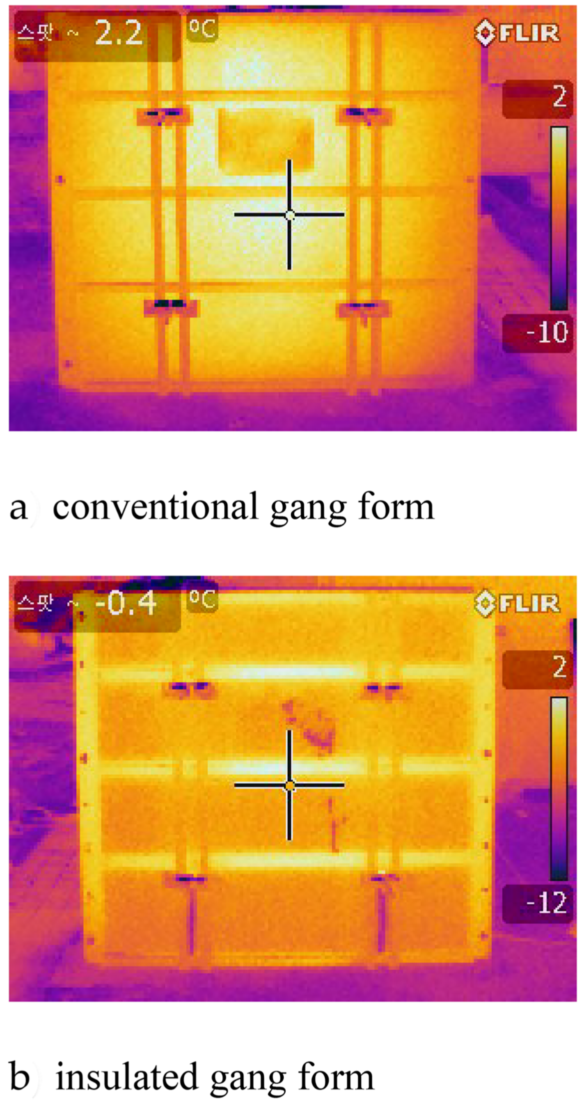

Fig. 10 Calorific values measured 6 h after the removal of the gang form

figure shows that the surface temperature of the conventional gang-form changes with the outside air temperature.

Fig. 16 presents the thermal vision camera image of the concrete surface obtained immediately after detaching the gang form. It can be observed that the concrete surface temperature of the insulated gang form (Fig. 16a) is maintained at a higher temperature than the conventional gang form owing to its insulation performance. With the conventional gang form, the concrete temperature is similar to the surrounding bottom structures, showing no effect of thermal insulation. These results can be clearly identified with visual observation without the use of a thermal vision camera. In the insulated gang form, the concrete surface is dry owing to the sufficient protection effect; however, the surface of the conventional gang form is in a wet state. These results indicate the possibility of a sharp temperature decrease in winter owing to the moisture on the concrete surface, which led to the prediction of the increased possibility of temperature cracking (Concrete Standard Specification—KOR). At the site, as shown in Fig. 15, after 72 h had elapsed, cold air had to be prevented from touching the concrete surface after the mold was removed, and odor control had to be implemented to maintain the concrete temperature at 5 °C or higher.

The difference in temperature between the insulated gang form and the conventional gang form arose

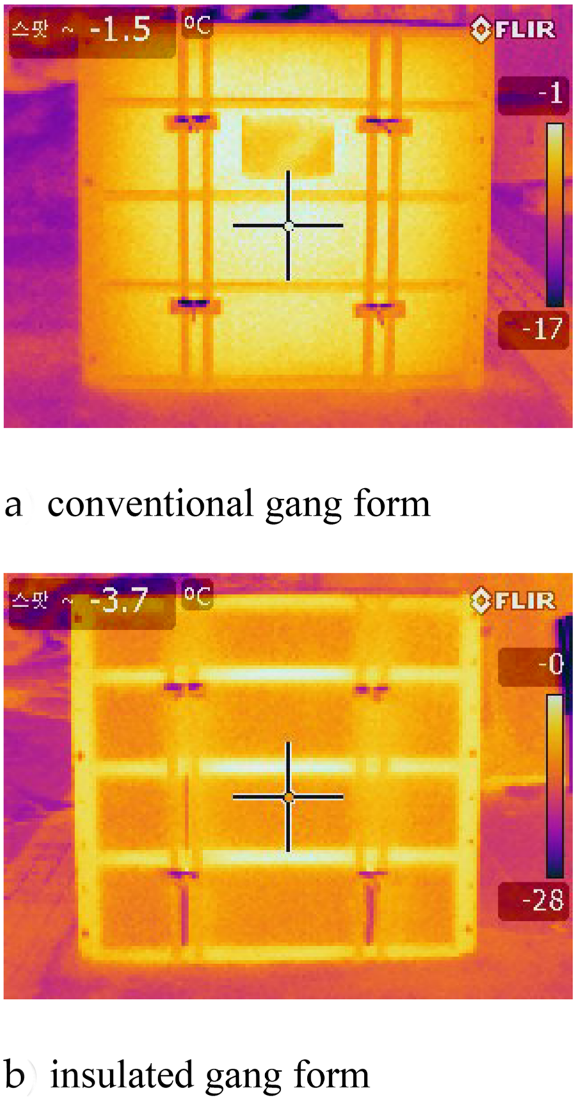

Fig. 11 Calorific values measured 12 h after the removal of the gang form

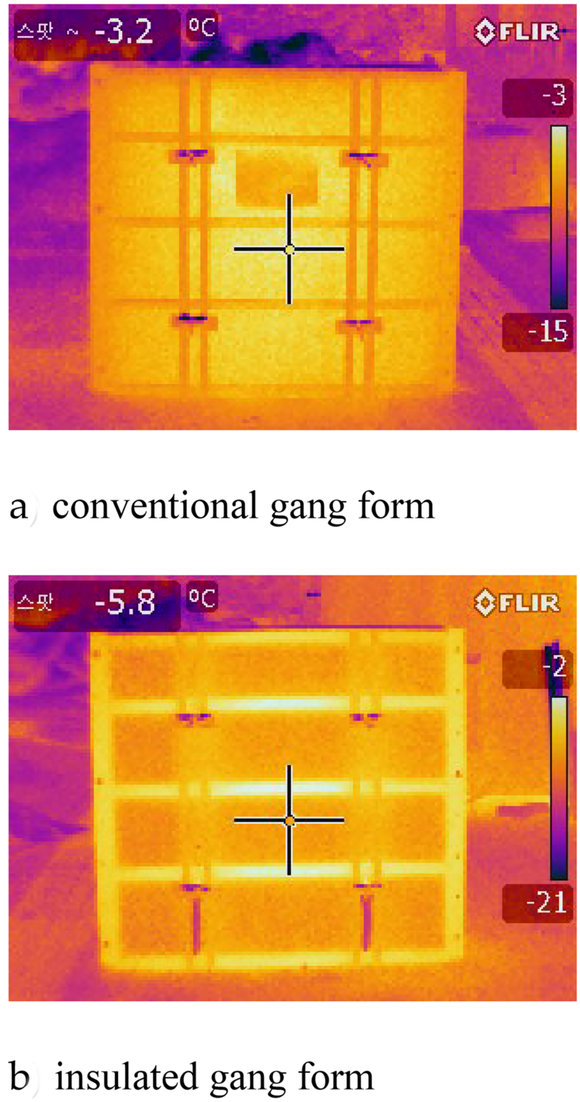

Fig. 12 Calorific values measured 18 h after the removal of the gang form

from the adhesion performance difference between the 30-mm rigid urethane board and the steel panel other than the one that both gang forms had in common (3 mm of steel panel). The steel panel constituting the gang form significantly reduced the insulation performance owing to its high thermal conductivity (50W/m·k or higher). However, in the case of the rigid urethane board (0.024W/m·k) affixed to the steel panel, its thermal conductivity was lower than that of the existing EPS insulation board (0.037W)/m·k) or XPS insulation board (0.028W/m·k). It is believed that the heat of hydration of the insulated gang form is higher than that of the conventional gang form because the insulated gang form is protected from the influence of outside air temperature owing to its low thermal conductivity, facilitating cement hydration in early stages (Escalante-Garcia & Sharp, 2001; Korhonen, 1999; Lothenbach et al., 2005; Price, 1951).

Based on the results of this study, we plan to supplement the weak areas of the insulation gang form in the future. We also intend to systematize the experimental data to quantify the concrete quality characteristics associated with changes in the thickness of insulating gang form insulation.

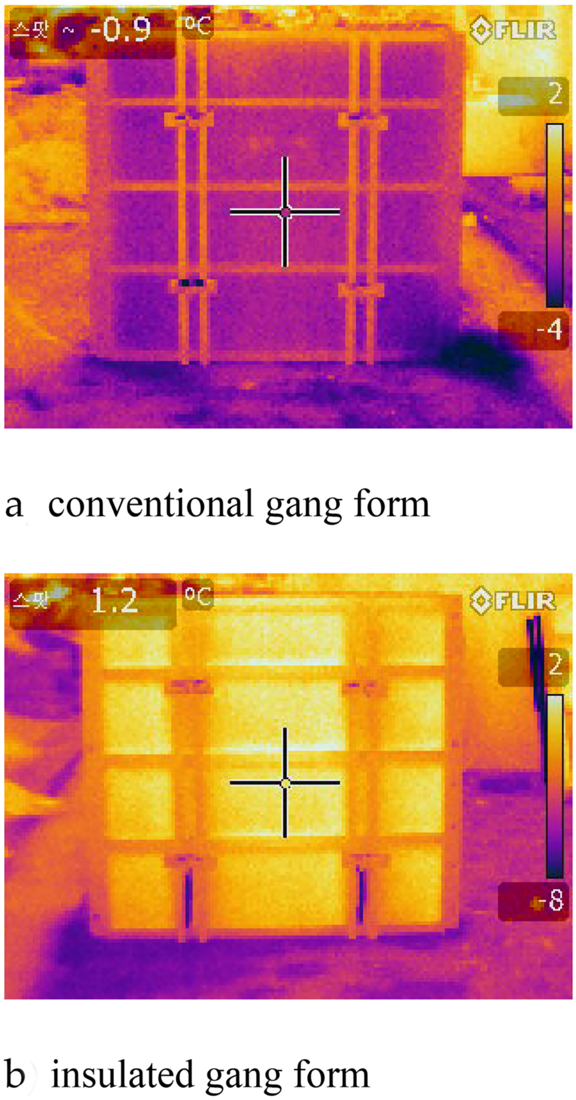

Fig. 13 Calorific values measured 24 h after the removal of the gang form

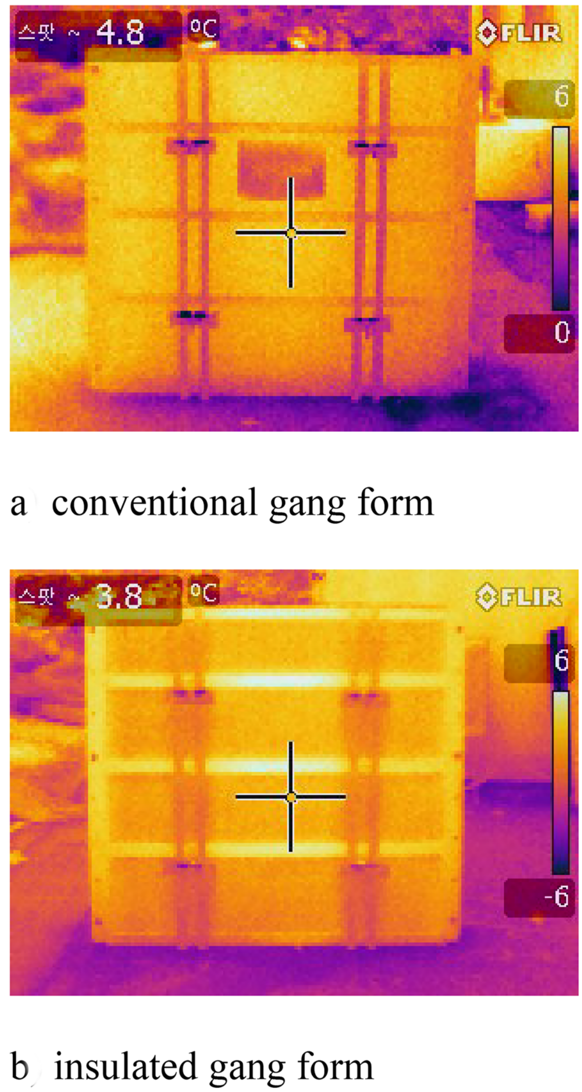

Fig. 14 Calorific values measured 48 h after the removal of the gang form

4 Conclusions

This study compared the power consumption between the insulated gang form and the conventional gang form that are used for concrete protection to investigate the cold-weather efficacy of the insulated gang form. The calorific value on the surface of the insulated gang form was measured using a thermal vision camera. The following conclusions were drawn:

1. The conventional gang form consumed approximately11 kW·h of electrical energy at 1 day of age, which was significantly higher than that of the insulated gang form, which consumed minimal electrical energy.
2. The power consumption by age indicated that the conventional gang form required three power-consumption interventions in the first 12 h after concrete pouring, whereas the insulated gang form required no power consumption, even at 21 h after concrete pouring.
3. The total power consumption of the conventional gang form was 3.7 times that of the insulated gang form. This result implies that the insulated gang form is superior to the conventional gang form in terms of concrete protection, particularly considering that the 24-h period after concrete pouring is important for curing.

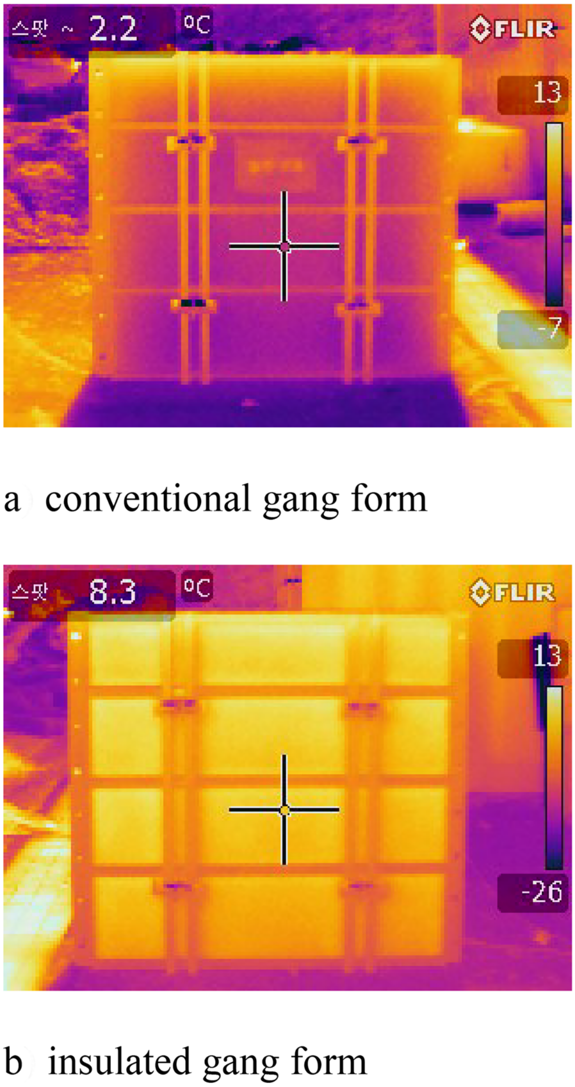

Fig. 15 Calorific values measured 72 h after the removal of the gang form

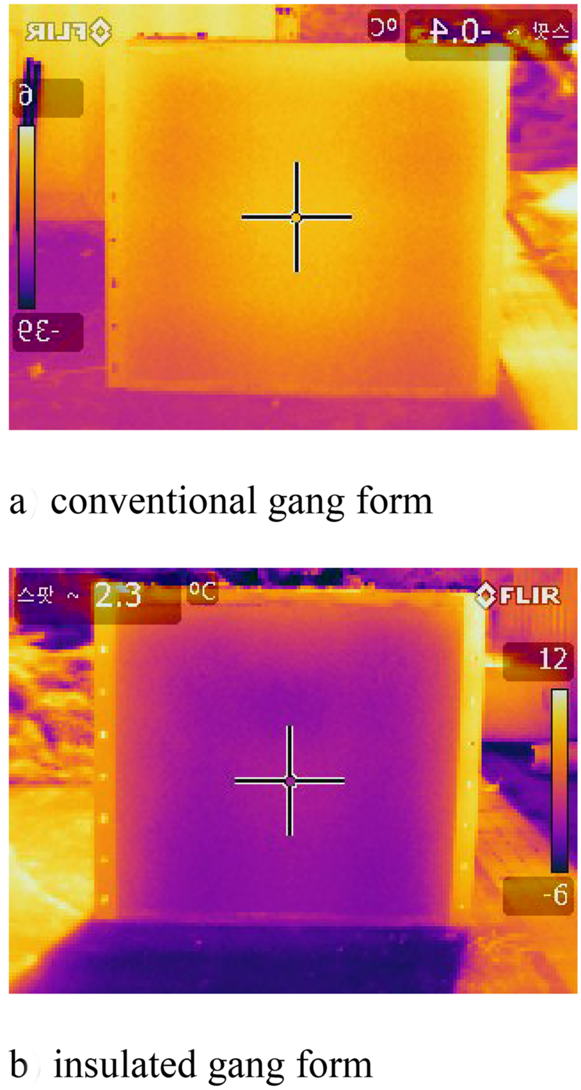

Fig. 16 Calorific values measured immediately after the removal of the gang form

4. In the conventional gang form, significant surface heat loss occurred at subzero temperatures owing to the high calorific value on the gang-form surface between 6 and 12 h after concrete pouring. In the case of the insulated gang form, a constant heating pattern that minimized heat loss was observed from the moment immediately after concrete pouring until the removal of the form.
5. The insulated gang form maintained a higher calorific value on the concrete surface than the conventional gang form immediately after the removal of the form, thereby indicating its superior insulation performance.

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Author contributions

Hyeonggil Choi and Myung-Kwan Lim directly performed all the experiments. Hyeonggil Choi and Kyung-Yong Nam analyzed the results of the experiment. Myung-Kwan Lim wrote the paper based on the analysis results. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published paper.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
No competing interests exist in the submission of this manuscript, which was approved for publication by all the authors. The authors declare that the work described is original research that has not been previously published and is not under consideration for publication elsewhere in whole or in part.

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