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An Experimental Study on Monitoring the Filling Status of Concrete in Thick Walls with Steel Plates on the Outside Using Infrared Cameras

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Abstract: This paper presents an experimental study using test specimens to demonstrate that the filling status of concrete on the inner surface of a thick wall's steel plates can be monitored on the outside using infrared cameras. In previous research, it was feasible to monitor the filling status of concrete on the wall with a steel plate thickness of 10 mm or less on the outside using infrared camera. In this study, the steel plate thickness is increased from 10 mm to 22 mm and 32 mm.

Keywords: Infrared thermography; non-destructive test; internal defects, concrete

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1. Introduction

In concrete placement in thick walls with steel plates during the construction of a cast-in-place concrete wall, the plates are not removed so that the concrete surface is not exposed. Consequently, any defective filling, including voids and honeycombs, is difficult to identify and repair. Therefore, it is necessary to have a method for monitoring the filling status of concrete during and after concrete placement.

As a method for monitoring the filling status of concrete in a thick wall with steel plates, Uomoto et al. showed that the quality could be controlled by detecting voids and honeycombs using infrared cameras during concrete placement or curing [1]. In addition, Mizuno et al. also showed that infrared cameras could be used to monitor the filling status of concrete after the concrete placement of composite floor slabs using 8 mm steel plates [2,3]. Furthermore, Kobayashi et al. showed that the filling status could be monitored using infrared cameras in full-scale sandwich-type composite floor slabs using 9 mm thick steel plates [4]. Based on the above, infrared cameras are considered to be effective for monitoring the filling status of concrete in thick walls with steel plates.

However, previous research verified only steel plates with a thickness of 9 mm or less and did not verify those with a thickness of more than 10 mm.

Therefore, in this study, the filling status of concrete was monitored using infrared cameras on thick-wall test specimens with 32 mm thick and 22 mm thick steel plates with Styrofoam pieces simulating voids and honeycomb blocks* simulating honeycombs attached to the inner surface of the steel plates.

*: Honeycomb blocks were fabricated by removing the mortar from the concrete blocks immediately after casting.

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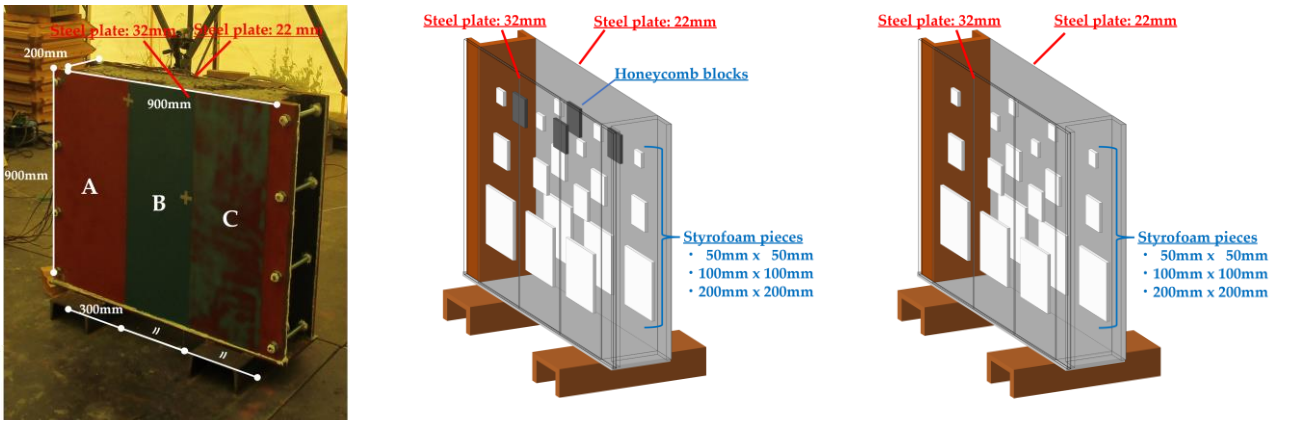
2. Method

2.1. Test specimen

In this test, two test specimens of similar configuration were fabricated to confirm the repeatability of the test result. As shown in Fig. 1(a), the size of each specimen was 900 mm high, 900 mm wide, and 200 mm thick with one surface having a steel plate thickness of 32 mm and the other having a plate with a thickness of 22 mm.

In addition to the steel plate thickness, the surface finishes of the steel plates were modeled as test parameters. Part A was rust-proofed, part B was rust-proofed and then coated with phthalate resin, and part C was rust-proofed and then finished with a vinyl sheet attached, which were intended for coating during construction, indoors after construction, and outdoors after construction, respectively.

As shown in Figs. 1(b) and 1(c), Styrofoam pieces simulating voids and honeycomb blocks simulating honeycombs were placed on the inner surface of the steel plates of the test specimens to simulate the defective filling of concrete. Three types of 10 mm thick Styrofoam pieces were placed: 50 mm x 50 mm, 100 mm x 100 mm, and 200 mm x 200 mm. The honeycomb blocks were 110 mm x 110 mm with a thickness of 30 mm.



(**a**) (**b**) (**c**)

Figure 1. Test specimen overview. (**a**) Appearance of test specimen; (**b**) Test specimen 1; (**c**) Test specimen 2

2.2. The outline of test

In this study, infrared cameras were placed on both sides of each test specimen shown in Sec. 2.1 to capture thermal images of the 32 mm thick and 22 mm thick steel plates every 10 seconds from the start of concrete placement.

The infrared cameras were R500 of Nippon Avionics. Camera specifications are shown in Table 1.

For test specimen 1 before concrete placement, the ambient temperature was 22.4°C, the steel plate temperature was 24.9°C, and the concrete temperature was 32.6°C. For test specimen 2 before concrete placement, the ambient temperature was 26.5°C, the steel plate temperature was 27.4°C, and the concrete temperature was 34.0°C.

Table 1. Specifications of infrared camera R500.

Detector	Measurement wavelength	Temperature resolution	Number of pixels	Frame rate
Microbolometer	8.0 to 14.0 μm	0.025°C	640 x 480	30 Hz

3. Result and Discussion

Fig. 2 shows thermal images taken approximately two minutes after the start of concrete placement on the 32 mm thick and 22 mm thick steel plate sides of test specimen 1. The temperature range of the thermal image on the 32 mm thick steel plate side in Fig. 2(a) was 23.0°C to 25.0°C, and that on the 22 mm thick side in Fig. 2(b) was 25.0°C to 27.0°C, where the black areas were at low temperature and the white areas at high temperature.

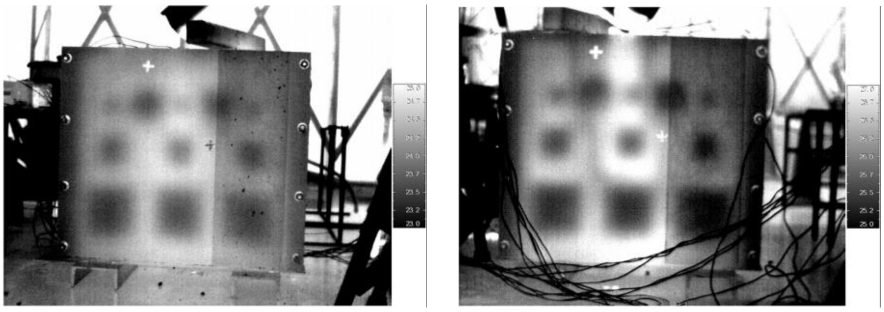
The thermal image in Fig. 2(a) showed that the temperature of the steel plate surface increased to approximately 25.0°C on the 32 mm thick steel plate side and turned white on the whole, while the areas of the Styrofoam pieces and honeycomb blocks remained black at approximately 23.0°C. The thermal image in Fig. 2(b) showed that the temperature of the steel plate surface increased to approximately 27.0°C on the 22 mm thick steel plate side and turned white on the whole, while the areas of Styrofoam pieces and honeycomb blocks remained black at approximately 25.0°C.

This was because the defective filling of concrete made it difficult for heat to transfer to the steel plates and, for both the 32 mm thick and 22 mm thick steel plates, the filling status of the concrete could be monitored. Note that there was little difference between the coated and uncoated steel plates.

Table 2 shows the approximate detectable time for defective filling areas after the start of concrete placement in this experiment. A larger defective filling area made it difficult for heat to transfer from the concrete to the steel plate surface, enabling the monitoring of the defective filling areas for a longer time.

In addition, after the completion of concrete curing, a test was conducted by heating the test specimens using a heater, which caused temperature differences in the defective filling areas of the concrete, allowing for monitoring of the areas.

Note that test specimens 1 and 2 showed similar results, ensuring repeatability of the test results.



(**a**) (**b**)

Figure 2. Detection results of defective filling areas two minutes after the start of concrete placement in test specimen 1. (**a**) 32 mm thick steel plate side; (**b**) 22 mm thick steel plate side.

Table 2. Detectable time for defective filling areas on the outside of the steel plate surfaces after the start of concrete placement in this experiment.

Test	Steel plate thickness	Detectable time for defective filling area			
		Styrofoam piece 50 mm x 50 mm	Styrofoam piece 100 mm x 100 mm	Styrofoam piece 200 mm x 200 mm	Honeycomb block
Test specimen 1	32 mm	4 min.	11 min.	23 min	15 min.
	22 mm	6 min.	13 min.	31 min	18 min.
Test specimen 2	32 mm	4 min.	8 min.	22 min	-
	22 mm	4 min.	8 min.	24 min	-

4. Conclusion

The filling status of the concrete on the inner surface of the steel plates has been difficult to monitor. Under such circumstances, it has been proven that measuring the outer surface temperature of a steel plate with an infrared camera is an effective method for monitoring the filling status. As a result of an experiment conducted using test specimens with relatively thick steel plates (32 mm and 22 mm thick), the filling status of concrete could be monitored in real time, and relatively-minor defective filling areas (50 mm x 50 mm, 10 mm thick) on the inner surface of the steel plates could be successfully detected.

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Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Uomoto, T.; "Application of Thermography to Concrete Structures and Concrete Construction"; *Journal of Institute of Industrial Science*, The University of Tokyo; 1992, Volume 44 (11), pp. 32-36.
2. Mizuno, H.; Izumi, Y.; Sakagami, T.; Matsui, S.; Sugiyama, T.; "Study on nondestructive testing for steel-concrete composite slab by infrared thermography technology"; *Journal of Structural Engineering*; Japan Society of Civil Engineers. A; 2013, Volume 59A, pp. 1161-1169.
3. Mizuno, H.; Izumi, Y.; Nakano, K.; Sakagami, T.; Matsui, S.; "Study of fatigue durability inspection and evaluation for steel-concrete composite deck by infrared thermography technology"; *Journal of Japan Society of Civil Engineers*, Ser. A1 (Structural Engineering & Earthquake Engineering (SE/EE)), vol. 72, issue 2, pp. 338-349
4. Kobayashi, Y.; Kitahama, Y.; Nakagawa, K.; Kamijo, T.; "Inspection of concrete fill density in sandwich-type composite floor slabs using an infrared thermoviewer" (in Japanese); *Journal of Japan Society of Civil Engineers*, the 59th Annual Academic Conference September 2004.