

B-2-1 Inspection of initial failure of polymer cement waterproofing membranes by using active thermography

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ABSTRACT: Polymer cements are composite materials composed of cement and polymer. These materials are designed to have appropriate strength and elongation property so that they can be used as waterproofing materials. However, several initial failures are a factor in decreasing the physical properties of waterproofing membrane. Determination of the initial failures by visual inspection is generally difficult. In this study, a non-destructive testing method using the active thermography method is applied to the inspecting of initial failure. Concrete test pieces of $30 \times 30 \times 10$ cm size with one surface side treated with a polymer cement membrane were prepared. The pieces were prepared with artificial defect already in the test piece such as insufficient coating thickness, false mix proportion, and partial peeling. After the lapse of a curing time, surfaces of the membranes were heated by halogen lamp with a power of 500 W for 240 sec. Then the temperature distributions were monitored using an infrared camera. Artificial defect areas have good contrast compared with healthy material area during heating. In order to estimate the mix proportion of polymer and cement, temperature history and maximum temperature, ΔT_{max} of the various mix proportions were compared. As related to the mix proportion of the membranes, ΔT_{max} increases with increase in the polymer ratio. This study demonstrates that active thermography is a useful method for detection of initial failure of polymer cement waterproofing membranes.

KEY-WORDS: Polymer cement, waterproofing membrane, initial failure, active thermography, non-distractive test method

INTRODUCTION

Polymer cements are composite materials composed of polymer, cement and aggregate. These materials are designed to have appropriate strength and elasticity so that they can be used as waterproof membranes. The physical properties of the polymer cement waterproofing membrane depend on the mix proportion. In general, the polymer cement waterproofing membranes have a polymer ratio of 45-65 % when the entire volume is 100% so that they ensure a high resistance to fracture caused by a crack-bridging tension from substrate concrete. However, aggregate and cement sink due to the use of too much water or the poor construction method. Segregation results in uneven polymer cement texture and the deterioration of the physical properties. Furthermore, in order to provide the sufficient performance of waterproofing membranes, the correct thickness of the membrane is required. Therefore, it is necessary to clarify the distribution of component materials and the thickness of membrane in order to understand the physical properties of the polymer cement waterproofing membrane.

Generally, organic materials and inorganic materials have different coefficients of heat transfer. By noticing these points, inspection method for defect of polymer cement waterproofing membrane by infrared thermography was investigated.

EXPERIMENTAL

Preparation of polymer cement waterproofing membrane

Ordinary Portland cement was used as the cement component. This type of cement has a density and particle diameter of 3.16 g/cm^3 and $\leq 100 \mu\text{m}$, respectively. Acrylic acid copolymer (re-emulsifiable emulsion powder) was used as the polymer component; its density is approximately 1.0 g/cm^3 when hardened. Silica sand was used as the sand component. This type of sand has a density and particle diameter of 2.57 g/cm^3 and $\leq 200 \mu\text{m}$, respectively. As shown in Table 1, test pieces were prepared with: four polymer-to-cement ratios (mass ratio, hereafter referred to as P/C) of 50, 100, 150, and 200 %; two water-to-binder (cement + polymer) ratios (mass ratio, hereafter referred to as W/B) of 70, 100%; and sand-to-cement ratio (mass ratio, hereafter referred to as S/C) of 200%.

An aqueous emulsion was obtained by re-emulsifying by mixing tap water and polymer powder. The aqueous emulsion after re-emulsification was mixed with cement. Polymer cement before hardening was applied to a smooth acrylic plate measuring $200 \times 200 \text{ mm}$ coated with a releasing agent. After curing, the film shape waterproof membrane was peeled off from the substrate acrylic plate. The test pieces were cured for 7 days in a room at 20°C and 60% R.H. The amounts of polymer and cement applied were gradually adjusted to control the thickness of the membrane so that the final thickness was $2.0 (\pm 0.1) \text{ mm}$ in accordance with the specification.

Table 1. Mix proportion of polymer cement waterproofing membrane

W/B (%)		70				100	
P/C (%)		50	100	150	200	150	
S/C (%)		200					
Water (kg/m)		397	401	403	404	491	
B (kg/m)	Polymer	567	189	572	286	575	345
	Cement		378		286		230
Sand (kg/m)		756	572	460	385	392	

Tensile strength test

The test pieces were die cut into dumbbell shape test pieces for film type membrane, and tensile tests were performed in compliance with JIS K 6251 (Tensile speed : 50 mm/min , Test condition : $20 \pm 2^\circ\text{C}$, $60 \pm 6 \% \text{R.H.}$) as shown in Photo 1. Fig. 1 shows the example of test result. The relationship between the mechanical properties of the polymer cement waterproofing membranes and P/C are shown in Fig. 2. The results indicated that with an increase in P/C of the test pieces, the tensile strength and elongation increased. The effect of water content ratio was apparent in the test pieces fabricated in $W/B = 100\%$; such pieces showed a behavior similar to brittle failure, with enhanced tensile strength and a significantly reduced rate of elongation.

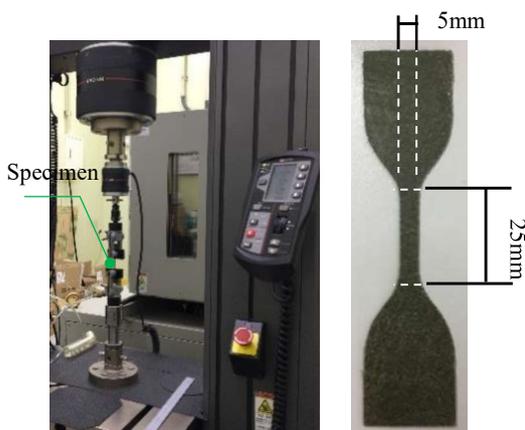


Photo1 Tensile strength test and test specimen

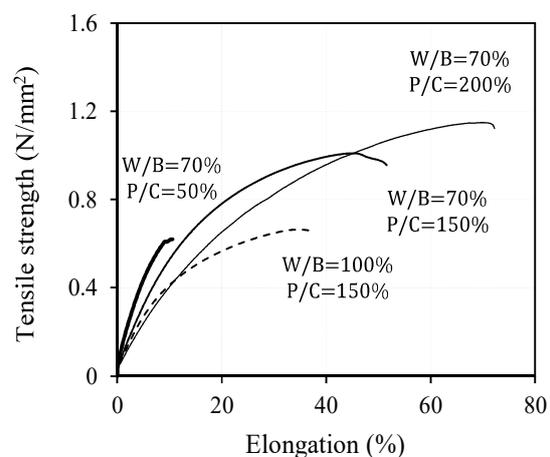


Fig.1. Result of tensile strength test

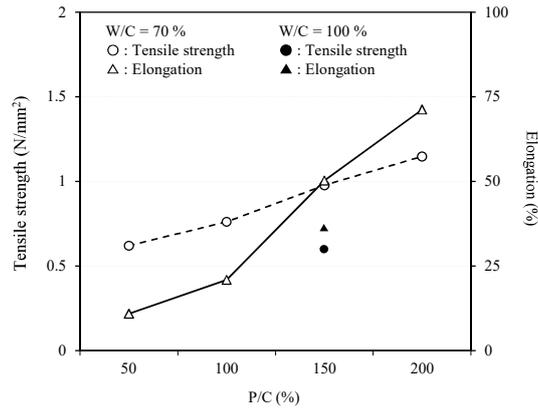


Fig.2. Mechanical property of polymer cement

Microstructure observation by SEM

The test pieces were examined by scanning electron microscope (SEM) observation in order to obtain a backscattered electron (BSE) image. For the SEM observation, the polymer cement was cut and placed in a cylindrical frame (diameter: 20 mm, height: 10 mm); then, the frame was filled with epoxy resin. This sample was polished and the measuring surface exposed. Measurements were carried out using a JSM-6510A (acceleration voltage: 15.0 kV). Photo 2 shows the observation results of microstructure of polymer cement waterproofing membrane in order to observe the difference of P/C.

The contrast of the BSE image is based on the atomic number. The bright areas of BSE image indicate high atomic number (Cement content: Ca or Aggregate content: Si) and dark areas are where the atomic number is low (Polymer content: C) [1], [2]. For the test pieces fabricated with low P/C, Ca was distributed in the entire area, apparently forming a framework. On the other hand, at a high P/C, Ca was present only in some of the regions and also, C seemed to fill in the spaces. The cross section observation results of the waterproofing membrane were shown in Photo 3. In a high W/B, material separation in the cross sectional direction was observed such as higher C content in the upper side of the test piece and higher Ca content in the bottom side. There is a risk with thin polymer cement membrane that even a small material separation would affect the physical properties greatly [3], [4].

Test specimen of simulated initial failure

The square shaped substrate concrete (W/C=60%) test pieces were prepared with a length of 300 mm and a thickness of 50 mm. One surface side (bottom side for casting of concrete) was treated with a polymer cement membrane, and cured at 20°C and 60 % R.H. for 7 days as shown in Photo 4. The specimens consisted of 3 types of initial failure such as debonding of membrane, insufficient coating thickness and incorrect mix proportion.

Debonding of membrane

One of the most prevalent failures for waterproofing membrane is debonding of the membrane from the substrate concrete. The cause of debonding of membranes is moisture evaporation pressure from the concrete substrate. In order to simulate debonding of the membrane, circular teflon sheets of a thickness of 0.1 mm with a diameter of 5.0 cm were attached to the concrete surface before applying a polymer cement waterproof membrane.

Insufficient of thickness of membrane

In this study, a flat roof slab was constructed assuming similar levels of slight sloping normally found in actual construction to accommodate rainwater drainage. Then, the substrate concrete was installed with a 1/300 slope. The polymer cement before the hardening had a low viscosity. Therefore, thickness of polymer cement waterproofing membrane on upper side of slope was approximately 0.5 mm and the lower side was 2.5 mm.

Incorrect mix proportion of polymer cement

Lastly, in order to simulate mixing failure during construction, two different mix proportion (P/C = 100% or 200%) of polymer waterproofing membrane were applied to the substrate concrete and connected in the middle to form one sheet before hardening. The thickness of membrane after curing is 2.0 mm in both P/C areas.

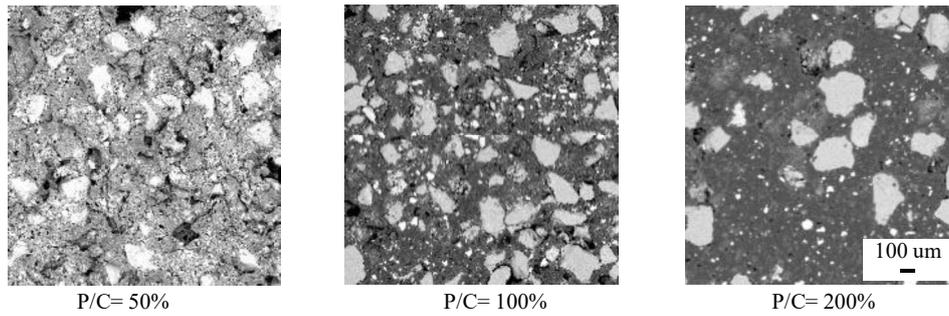
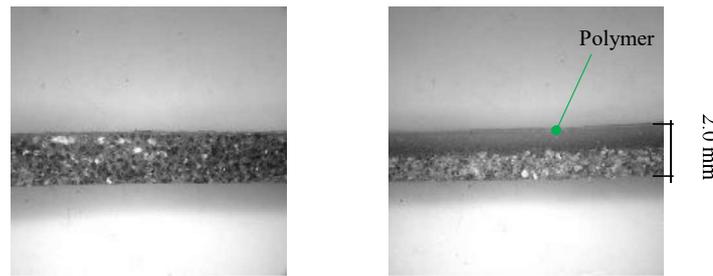


Photo 2 Microstructure of polymer cement (SEM observation results)



W/B=70% (Fine condition)

W/B=100% (Segregation)

Photo 3 Cross section of polymer cement

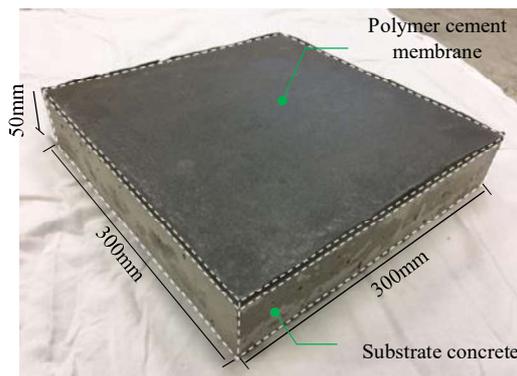


Photo 4 The appearance of test specimen

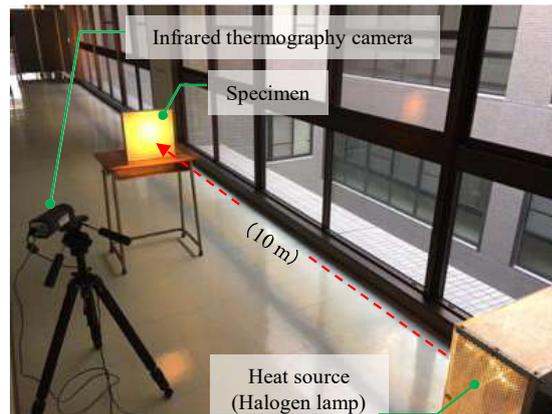


Photo 5 Observation by an infrared thermography camera

Experimental setup of thermography test

The infrared thermography camera detects the thermal energy and maps the temperature contours of the surface of a target object. In this way, local changes of surface temperature indicate defective parts. There are two types of infrared thermography method, such as passive thermography and active thermography. Passive thermography using solar radiation to perform diagnostic tests on the concrete materials have been used [5]. However, temperature of concrete surfaces vary not only due to defects of concrete but also due to weather conditions and site or direction of buildings. On the other hand, in the active thermography method, a heat flow for the target object is induced by an external heat source. The resulting heat flow is influenced by material layers or defects [6], [7], [8]. It is said that this method is not so strongly affected by weather and positional influences and is able to easily inspect a large area. In this study, location of the defect of the polymer cement waterproofing membranes were estimated by using the active thermography method. Data acquisition device was an infrared camera (A315 FLIR, Resolution 320×240 pix), working at a sampling frequency of 1 Hz. A set of heating lamps providing 500 W was used as heating source for tests and was set at 10 m from the test specimen as shown in Photo 5. The heating time by the lamp was 240 sec, and then the concrete was cooled at room temperature for 120 sec.

RESULT AND DISCUSSION

Experimental results are shown in Fig.3, 4, and 5. The test specimen of simulated initial failure of waterproofing membranes are shown in Fig. (a). In visual observation from the surface of membranes, it is difficult to confirm debonding area, difference in thickness or difference in P/C of membrane. The infrared thermographic images immediately after heating by the halogen lamp are shown in Fig. (b). The maximum temperature to the lowest temperature are indicated in 10 levels of gray scale. The defect location of membrane appeared as a rate of rise of temperature difference. The temperature distribution around the defective areas at the immediately after heating are shown in Fig. (c). The temperature changing history during 240 sec heating to 120 sec cooling of defective area and healthy areas are shown Fig. (d).

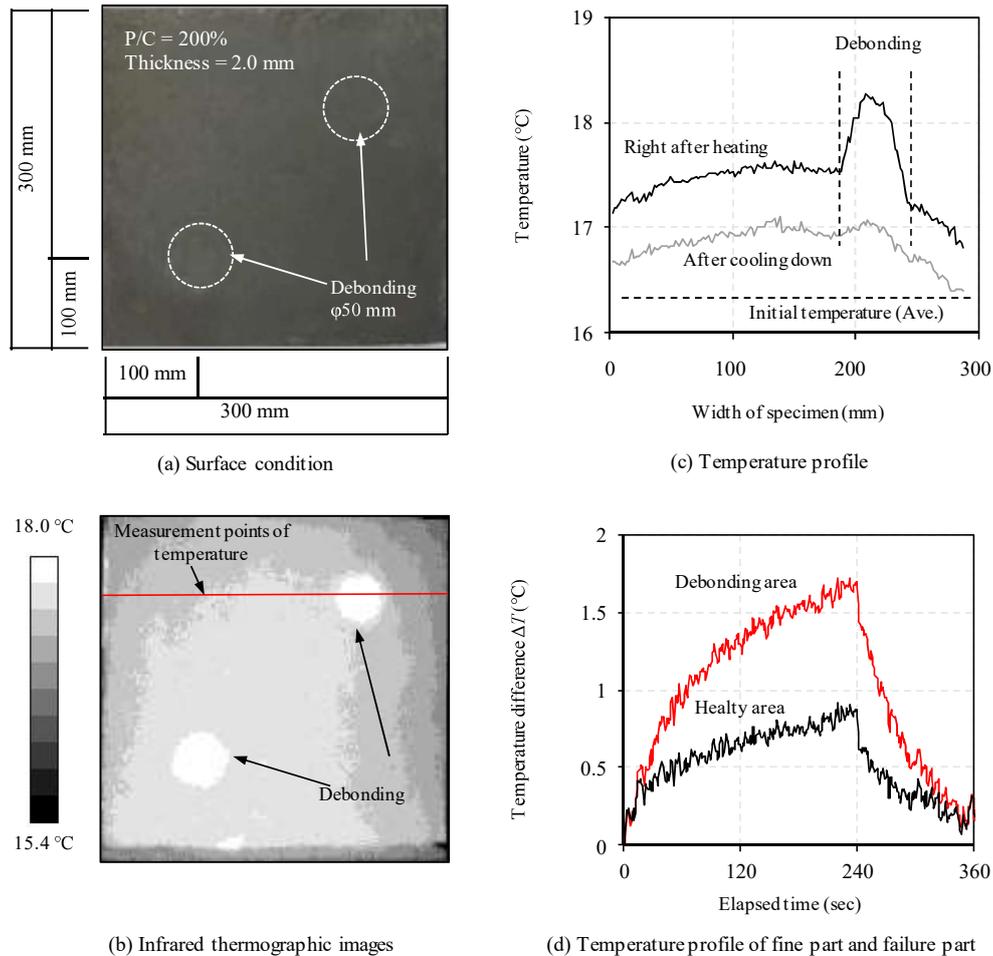
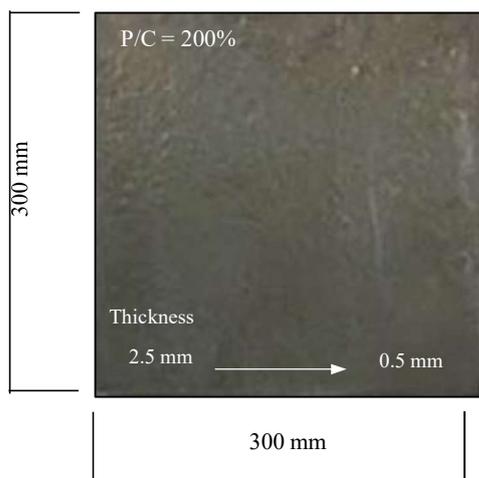


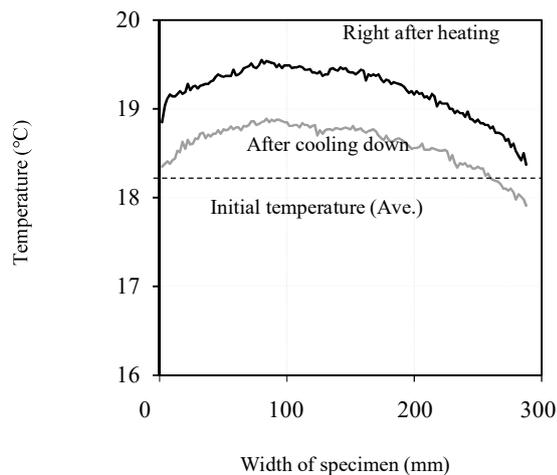
Fig.3. Inspection results of infrared thermography camera.
(De-bonding test specimen)

Debonding of membrane

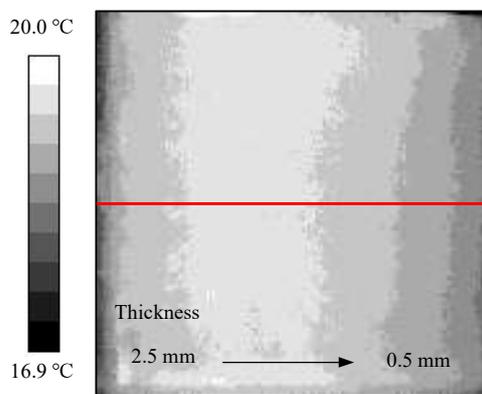
The temperature of the debonding area was higher than the healthy area. The difference between the debonding area and the healthy area immediately after heating is about 0.8°C. It is assumed that the air in debonding gap between membrane and concrete acts as a heat insulating layer. When the heat is induced by an external heat source, heat is accumulated in this debonding gap and the temperature is raised. Following cooling of 90 seconds after heating was stopped, the temperature of the debonding area fell to the same level as the healthy part. So, it is difficult to detect of debonding area by the temperature contours. Note that, as the specimen edge was not insulated, the temperature became lower than the center area.



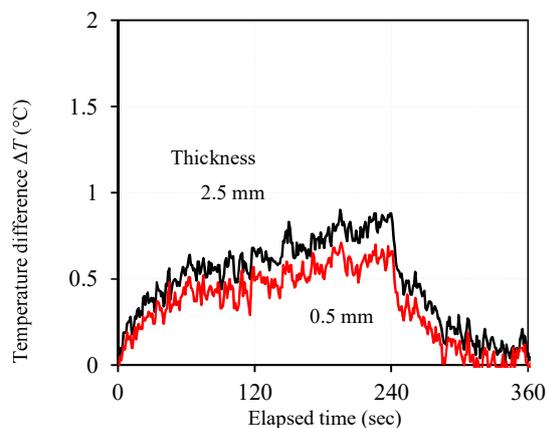
(a) Surface condition



(c) Temperature profile



(b) Infrared thermographic images



(d) Temperature profile of fine part and failure part

Fig.4. Inspection results of infrared thermography camera.
(Effect of membrane thickness)

Insufficient thickness of membrane

The temperature of membrane surface immediately after heating tends to be higher as the film thickness is thicker. The thermal conductivity of the polymer is about 0.2 W/(mK), the thermal conductivity of the cement is about 1.2 W/(mK), and the thermal conductivity of the polymer is about 1/6 of the cement. In this test, a polymer cement waterproofing membrane was produced with P/C = 200%.

A waterproofing membrane with a large amount of polymer has lower thermal conductivity than concrete. So, the waterproofing membrane has a large heat reserving volume. Although the temperature decreased after cooling of 60 sec, the proportion of temperature distribution was same as after heating.

Incorrect mix proportion of polymer cement

The higher the P/C of the membrane the higher the temperature immediately after heating tends to be. As described above, the amount of heat reserving volume is larger in the membrane containing more polymer, which has low thermal conductivity.

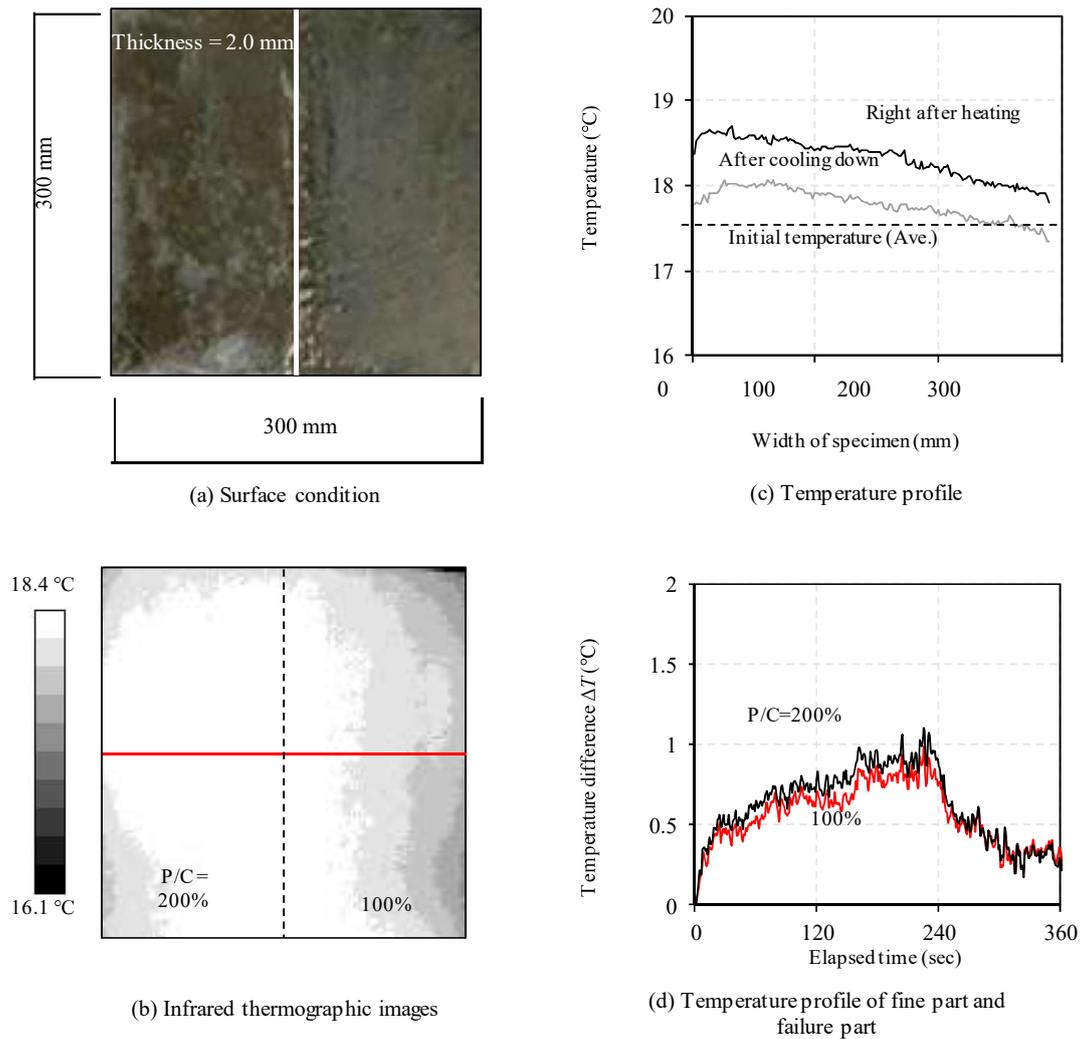


Fig.5. Inspection results of infrared thermography camera.
(Incorrect mix proportion)

CONCLUSIONS

The following conclusions can be drawn from this study:

1. The temperature difference between the debonding waterproofing membrane area and the healthy area immediately after heating could be detected by the infrared thermography camera. It is presumed that air exists at the debonding area between the waterproofing membrane and substrate concrete, and this acts as a heat insulating layer.
2. As the thickness of polymer cement waterproofing membrane was thicker or as P/C was higher, the temperature of the membrane surface immediately after heating became higher. The thermal conductivity of polymer is as small as 1/6 of the cement. For that reason, temperature difference after heating is presumed to have occurred.

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