Preventive Work and Health Monitoring for Technology by Cracks of Concrete Surface Using IR Camera and Resin Sensor

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Abstract. Safety inspections of infrastructure rely on visual inspections and hammering inspections by inspectors. However, there is a problem that inspection results vary because of differences in the technical level of inspectors. In order to solve these problems, we propose an inspection method and preventive work using Coating Type Resin Sensor and an infrared camera. The Non-destructive evaluation technique by thermography is increasingly being used as a tool for the maintenance of concrete structures. In most applications, the evaluation of only the location and shape of defects on planes is expected, therefore, no method has been developed for evaluating the depth of defects. After the application of infrared reactive resin, the target area, and thermos graphics are taken sequentially. Then, Analyses the temperature curves obtained at each pixel during cooling defect states in different parts of the temperature distribution by Fourier transform. This particular temperature change is related to the size of the defect. Approximately 10% of aluminium powder is mixed in the applied gel resin, and this aluminium powder has the property of concentrating due to its specific gravity in areas damaged by compression failure or floating. In this paper, we report on the technology related to the identification and size measurement of defects in infrared reactive resin, and the effect of preventive work to prevent the scattering and collapse of defects caused by destruction.

Keywords: Infrared thermography, Non-destructive inspection, Spalling prediction, Reinforcement

1. Introduction
In Japan, many infrastructurally important structures such as bridges and tunnels have been produced for more than 50 years [1]. However, in real life, bridges that have already reached the end of their useful life must continue to be used. It therefore becomes necessary to detect dangerous conditions such as the collapse of these structures as soon as possible. It is important to monitor deterioration and structural changes constantly over the long term, because those changes play a major role in
building a safe and secure society. Realizing such monitoring can be supported by the study of measurement and evaluation methods after fully understanding the usage environment, such as the characteristics of the structure to be measured and its years of use. In 20 years, 65% of bridges and 45% of tunnels are expected to be over 50 years old. Monitoring technology to check the soundness of structures is very important to constantly monitor deterioration and structural changes under long-term monitoring. I think that it plays an important role in constructing the system. In the past, safety inspections of infrastructure structures were targeted within 50 years after construction, when safety was guaranteed. The development of new monitoring technology is urgently required. In order to realize such soundness monitoring, it is desirable to fully understand the characteristics of the structure to be measured and the usage environment such as the number of years of use, and then consider the measurement method and evaluation method before implementing it. In order to reliably maintain the soundness of infrastructure structures, it is necessary to accurately evaluate the state of structures by judging the presence, frequency, and location of damage from survey and inspection data. Specifically, we will quantify empirical evaluation methods such as “visual inspection” and “hammering inspection,” and further improve the efficiency of “non-destructive inspection” such as X-ray inspection and magnetic flaw detection (standardization and Cost reduction, etc.) and high performance (improvement of accuracy, automatic data judgment, etc.) are important [2].

Therefore, the authors have developed a method that can measure the soundness of concrete piers of bridges, inner walls of tunnels, tiled walls of high-rise buildings, etc. in a simple, long-term, inexpensive manner, such as concrete cracks, defects, and wall floats. A technical method was examined. As a result, it was thought that the problem could be solved by using the original infrared reactive resin and image analysis technology that enables passive measurement with a long-wave infrared camera. This technology is mainly based on active measurement such as heating and pre-cooling due to the temperature change of the measurement object, which is usually measured by an infrared camera. In order to enable passive measurement at room temperature, we mixed aluminium powder into the gel resin and applied it to the concrete to be treated. When a crack occurs on the concrete wall surface shown in Figure 1(a) or a float shown in Figure 1(b) occurs, the aluminium powder in the gel resin flows and concentrates on the defect. Therefore, when the wall is heat-retained by sunlight, the missing part is emphasized by the temperature difference between the infrared radiation and the atmosphere. In addition, even if there is no heat radiation from the sunlight from the wall surface, it is possible to detect defects, etc. from the temperature difference between the wall surface and the wall surface due to the radiative cooling effect from the aluminium powder in the gel resin due to the difference in materials. It was confirmed that, in addition, the coated gel resin for this measurement has a repair effect because it flows into cracks and defects due to the difference in specific gravity between resin and metal. Therefore, this measurement method is considered to be a measurement technology that serves both as a measure of defects in concrete walls and as a preventive measure. It has been reported that rainwater that flows into the concrete structure from the defective part flows into the room and causes rain leakage, accelerating deterioration [3].

![Figure 1](image1.png)  
**Figure 1.** The concrete flaking occurs and cracks in concrete surface
2. Preventive work and measurement technology using infrared reactive coating type resin sensor.
In recent years, it has been used to measure "float" and "surface cracks" related to reinforcing steel corrosion in concrete using an external camera. However, the radiant energy of infrared rays is proportional to the temperature. An infrared camera detects the infrared energy and converts it into a pseudo-temperature image. The detection wavelength of infrared rays is thought to be around the middle infrared wavelength. It is expected that the density of heat energy will increase as it decreases.

2.1. Comparison with Conventional Technology
Various methods are used for quantitative evaluation of soundness for the purpose of disaster prevention and mitigation of structures. As a sensor system for measuring displacement and vibration due to static load, there is a method of measuring displacement using a laser displacement meter or a contact-type displacement meter, and a method of measuring natural vibration with a micro vibration meter and analysing the fracture state and stress concentration by FEM analyses. There are methods to identify locations [4-5]. In addition, X-ray analysis using FEM is useful as a non-destructive and quantitative evaluation method for residual stress in structures, but it is difficult to analyse crack growth with this method. Among these methods, microtremor vibration measurement obtains the Fourier spectrum ratio of vertical and horizontal motion components, normalizes the horizontal vibration to the vertical vibration, and determines the amplification characteristics and natural period of the structure. There are other methods to obtain it. The measurement system consists of a microtremor meter, a data logger, and a PC. The laser Doppler velocimeter (LDV) method [6] detects the velocity from the phase difference due to the Doppler effect between the irradiated light and the reflected light when the object is irradiated with laser light. This measurement system consists of two LDV devices, a data logger, a PC, and a digital displacement gauge, and costs about 4.5 to 6 million yen per measurement unit. In addition, X-ray non-destructive equipment can be installed for monitoring limited areas, but it is not practical for long-term measurement because it requires equipment costs of about 8 to 10 million yen and power supply. On the other hand, in the wall inspection technology of structures using an infrared camera, the thermography method, which utilizes the temperature difference due to the sunlight on the outer wall of the building, uses the difference in the conductivity of the wall material to measure the difference that occurs in the defective part. There is [7]. In addition, we have also developed a technique to study an image filter processing method that emphasizes the damaged area from an infrared thermal image and a statistical establishment method for estimating the probability of damage prediction as an index of the degree of damage in the temperature change part based on the feature value of the processed image. Exists [8]. In addition, Nakamura et al. of Kyoto University used infrared thermography to measure specimens at each damage stage in a reinforcement corrosion expansion pressure simulation test for the purpose of quantitatively evaluating the risk of spalling. The degree of risk of spalling is calculated as an index that can evaluate the degree of deterioration without considering the form [9-10]. In order to evaluate the safety and soundness of concrete structures, long-term monitoring of more than 20 years is considered necessary. However, there is a problem that a measuring device that can guarantee the required monitoring period and a smart sensing method that enables danger prediction do not exist at present [11-13]. Table 1 shows the specifications of the infrared camera used in the measurement, and Figure 2 shows the outline drawing of the camera used in the test.

2.2. Issues related to structure monitoring
As a method to measure the deterioration of structures mainly due to secular change, the measurement of "strain" and "deflection", which accompany the deterioration of structure strength due to corrosion and concrete failure, is considered for soundness evaluation. However, it is difficult to accumulate and evaluate long-term measurement results over a period of 10 to 20 years due to the difficulty of reproducibility due to the passage of time in fixed-point observations, and the accumulation of quantitative observation data due to the influence of atmospheric conditions due to weather conditions. In addition, the effect of "unevenness" due to changes in the temperature around the measurement in the structure, the thermal effect due to uneven thickness of the concrete wall, and the occurrence of erroneous detection due to the adhesion of relics to the surface can be considered. In addition, if the image analysis by the infrared camera is completed and the part evaluated as a defective part is different from the part evaluated as a defective part by the hammering inspection at a
later date, the final judgment is made by X-ray image analysis or magnetic inspection. There is also concern about the complexity of Even if these test results are accumulated, if a long period of time passes, it is thought that the evaluation method will progress greatly due to improvements in measurement methods and data image analysis software, etc., and there is a possibility that it will be wasted. also exists. However, considering the 50-year replacement period of infrastructure structures, we must consider the method and necessity of storing these images as digital data.

### Table 1 Specifications of infrared camera specs

<table>
<thead>
<tr>
<th>Infrared camera specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>Inf Rec R450</td>
</tr>
<tr>
<td>Detector</td>
</tr>
<tr>
<td>Two-dimensional non-cooling method</td>
</tr>
<tr>
<td>Measurement temperature range</td>
</tr>
<tr>
<td>-40 to 1500 degrees,</td>
</tr>
<tr>
<td>Measurement wavelength</td>
</tr>
<tr>
<td>8 to 14 μm, 480 × 360</td>
</tr>
<tr>
<td>Number of pixels</td>
</tr>
<tr>
<td>24 degrees × 18 degrees</td>
</tr>
<tr>
<td>Measurement field of view</td>
</tr>
<tr>
<td>24 degrees × 18 degrees</td>
</tr>
<tr>
<td>Standard lens</td>
</tr>
<tr>
<td>10 cm to ∞</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>3.8kg</td>
</tr>
</tbody>
</table>

2.3. Principle of infrared thermography

Objects that exist at room temperature emit energy by infrared radiation. Planck's law of radiation is expressed in equation (1), which states that all objects emit energy proportional to the fourth power of their absolute temperature. Boltzmann's law is shown in equation (2)[14].

\[
E(\lambda b) = \frac{2 \frac{h c^2}{\lambda^5}}{e^{\frac{hc}{\lambda kT}} - 1} \quad [\text{W} / (\text{m}^2 \text{μm})]
\]

\[
\sigma T^4 \quad [\text{W} / \text{m}^2]
\]

\[
\lambda_{max} = \frac{2897}{T} \quad [\text{μm}]
\]
When the measurement target is 40°C (absolute temperature \( T = 273 + 40 = 313 \) K), wavelength \( \lambda \) is \( 2897 \div 313 \approx 9.2 \) µm from equation (3).

2.4. Infrared thermal radiation relational expression

Figure 3 portrays an image acquired using infrared thermal radiation. The infrared rays emitted from the measurement target are propagated by equations (4)–(6). From the principle of the infrared thermography method, when measured with an infrared camera indoors, if no difference exists between the outside temperature in the air and the temperature of the test object, then the heating of the test object must also be considered. We compare changes in the infrared thermal images with and without preheating. Moreover, we measure the effects of applying gel resin under similar conditions [15].

\[
\begin{align*}
(1 - \varepsilon) \times W(Ta) & \quad (4) \\
\varepsilon \times W(T) & \quad (5) \\
\varepsilon < 1 & \quad (6)
\end{align*}
\]

\( T \): Object temperature  
\( E \): Spectral radiant heat of the object  
\( Ta \): Temperature of the facing surface

3. Measurement Method and Performance Evaluation of Infrared Reactive Coating type Resin

3.1 Image analysis using an infrared reactive coated resin sensor

From the principle of the infrared thermography, when measuring with an infrared camera indoors, if no difference exists between the outside temperature in the atmosphere and the temperature of the test object, then one can forcibly heat the surface, perhaps using a halogen lamp, to heat the interior of the test object. A method of measuring cracks and floats based on the temperature difference between the surface and interior can be used. However, the use of such a method requires that the measurement conditions always be established and implemented under favorable conditions, with due consideration devoted to the influence of the outside air temperature, the measurement target material and color, the spectral reflectance, and the measurement distance. Actual practical measurements are expected to be difficult. Figure 4 portrays the influence of the loading tester of the specimen (a) and the reinforcement arrangement of the specimen (b). A test specimen is prepared using ordinary concrete with a 2 cm cover thickness on this reinforcing bar. For this study, to improve the measurement level considering the problems caused by these thermal image characteristics, specimen A was an RC post with a φ65 hole drilled 23.5 cm below the center on the left side of the lower part of the specimen (a). Specimen (b) is an RC post with a φ65 hole
drilled 235 mm above the center on the right side of the specimen. A hole of φ65 was artificially machined to imitate the defect of a concrete support column. It was conducted to measure the strength effects on the upper and lower parts. However, to ascertain the measurement effects of the infrared camera by resin coating and the result of preventive work in the fracture situation, gel-like resin (CY52-276; Dow Corning Toray Co. Ltd.) was applied to the entire lower surface of each test body AB, except for the upper 300 mm. A coating film containing 1% aluminum powder with particles of 10–20 μm was applied to about 0.1 mm thickness. The material properties of this resin include resistance to ultraviolet rays, lack of hardening over time in the coating film, and maintenance of a gel-like property. Moreover, it does not retain water. It takes about 1 hour to harden after mixing 1 liquid and 2 liquids equally. The price is 1,000 yen per kilogram.

3.2 Infrared imaging using resin coating

(1) Examination of thermal image analysis by passive measurement

To compare the effects of thermal imaging with and without surface overheating, specimen A was heated from the back side for about 20 min using a carbon heater (900 W; Yamazen Corp.). Because the thermal conductivity of concrete is 1.6, about 61.05 times higher than the thermal conductivity of air, which is 0.026, we predicted that the surface temperature would rise after about 30 min. Therefore, after another 30 min had passed, we conducted a destructive test. Figure 5 presents temperature changes of specimens (a) and (b). Panel (a) shows a temperature comparison of specimen (a) by measurement with overheating. Panel (b) presents the measurement results found for specimen (b) measured at room temperature (21°C) without overheating by passive measurement. The temperature difference on the surface of the specimen from the start to the end of the test was 4°C for (a) and 0.6°C for (b). Figure 6 portrays details of the position and shape of the through-holes made in specimens (a) and (b).

(2) Construction evaluation of preventive work
On specimens (a) and (b), the gel-like resin (CY52-276; Dow Corning Toray Co., Ltd.) was applied to the entire lower surface, except for the upper 300 mm at about 0.1 mm thickness. We observed the damage and the state of falling fragments after the destructive testing of the parts coated with this resin and parts not coated with this resin. Figure 7 presents specimen (b) after completion of the destructive test. Destruction is generated by the shearing force generated obliquely from the right side of the screen and compressive force applied from the top. Particularly, it seems that infrared measurement was able to confirm the effects of suppressing the scattering and collapse of concrete fragments because of compression failure and the "floating" situation indicated by the arrow, which is difficult to detect using a visible light camera. Panel (a) depicts a thermal image of Specimen B taken using an infrared camera. Panel (b) portrays an image taken using a visible light camera. In both cases, the elapsed times of force application were equal.

4. Measurement Results and Discussion

4.1 Infrared images compared by application of gel resin

Figure 8 presents results obtained from the destructive tests conducted on specimens with upper and lower defects. Panel (a) presents a comparison of (1) an infrared thermal image and (2) a visible light image at the time of maximum load, and (3) an infrared thermal image and (4) a visible light image at the end of loading, for the specimen in Fig. 6(a) with preheating. Panel (b) presents the (1) infrared thermal image at maximum load and (2) visible light image, (3) infrared thermal image at the end of loading and (4) visible light image of the specimen in Fig. 6(b) without preheating. Panel (c) shows (1) an infrared thermal image at maximum load and (2) a visual comparison of the visible light image with the optical image, and (3) the infrared thermal image at the end of loading.

In panel (a), the test was started 30 min after heating the test piece with a carbon heater for 20 min. As shown in Figure 9, the temperature was measured and recorded (1) at the center 50 mm from the top of the surface, (2) at the center 250 mm from the top of the surface, (3) at the center 50 mm from the top of the back, and (4) at the center 250 mm from the top of the back. The infrared thermal image reproduces a state in which the upper temperature is high and the lower temperature is low. In the visible light image, the state of damage caused by the load applied to the test object is recognized only on the surface, but in the infrared thermal image, the damage state of the surroundings directly affected by the applied force in the deep part is also recognized. Our findings demonstrated the possibility of observing invisible parts in
contrast to visible light images. The temperature difference of the specimen was confirmed as matching the theory-based prediction: the residual heat strongly affected the external thermal image of the specimen surface after a certain period of time. Figure 8(b) presents a comparison of the infrared thermal image (1) and visible light image (2) under the maximum load, and the infrared thermal image (3) and visible light image (4) after the end of the load at room temperature of 21°C without any preheating. In the infrared thermal image, as Table 2 shows, the temperature difference of the specimen is only 0.6°C, but it is recorded in a state that is comparable to the image after heating shown in (a). This finding is attributable to the effects of the resin applied to the specimen surface. The resin has effect of a poultice and maintains the difference between the temperature of the specimen surface and room temperature, making it possible to obtain clear infrared thermal images [16].

Figure 8 The results of the destructive test on specimens with upper and lower defects and non-defects.
Table 2 Comparison of measurement surface temperature gap by specimens (a), (b) and (c)

<table>
<thead>
<tr>
<th>Strain No.</th>
<th>Test specimen a (°C)</th>
<th>Test specimen b (°C)</th>
<th>Test specimen c (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>16.3</td>
<td>14.9</td>
<td>14.5</td>
</tr>
<tr>
<td>(2)</td>
<td>16.0</td>
<td>14.4</td>
<td>15.0</td>
</tr>
<tr>
<td>(3)</td>
<td>19.3</td>
<td>15.2</td>
<td>15.2</td>
</tr>
<tr>
<td>(4)</td>
<td>20.3</td>
<td>15.5</td>
<td>15.3</td>
</tr>
</tbody>
</table>

Temperature gap 4 0.6 0.8

5. Conclusion

Using this measurement technology, this study produced the following findings.

1. Improving the resolution of infrared thermal images necessitates increasing the temperature difference from the outside air. We obtained clear thermal images while maintaining a large difference in radiant heat from the fracture site. In this case, it was more effective than measurement by heat generation from the outside.

2. Observing the mechanism by which a shear fracture occurs first in the fracture of the test specimen was not possible because of compression. Left and right bulges occur in the central part because of expansion. It was possible to visualize parts that are invisible to the naked eye.

3. The gel-resin-coated sensor improved thermal image acquisition during passive measurement and yielded results that were suitable for measuring "peeling" and "floating".

4. The resin coating effect can be useful as a construction method to prevent the progress of shearing and peeling at the time of destruction. Moreover, it can prevent falling from the top and collapsing.

5. Application of this resin is thought to prevent rainwater intrusion, metal corrosion, and deterioration.

6. The surface coating effect of this resin was found to be effective at reducing swelling and surface peeling caused by reinforced concrete column deformation during loading.

Acknowledgments

This research was partially supported by JSPS Kakenhi Grant No. 20H00290, for which we express our appreciation.

References

Books

Article in Journals


Books
