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Detection of Structural Damage of Infrared Thermal Image Using Computer Vision

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Abstract

In the field, accessibility due to the characteristics of large structures is limited, so NDT technology is required for maintenance inspectors. Therefore, many non-destructive inspection techniques that can be developed in a non-contact manner have been developed. Unlike other non-destructive evaluations, users do not need access to structures when evaluating defects in invisible areas using infrared thermal imaging. It is essential to prevent massive accidents by maintaining structure efficiently. However, there are limited on-site budgets and manpower, and analysis of IRT (Infrared Thermography) data to assess structural status still relies on user testing. In this study, we studied the image processing technique to detect the defects of the structure by using the infrared image to judge the defects without resorting to the naked eye. We propose a method of analyzing defects through thermal imaging of infrared images.

1. Introduction

The safety diagnosis of the existing structures is carried out by visual inspection and visual inspection of the damage of the structure by simple equipment and by the load test in the structure capable of load test. The strength of concrete is estimated by rebound hardness method or core sampling. Since the strength of concrete is greatly influenced by formulation characteristics, curing conditions, age, exposure conditions and test methods, it is necessary to develop a strength measurement and evaluation technology that can estimate the strength of concrete considering all of these effects. Therefore, in order to perform precise safety diagnosis of large concrete structures, it is necessary to carry out a systematic study on the strength measurement technique and the evaluation method of measured results according to deterioration damage type and concrete age.

Initial construction required safe and rapid construction. As time goes by and industrialization progresses, larger buildings and large structures are required to scale up. In addition, people are demanding the development of maintenance technology and preservation of the environment for buildings already built. Estimating the early strength of concrete is the most important factor in satisfying all of the above mentioned requirements. At present, the strength of concrete is measured by core sampling test method and nondestructive test method. Core sampling methods include core sampling methods. Non-destructive testing methods include rebound hardness method, ultrasonic method, and combination method. Although the core extraction method has high reliability, it has a disadvantage in that it is difficult to collect the core or local damage of the structure due to core collection.

A representative method of non-destructive test method is to make a concrete specimen and then use a universal testing machine (UTM) to destroy the specimen to obtain a value. The method of testing the hardened concrete surface with a Schmidt hammer, The rebound hardness method is used to measure the compressive strength of concrete using the relationship between compressive strength of concrete. However, in this case, since the concrete is sufficiently cured, there is a disadvantage that the air is stretched by that much, and when the concrete is laid on the site, it may be different from the value derived from the experiment due to the change of the external environment. Representative non-destructive testing techniques include measuring the early strength of concrete using Smart Rock sensors. After the concrete is mixed, the sensor is activated before moving it to the formwork, and when the device is placed on the formwork in conjunction with the smartphone application, the temperature inside the concrete is periodically recorded. The concrete has the property of rising in temperature at the early stage of curing due to the heat of internal hydration and then dropping again. By using this principle, the strength of concrete can be measured early. In this case, however, there is a clear limit to the possibility that errors between the actual strength and the estimated strength may occur due to the influence of the inserted portion of the sensor.

In addition, there is a method of measuring the strength by using a buried piezoelectric sensor. This is also a possibility that an error may occur because it is a method of measuring by embedding in a concrete like the above-mentioned Smart Rock sensor. These evaluation methods are proposed not only as theoretical formulas proposed by mathematical modeling but also as actual experiments or experience-based formulas. They require expensive equipment or complexity of the proposed formulas, It is not widely used. Therefore, it is required to reduce the cost of equipment and to use a simpler strength estimation formula. Therefore, it is essential to develop more accurate method of estimating early strength of concrete, which is easy to apply on site. Therefore, in this study, the infrared thermal imaging technique after concrete curing is compared with the Smart Rock sensor, which is commonly used in non - destructive testing of concrete strength, and the specimen center temperature data measured by Smart Rock sensor and the specimen We have tried to develop a quantified equation by comparing the early strength estimation equation of concrete with surface temperature data.

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2. Principles of Early Strength Estimation of Concrete and Infrared Thermal Imaging

In this study, to obtain the early strength of concrete, unlike the other sensors inserted in the concrete, the surface of the curing concrete was photographed with infrared camera every given time to obtain the temperature distribution image, A study was conducted to establish the early strength estimation equation.

As a research and development on the estimation of concrete strength using infrared thermography, we have developed an efficient concrete strength estimation formula which can minimize the error rate by applying the equation of early strength of concrete using existing hydration heat to infrared thermal imaging technique.

The hydration heat of concrete is used to compare the heat of hydration between concrete admixed with admixture and unloaded concrete, and the equation for estimating the early strength of concrete is quantified. We tried to derive the reliable result by comparing the difference of the physical properties of the concrete with the difference of hydration heat, and comparing the early strength of the concrete with that of the actual UTM machine.

2.1 Infrared Thermography

All objects emit infrared radiation energy above 0 K absolute. Radiation refers to the transfer of heat by radiation, not through the medium, unlike conduction and convection heat transfer using solid, liquid, or gas media. Infrared thermal image is an image that visually shows the temperature distribution of the object by detecting infrared rays emitted from nature on the surface of the object. That is, the temperature distribution of the object surface can be obtained as one image. Concrete can be displayed as an image through an infrared camera to not only know the temperature distribution on the surface of the structure but also to measure the temperature at each point.

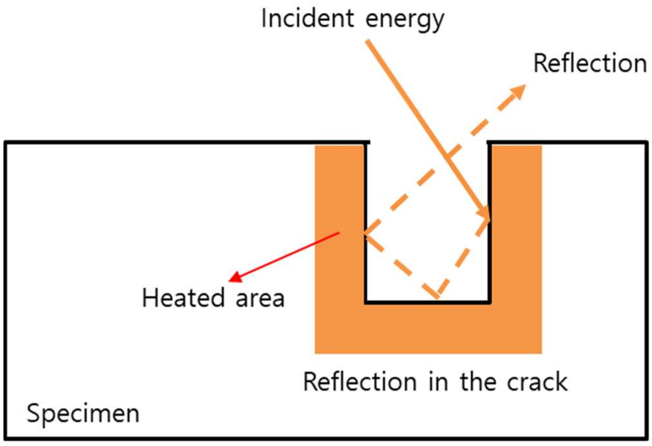

Fig .1. Infrared imaging device measurement principle

2.1.1 Heat of hydration of cement

Cement is hydrated when it is kneaded with water, and hydrates while heating. This heat is called heat of hydration. The hydration formation heat generated by hydration reaction of cement compound is shown in the following table.

Table. 1. The heat of formation and free energy change (Kcal / mol-CaO)

Hydration reaction	ΔH_{298}	ΔG_{298}
Cao + H_2O→ Ca(OH)$_2$	-15.60	-13.21
3CaO· SiO_2 + 2.17H_2O → 2Cao· SiO_2 ·1.17H_2O +Ca(OH)$_2$	-8.17	-6.23
Β-2CaO· SiO_2 + 1.17H_2O → 2Cao· SiO_2 ·1.17H_2O	-33.40	-0.86
Γ- 2CaO· SiO_2 + 1.17H_2O → 2Cao· SiO_2 ·1.17H_2O	-2.90	-0.36
3CaO· Al_2O_3 + 6H_2O → 3CaO· Al_2O_3 · 6H_2O	-23.03	-18.67
CaSO_4 · 1/2H_2O + 1.5H_2O → CaSO_4 ·2H_2O	-4.61	-1.32
CaSO_4 · 2H_2O + 2H_2O → CaSO_4 · 2H_2O	-4.00	-0.25

The heat of hydration is generated in the process of cement condensation and curing, and the amount of heat generated depends on the type of cement, chemical composition, powder degree, water and cement ratio as shown in the table above. When cement completely reacts with water, heat of 125 cal / g is generated.

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2.1.2 Estimation of early strength of concrete using maturity method

The maturity method is based on the temperature history of concrete and uses the product of temperature and time to estimate the strength. A maturity function was born by Nurse-Saul in the 1950s. In this study, we estimate the early strength of concrete by using the Nurse-Saul maturity function after measuring the surface temperature distribution of the curing concrete using IR infrared image at certain time intervals.

$$W_t = W_{obj}\tau\epsilon + W_{refl}(1-\epsilon)\tau + W_{atm}(1-\tau) \quad (1)$$

W_t: Thermal Cameras Total Radiant Energy, W_{obj}: *Target object*, W_{ref_i}: *External environment*

W_{atm} : Radiation energy emitted from the atmosphere

∈: The emissivity of the object

τ : Atmospheric Transmittance

$$M = \sum_{0}^{t} (T - T_0)\Delta t \quad (2)$$

M: the maturity index (° C-hours or ° C -days), T : the average concrete temperature (°C)

Δt: time (hours or days), T0 : initial temperature (℃)

2.2 Estimation of early strength using Smart Rock Sensor

In this study, after inserting the Smart Rock sensor into the formwork before concrete is put into the formwork, the temperature inside the concrete specimen is measured by curing the concrete on it, and then, We conducted a study to estimate early strength.

Concrete is cured by setting different proportions of materials in four concrete formwork of the same size and four molds. Before the concrete is laid, a Smart Rock sensor capable of measuring the internal temperature of the form is inserted in advance to enable the internal temperature of the curing concrete to be measured in real time, and after the installation is completed, Measures the surface temperature of the curing concrete at regular intervals. After the obtained temperature data is substituted into the Nurse-Saul maturity function, the early strength of the concrete is estimated, and the compressive strength of the concrete specimen cultured in the mold is measured using UTM equipment and the results are compared.

3. Methodlogy

Prepare molds and molds for cement and water, fine aggregate, coarse aggregate, and concrete to be used for concrete production. In this case, KS L 5201 ordinary portland cement was used as the cement, the size of the mold was 300 mm x 300 mm x 300 mm, and the size of the mold was 100 mm in diameter and 200 mm in height. Infrared thermal cameras (SC645, FLIR Systems, Sweden) have a resolution of 640 x 480 pixels and sensitivity of 7.5-13 μm. A schematic is shown in Figure 2 A total of four concrete specimens were made, and the surface temperature data obtained by periodically obtaining infrared thermographic images were tabulated. Experiments were carried out over the second stage. In the first experiment, concrete without admixture was added. In the second experiment, concrete with admixture was placed.

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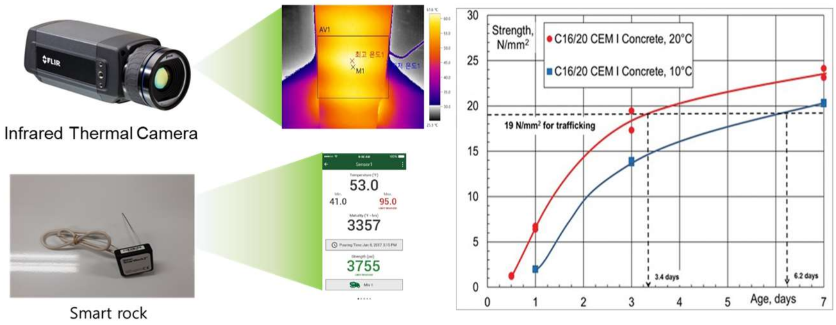

Fig. 2. Estimation Method of Concrete Strength Using Infrared Thermography

4. Results and Discussions

As a result of comparing the surface temperature of the concrete obtained with the infrared thermography image and the internal temperature of the concrete obtained using the Smart Rock sensor, the surface temperature was measured to be about 3 ° C lower than the inside temperature. Using this, 3 ℃ is added to the surface temperature obtained by infrared thermal imaging, and the result is substituted into the Nurse-Saul maturity function to compare the estimated strength after 6 days of concrete cultivation with that estimated by the actual Smart Rock sensor.

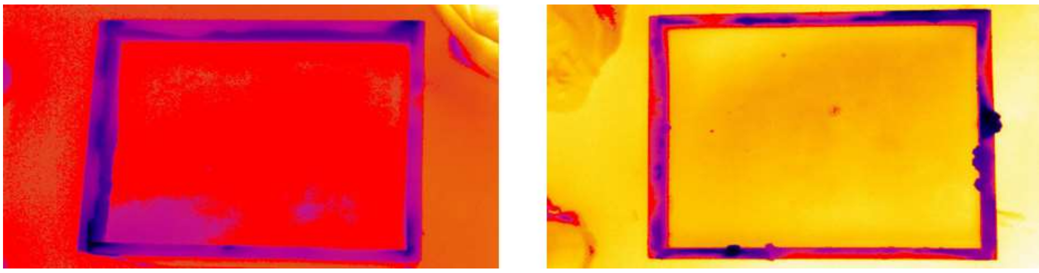

Fig.3. Surface temperature thermal image immediately after concrete casting

Experimental results show that the measured compressive strength and estimated strength of specimens 1, 3, and 4 tend to agree with each other within 10 ~ 20% error range. In the case of No. 2 specimen, it seems that there was a problem in mass measurement in the process of mixing the materials, so it is judged that it is necessary to carry out the re-experiment at the previously set proportion. Future work will further reduce the error by further studying the correlation between the surface temperature acquired with the infrared infrared image and the internal temperature acquired with the Smart Rock sensor.

In order to compare the estimated strength with the actual strength, the actual strength is measured by the compressive strength test using UTM equipment, which is the method that can obtain the most accurate compressive strength value at present. The measured figure is shown in Fig.4.

Fig. 4. Estimation of concrete strength using UTM

Table. 2. Comparison of strength values derived using each measurement and estimation method

	Infrared Image	Smart Rock	UTM
Specimen 1	15.7MPa	15.0MPa	16.7MPa
Specimen 2	14.9MPa	15.8MPa	22.8MPa
Specimen 3	15.8MPa	15.7MPa	18.3MPa
Specimen 4	15.4MPa	15.1MPa	16.7MPa

5. Conclusion

There is insufficient data to be used for the first research because research and development are not actively pursued in studying the early strength estimation of concrete through infrared radiography. Therefore, quantitative calculation is not performed in determining the composition of the specimen, the temperature data acquisition time, and the mixing ratio.

In order to obtain a quantitative data value on this, it is necessary to carry out an experiment with accurate calculation in the future. In carrying out laboratory-scale experiments, the size of the specimen must be limited. As a result, the heat of hydration does not rise so much that it is difficult to measure the temperature data value. The larger the specimen, the higher the heat of hydration, so it is possible to obtain a better data value if the field experiment is carried out.

We will quantify the temperature data of the hydration heat according to the property ratio and develop the compressive strength estimation formula suitable for the infrared thermal imaging technique to reduce the error rate and apply it to the field in order to derive highly reliable results.Although many safety assessments are currently being carried out on the structure, reasonable consideration is not given to the aging of the structure. Therefore, it can be a guideline for the development of technology for evaluating the safety of old structures considering the strength evaluated through this study.

Based on this research, it is thought that it will help smart city activation scheme and spread of smart city construction through building business model for smart city spread. In the future, it will accumulate a lot of data based on experiment result and apply computer vision algorithm We will make more accurate measurements by increasing the effect of images through

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