

Evaluate the Ability to Determine the Carbonation Depth of Concrete by Hyperspectral Imaging

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Abstract. *In recent years, using concrete to absorb CO₂ in the atmosphere has attracted attention as one of the global warming countermeasures. In general, destructive methods have been used to evaluate the amount of CO₂ absorption in concrete buildings and civil engineering structures. However, it needs to sample a portion of the concrete, and it is impractical to conduct continuous disruptive sampling of the structures in use. Therefore, it is necessary to develop non-destructive tests to evaluate the amount of CO₂ absorption in concrete. In this study, Multi-spectral imaging, which are the methods of non-destructive tests, were used to visualize the presence of calcium carbonate with depth-axis from surface of the concrete specimen which have been the preliminary drilled holes. In addition, moistened cotton swabs were used to extract the pore solution by pressing the inner wall of the hole and to test it for determination of the distribution of pH with depth. The results indicate that Multi-spectral imaging can evaluate different carbonation depths of concrete samples. Moreover, PH of each point examined in the specimens can evaluate as the depth distribution of calcium carbonate. Results were compared and discussed with each other depending on each methodological characteristic.*

Keywords: *hyperspectral imaging; carbonation depth; carbon dioxide absorption; concrete; sustainable development;*

1 Introduction

In the recent days, human production and life generate a large amount of carbon dioxide, which is accelerating global warming, bringing negative impacts such as sea level rise, droughts and floods, and breaking the human living environment. Therefore, reducing carbon dioxide emissions and promoting carbon dioxide absorption have always been important issues for environmental protection.

It is well known that concrete in buildings will undergo carbonation as a reaction, that is, the calcium hydroxide in cement reacts with carbon dioxide to produce calcium carbonate. Therefore, the use of buildings to absorb carbon dioxide is an important means to combat carbon emissions and mitigate the greenhouse effect.

To investigate the ability of buildings to absorb carbon dioxide, currently destructive sampling methods are used to obtain samples and then measure them in the laboratory using Thermogravimetric Analysis (TGA), X-ray Diffraction (XRD), and etc. to detect their calcium carbonate content, to know their depth of carbonation, and to determine the amount of carbon dioxide they fix. The aim of our research is to develop a new method to determine the depth of carbonation by directly testing the building itself without damaging it. Since the instruments used in both the thermal and radiometric methods do not have the capability to be used outdoors and to detect large samples.

Therefore, we chose a hyperspectral camera as the experimental instrument, which can output the spectral characteristics of substances of different compositions, can be used in an outdoor environment, and is easy to set up and use, making it ideal for the scenario we envisioned.

2 Materials and Methods

2.1 Sample

2.1.1 Accelerated carbonated concrete

In the first experiment, we simulated the cross-section of concrete after it had undergone carbonation, and observe the results captured by the hyperspectral camera. The 2 cylindrical concrete test specimens were divided into two pieces along the central axis to obtain a total of 4 half-cylinders, three of which were taken and numbered as 1, 2, and 3. Figure 1 shows a rectangular area with a width of 6 cm and a length of $4 \times X_i$ cm ($X_1=1$, $X_2=2$, $X_3=3$) drawn on the flat surface of each of the 3 half-cylinders starting from the top depending on the specimens' numbers. Each rectangular area with an area of $6 \times X_i$ cm² from top to bottom was subjected to accelerated carbonation for 12, 9, 6, and 3 days, respectively. Each layer was masked with aluminum tape and placed in an accelerated carbonation chamber with a CO₂ concentration of 5%. The temperature and relative humidity in the chamber were 20°C and 60% RH, respectively. The tape was removed from the top to the bottom of the layer every three days. Consequently, the final accelerated carbonation time for each layer was 12, 9, 6, and 3 days from top to bottom in that order. This is because the various depth of carbonated concrete should be investigated for an instant process.

The mix proportion of the concrete specimens are shown in Table 1, and the specimens have been cure in water for 180 days. Chemical admixture for air-entraining named Flowric S is introduced, that is a typical product using lignin sulfonate/polycarboxilate.

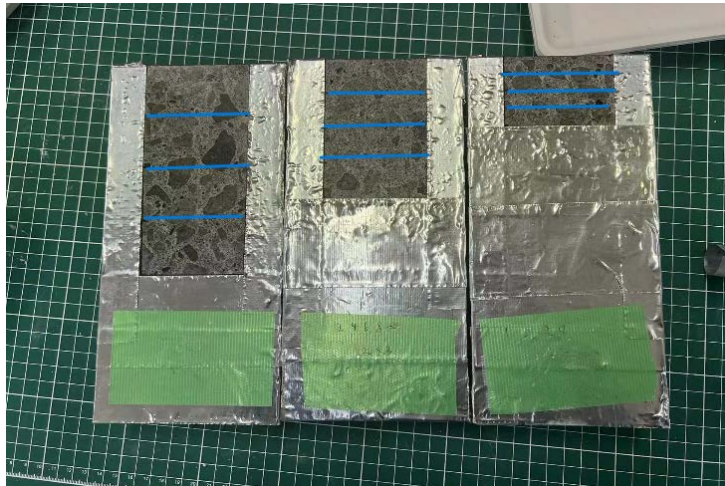


Figure 1. The width of each cell from left to right of the sample is 3cm, 2cm, 1cm respectively

Table 1. Mix proportion of concrete samples

Water (kg/m ³)	Cement (kg/m ³)	Coarse Aggregate (kg/m ³)	Fine Aggregate (kg/m ³)	Air (%)
182	264	963	865	4.5%

2.1.2 Mixed powder sample

In the second experiment, in order to provide a reference for the subsequent data interpretation, we made a powder mixture of calcium carbonate and calcium hydroxide in different proportions. By comparing the spectral data of these mixtures can be used to determine the calcium carbonate content of the spectral data of the experimental body, as well as to give the subsequent wavelength position methods as a reference. The weight ratios of the mixtures are Equation(1)

$$c_y + c_x = 100\% \quad (1)$$

where x is calcium carbonate, y is calcium hydroxide, and the values of C_x are in the range of 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 wt%. Total 12 samples were taken.

Both the powdery samples of Ca(OH)₂ and CaCO₃ are Guaranteed Reagent by FUJIFILM Wako Pure Chemical Corporation.

2.2 Hyperspectral imaging

2.2.1 Equipment and measuring mechanisms of hyperspectral camera(hyperx system)

It is a kind of hyperspectral camera manufactured named swir640 by NEO company, a manufacturer of hyperspectral camera, which can be used in all weather. It can be set up in the laboratory or outdoors, and is also used on remote sensing satellites and aircraft. As shown in the Figure 2, it is the hyperX system we use in the lab, underneath the camera is a computer-controlled movable carrier plate. Once the shooting parameters are set, the subject is placed on the carrier plate and the shooting begins. The lab uses a step-and-scan approach for filming.

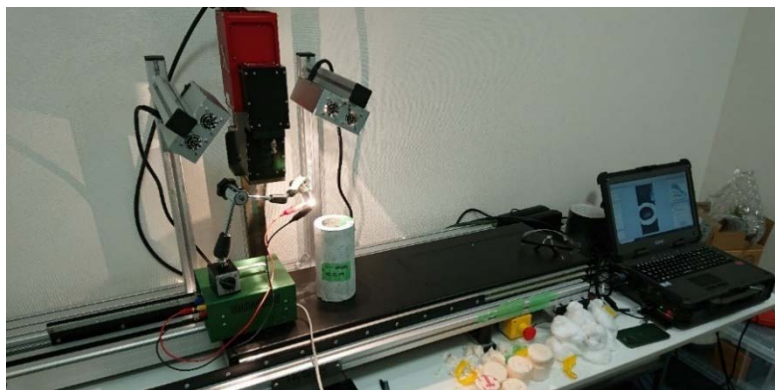
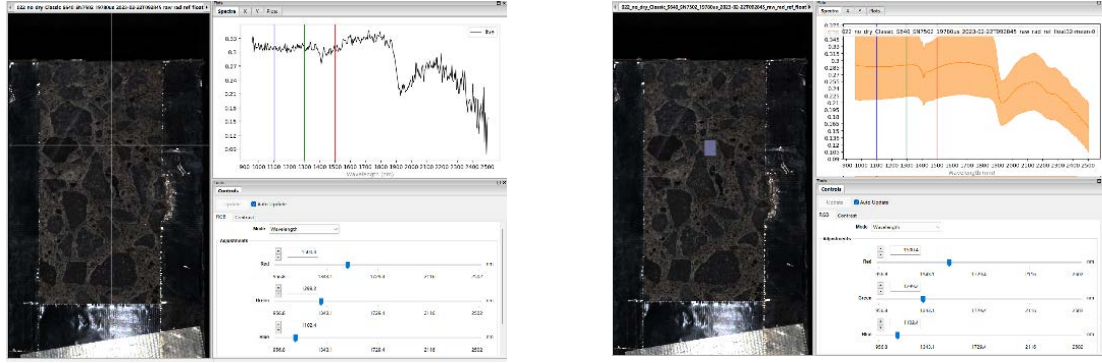


Figure 2. Appearance of small-destructive assessment of carbonation depth to drilled hole for monitoring using hyperspectral camera

2.2.2 Analysing methodology

After imaging, the acquired spectral data can be viewed using software named ‘‘Spectonon’’ made by the same production with the equipment. Extracted spectral data for each pixel can be visualized and displayed as the graphs in plotting the average of the intensity of spectral. The operation interface is shown in Figure 3



(a) Spectral graph at pointed position

(b) Spectral graphs at the chosen region

Figure 3. the schematic view of analyzing process

2.2.3 Continuous removal method

About the use of the continuum removal method (Lagacherie et al. 2008). The purpose of continuum removal is to quantify the absorption of a material at a specific wavelength, provided that no other material around this specific wavelength shows a strong absorption signature. The continuum is approximated by a straight line connecting two local reflection maxima that lie at the two shoulders (λ_{min} and λ_{max}) of the peak absorption wavelength (λ_{peak}). The continuum removal rate, CR_{λ} , is written as a Equation (2).

$$CR_{\lambda} = \min \left(1, R(\lambda_{peak}) / \left(R(\lambda_{max}) + \frac{\lambda_{min} - \lambda_{peak}}{\lambda_{min} - \lambda_{max}} (R(\lambda_{min}) - R(\lambda_{max})) \right) \right) \quad (2)$$

where $R(\lambda)$ is reflection value at wavelength λ . The values of λ_{min} and λ_{max} were determined based on our measurement experience with $\lambda_{min}=2275$ nm and $\lambda_{max}=2375$ nm for $CaCO_3$.

3 Results and discussions

3.1 Multispectral imaging of powdery samples

3.1.1 Powder samples

As mentioned above, we examined a mixture of calcium carbonate(0~100wt%) and calcium hydroxide(0~100wt%). 12 samples were photographed at once on the same tray as shown in Figure 4, ensures that all samples are photographed under the same lighting conditions, reducing the possible errors caused by different lighting.

As shown in Figure 4a, in the spectral data curve (wavelength-reflectance) of the powder

sample composed entirely of calcium carbonate, there is a peak between wavelength 2340nm to 2497nm. And in the same wavelength interval, the wavelength-reflectance plot for a powdery sample composed entirely of calcium hydroxide consists of a valley at 2390 nm and a peak at 2450 nm.

As shown in Figure.4b, in the 50%-90% calcium carbonate powder mix, there is a valley at wavelength 2343 nm, a peak at 2369 nm, and another valley at 2394 nm and another peak at 2442 nm. Visually, a valley appears in the peak of the 100% calcium carbonate mix, and as the calcium hydroxide increases and the calcium carbonate decreases, the valley gets deeper. With the increase of calcium carbonate content, peak at 2369 nm gradually increases and a valley at 2394nm gradually decreases. Making a straight line from 2343 nm to 2369 nm to get linear equation 3, and making another straight line 2343nm to 2394 nm to get linear equation 4 are conducted for normalization.

$$R_1 = aW + b \tag{3}$$

$$R_2 = cW + d \tag{4}$$

According to the parameters a and c shown in Table 1a, it can be seen that in the samples with calcium carbonate content greater than 50%, a keeps increasing and c keeps decreasing as the calcium carbonate content increases.

When the calcium carbonate content is below 50%, the spectral curve in the mixed powder samples with 10-40% calcium carbonate powder content is as shown in Figure.4c, only a valley at 2394 nm and a folded corner at 2360 nm, the graphs of the five groups of samples are very close. Connecting the starting point of the valley with 2360 nm, we can get their linear equation3.

$$R_3 = eW + f \tag{5}$$

The corresponding slopes c for these five groups of samples are shown in the Table 1(b).

Table 2. Samples with their corresponding a, c and e

(a)		(b)	
	a	c	e
90%cc	0.00164	0.00036	40%cc -0.00245
80%cc	0.00086	-0.00042	30%cc -0.00246
70%cc	0.00048	-0.00112	20%cc -0.00249
60%cc	0.00033	-0.00140	10%cc -0.00255
50%cc	0.00027	-0.00191	

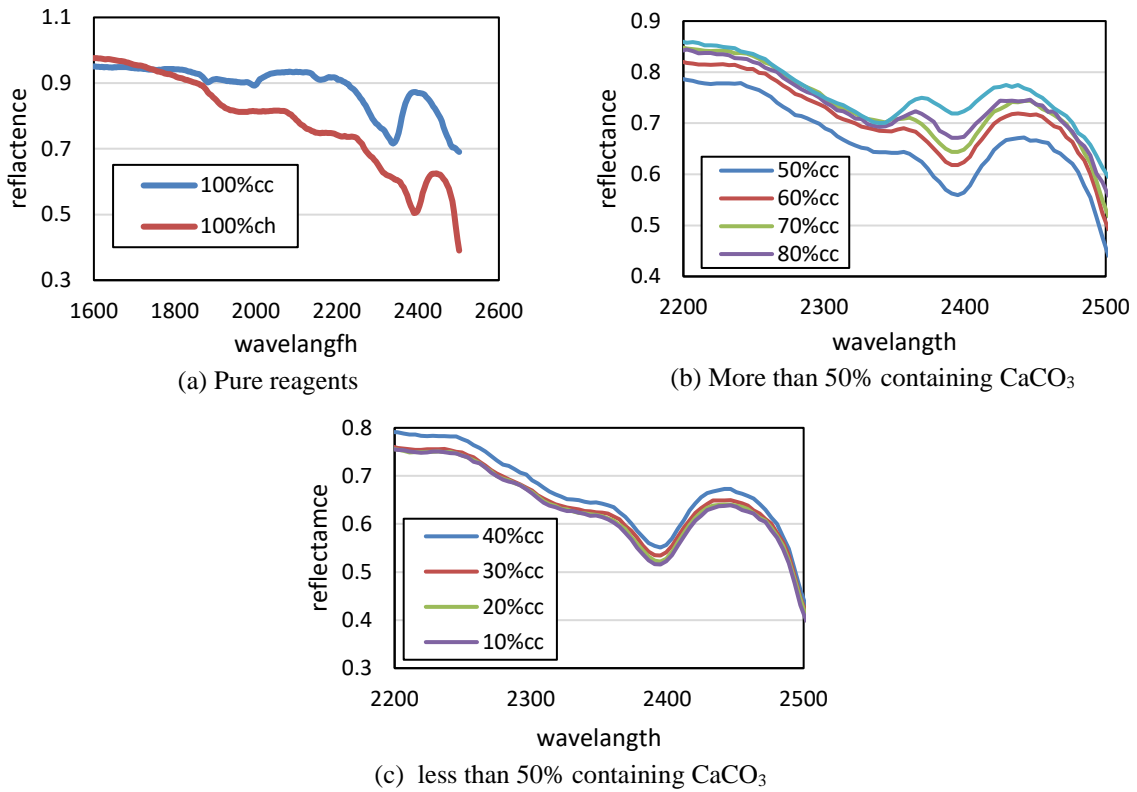


Figure 4. Referential spectra of powdery samples mixed with Ca(OH) and CaCO₃ reagents

3.2 Multispectral imaging of concrete samples

1, 2 and 3 cm depth from the top of each surface of concrete specimen as mentioned above are measured. Unlike powdery samples, wavenumber 2401-2404 nm at spectra of the concrete specimens exhibited weaker feature than the mixed powder sample, but instead it shows a flat curve. This is since the wavelength-reflectance curve shows the average of the reflectance curves of all pixels in a region, and the concrete contains not only cement, but also a lot of coarse and fine aggregate. These components make mixed spectra which have large and sharpened fluctuations.

For the analysis of spectral data of concrete surface, we used the continuous removal (CR) method described above. Generally speaking, a CR value was applied to evaluate the calcium carbonate content of land surface consisting of clay and calcium carbonate mixtures, and it has a negative proportion to concentration of calcium carbonate. On the other hand, CR values for calcium carbonate of the concrete samples are shown in Table 3. In general, content of calcium carbonate of the concrete specimens should be decreasing in proportion to depth from surface and negative proportion to duration of carbonation. However, there does not seem to be a correlation between them. This is because of the difference of the components of the surface between land and concrete surface. CR method were established based on the component of land surface, and fundamental spectral distribution of the images taken to land surface is different from spectral distribution of concrete surface. CR value for calcium carbonate is probably available to the soil surface taken from a hyper spectral camera mounted in the aircraft,

and need to be further sophistication for applying to carbonation on surface of concrete specimens.

For this reason, we propose a new treatment method. At the wavelength 2400-2440nm, which is the range where the spectral data of pure calcium carbonate powder becomes a valley feature and pure calcium hydroxide powder appears as a peak feature, the original downward curve at 2400nm curve appears a turning and then an upward trend, at 2420nm again turns downward and at 2440nm again turns upward, thus a bump appears between to 2440nm. Connecting 2400 and 2440nm to form a closed figure, dividing it vertically at 2420nm, the ratio of the area between 2400-2420nm to the area between 2420 and 2440nm is supposedly standing for the ratio of calcium carbonate to calcium hydroxide. According to this method, the data calculated are shown in the graph (Fig.4a,4b,4c), and the ratio of calcium carbonate to calcium hydroxide (calcium carbonate/calcium hydroxide) follows an increasing trend as the carbonation time increases.

Table 3. Each part with its corresponding cr value

CR value_for carbonate calcium	12day	9day	6day	3day
1cm	0.972535181	0.984173206	0.982722496	0.981040483
2cm	0.984532315	0.988898084	0.982902682	0.987651832
3cm	0.984532315	0.988898084	0.982902682	0.987651832

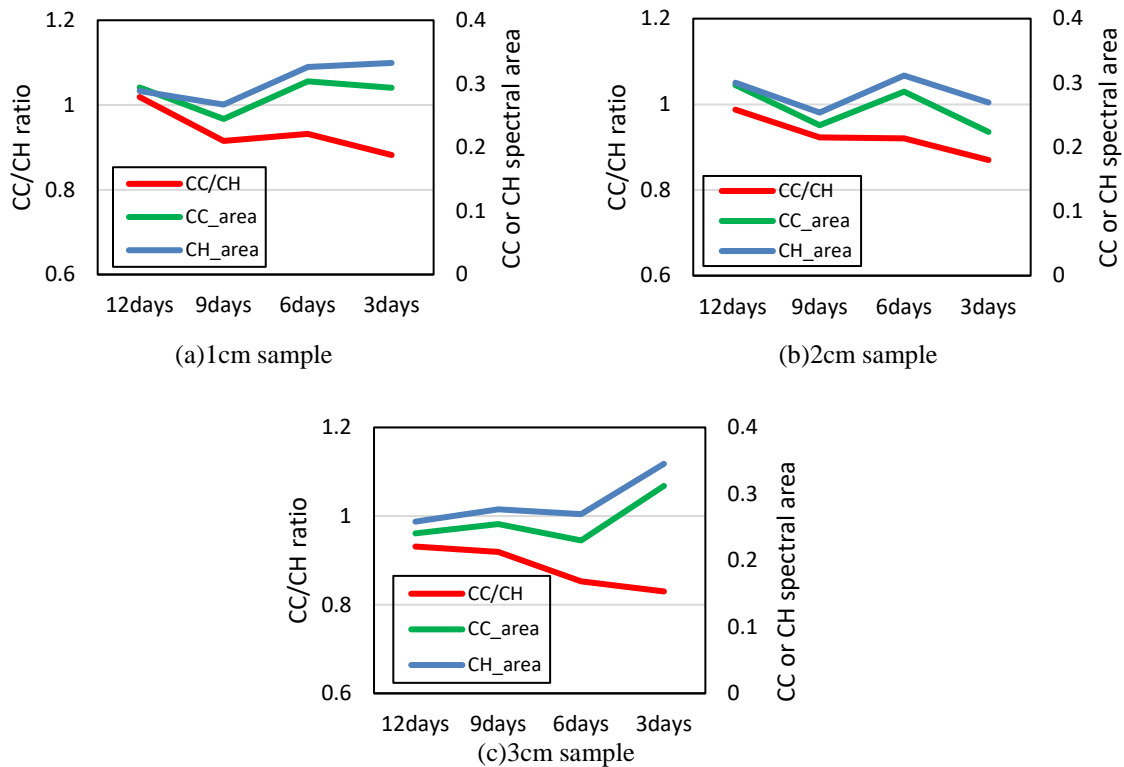


Figure 5. Each region and their corresponding cc/ch ratios

4 Conclusion

As a result of our research, we currently believe that the analysis of powder sample characteristics is reliable, but when applied to concrete, the calcium carbonate content of the concrete cannot be determined solely from the characteristics of the powder due to the presence of other components, as the spectral data shows the average of all pixel spectral data in the area. The continuous removal method and the self-invented graphical method currently used, although used as a reference, cannot be determined to give an accurate indication of the calcium carbonate content as no control was designed at the beginning of the experimental design, and we will refine this in later experiments.

In subsequent experiments, we will refine our ability to evaluate the depth of carbonation through computer techniques, including programming techniques to remove fractions containing bone resorption features, or through methods such as wavelength position analysis.

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