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Original article

Use of Terrestrial Hyperspectral Sensors for Analyzing Spectral Reflectance Characteristics of Concrete

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Abstract

The purpose of this research is to extract spectral reflectance characteristics of concretes through basic experiment on concrete specimens and site experiment on actual concrete structures using a field portable spectrometer and a VNIR hyperspectral sensor. A spectrometer (GER-3700) and a VNIR hyperspectral camera (AisaEagle VNIR Hyperspectral Camera) were utilized for extracting spectral characteristics of concrete specimens. Concretes normally show similar patterns that have correlation above 80%, while the high-strengthened concretes display very different results from the normal-strength concretes. We also made a certain conclusion in the laboratory experiment on concrete specimens that both the spectrometer and the VNIR camera vary in spectral reflectance depending on concrete strengths.

Keywords : Hyperspectral Images, Spectrometer, VNIR Hyperspectral Camera, Spectral Reflectance, Concrete

1. Introduction

Recently, developments and improvements in the system related to concrete characteristics have been recognized necessarily, especially for maintenance regulations of concrete facilities in construction markets. Techniques of concrete structures have been continuously advanced over along with the industrial developments as well as the structural monitoring techniques. As the reflectance measurement is easily, rapidly and accurately obtained, it can be used in the field that provides an in-situ tool for engineers to inspect the concretes' status(Brook and Ben-Dor, 2011).

The use of reflectance spectroscopy across the visible near-infrared and short-infrared spectral region (400 to 2500 nm) was suggested as a tool to assess the status of concrete in situ(Brook and Ben-Dor, 2011). Hyperspectral remote sensing method was investigated to assess degradation of concrete in artificial structures such as tunnels, bridges or buildings (Arita *et al*., 2001)

The hyperspectral imagery has been often used to detect and map a wide variety of reflectance spectra of materials. There are several examples in using the hyperspectral imagery; firstly, those hyperspectral images have been used by geologists for mineral mapping (Clark and Swayze, 1995) and detecting soil properties, which are moisture, organic contents, and salinity (Ben-Dor *et al.,* 2001); secondly, Vegetation scientists have successfully used hyperspectral imagery to identify vegetation species(Clark and Swayze, 1995), to study plant canopy chemistry, and to detect level of vegetation stresses. Military personnels have been also used hyperspectral imagery to detect military vehicles under the partial vegetation canopy, and also to detect targeted objectives in many other militaries (Shippert, 2003). Following lately, Yavari *et al*.(2010) has evaluated qualities of

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changes in heated oils, based on visible/near infrared spectral analysis using a spectrometer.

Several spectral libraries include wide collections types of materials, which have different reflectance spectra. These high-quality libraries provide valuable information for many investigators, who collect spectral libraries for materials in sites, by providing analysis of multispectral or hyperspectral imagery from those sites. Those ASTER Spectral Library and USGS Spectral Library are the most trusted and comprehensive mass spectral libraries in the world for identification and quantification of hyperspectral images (Baldridge *et al.,* 2009; Randall, 2012; Shaban, 2013).

The spectral signature is a unique spectral reflectance of an object that can be used to identify and discriminate different types of materials. As an example, Fig. 1 describes the reflectance spectra (i.e. the percentage of reflected electromagnetic radiation), measured by laboratory spectrometer for four materials: granite, concrete, asphalt and basalt.

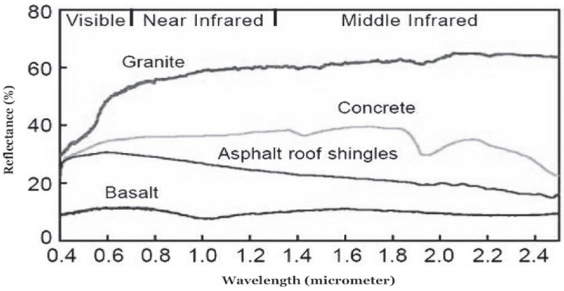


Fig. 1. Reflectance spectra measured by laboratory spectrometers for four materials: granite, concrete, asphalt & basalt (Randall, 2012)

This research has been started from the idea that a hyperspectral remote sensing is also able to be utilized for monitoring the concrete structures. If the concrete conditions were understood by spectral characteristics, the hyperspectral imagery can become an useful instrument for examining the current states of concrete structures or facilities, distributed in an urban area. The purpose of this research is to extract spectral reflectance characteristics of concretes through the basic experiment with a spectrometer and a VNIR (visible and near-infrared) hyperspectral sensor. For the experiment, a spectrometer (GER-3700) and a VNIR hyperspectral camera (AisaEagle VNIR Hyperspectral Sensor) were utilized for extracting spectral reflectance characteristics of concrete specimens. By two types of hyperspectral sensors, we tried to analyze reflectance spectroscopies of the range of visible, near-infrared and shortwave infrared with evaluating statuses of the concretes. The spectral data, collected by both a hyperspectral camera and a spectrometer, are able to be applied as terrestrial truth data for extracting accurate spectral reflectance, analyzing airborne or satellite hyperspectral images.

2. Experiment for Extracting Hyperspectral Characteristics of Concretes by a Spectrometer

For understanding characteristics of concretes, the concrete specimens for compressive strength test were produced not only with different ratio of water to cementitious material (W/C) but also with different concrete curing time. The design compressive strengths of eight specimens of general concrete were 15MPa(22), 15MPa(24), 21MPa(27), 21MPa(28), 24MPa(37), 27MPa(36), 27MPa(38), and 27MPa(37) at 27 days material age which were planned by different W/C ratio (the numbers in parentheses refer to actual strengths). Compressive strengths were measured with an universal testing machine. Furthermore, in the study of material strengths, the compressive strength indicates the capacity loads of materials or structures to withstand compressive loads in tending to reduce its size. The mean of design strengths refers strictly to the compressive strengths of the concrete-mixed-designs, which designed for a targeted strength when determining concrete mix of cement, aggregate, water and so forth. Also, the actual strengths imply for the compressive strengths measured by a universal testing machine.

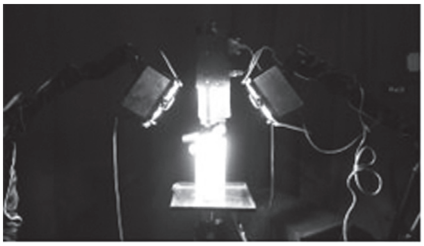
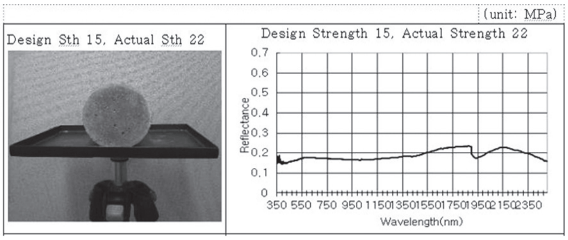


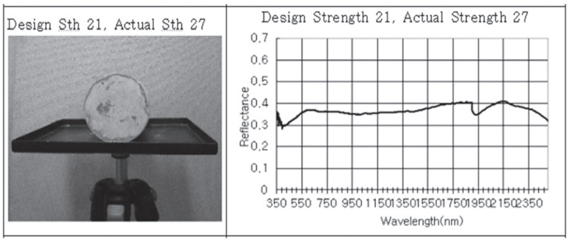
Fig. 2. Specrometer GER-3700

A field portable spectrometer, GER-3700 shown in Fig. 2 has 350 nm to 2500 nm in spectral range, namely 704 in band number. However it's characteristic is to measure only an object at once because it can acquire just point data.

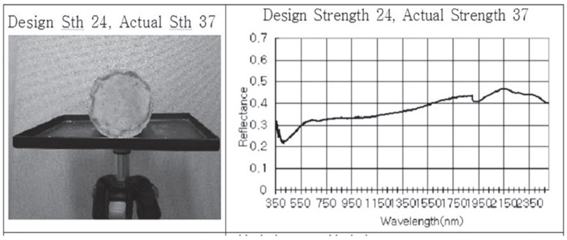
The measurements of the white reflectance panel with 99% spectral reflectance ratio by GER-3700 and the spectral information from concrete specimens have been considered as a reference data, respectively.



(a)



(b)



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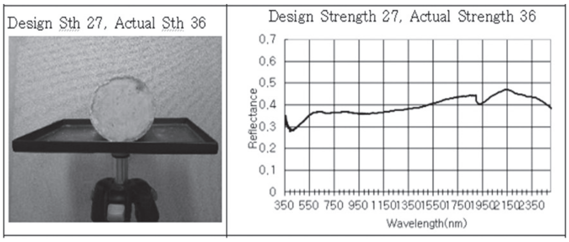

(d)

Fig. 3. The examples of reflectance curve of concrete specimens according to compressive strength depending on different ratio of water to cementitious materials

Fig. 3 describes spectral reflectance characteristics of only four specimens with actual strength of 22MPa(design strength of 15MPa), actual strength of 27MPa(design strength of 21MPa), actual strength of 37MPa(design strength of 24MPa) and actual strength of 36MPa(design strength of 27MPa) among nine specimens. As the concrete strengths increase, the reflectance ratio also entirely grows. A specimen with 36MPa actual strengths shows about 10~20% higher reflectance, which is almost twice higher than the actual strength 22MPa.

From comparing two specimens of actual strengths of 36MPa and 37MPa, we could cautiously conclude that concrete strengths have little effects on reflectance beyond a certain strength point. In fact, it is noticeable that reflectance falls sharply between 1,900 nm and 1,950 nm in all cases, which could be also found certain through concrete's curve in Fig. 1.

Normalization should be performed prior to specimen analysis, and needed to compare with the spectral reflectance of airbornes or satellites remote sensing data. Most of concretes specimens with different strengths and a super high-strengthened specimen were measured by the spectrometer. Fig. 4 shows compressive strengths for spectral reflectance of each concretes specimens with different W/C. Measurements of base planes mostly resulted in similar patterns of spectral characteristics, even if the reflectance ratio appeared significantly different levels due to each concrete strength.

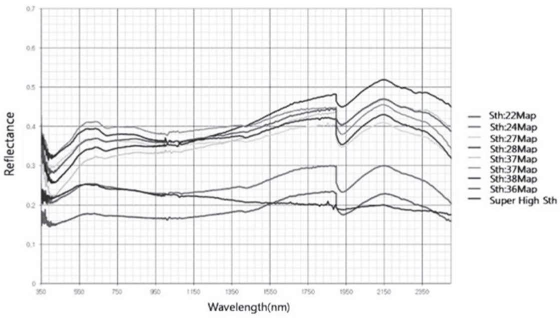

Fig. 4. Spectral signatures of compressive strengths of concretes with different ratio of water to cementitious materials

The reflectance increases below 1,900nm wavelength range. At the wavelength range of 1,950nm, the reflectance of all specimens drops sharply, but reached the peak around at 2,150nm wavelength. Afterwards, it decreases gradually following the wavelength over 2,150nm.

The reflectance curve of 27MPa specimens, however, displayed different patterns after 1,000nm wavelength, which gives out low correlation of 0.35. For this reason, the specimen of 27MPa should be excluded from the data analysis as an erroneous. Therefore, there are eight concrete specimens in similar patterns with more than 80% correlation, and a high strengthened-concrete with a different pattern.

3. Experiment for Extracting Hyperspectral Characteristics of Concrete Using VNIR Hyperspectral Camera

AisaEagle VNIR hyperspectral camera, shown in Fig. 5, has 400~970nm in spectral range and at maximum 1040 in band number. Spectrometer data are also helpful in maintaining the concrete-based structures, buildings, highways and so forth by means of airborne- or satellite-based hyperspectral imagery. In addition, the hyperspectral data for objects need to be saved in the form of the spectral library for rapid and appropriate decision-makings, such as maintenance of the concrete structures or facilities.

Fig. 5. VNIR hyperspectral camera

Likewise, the same concrete specimens were used as subjects in VNIR hyperspectral camera as stated in Chap. 2.

We photographed not only four types of 99%, 75%, 50% and 2% reflectance panels but also the concrete specimens with different strengths at 27 day of material ages to be included in only an image using the VNIR camera shown in Fig. 6. It is because targeted objects should be taken together with reflectance panels to get accurate reference values.

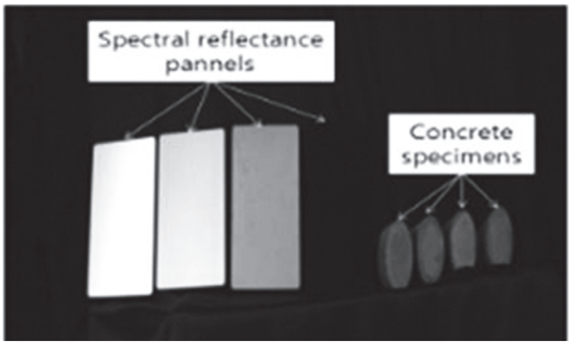

Fig. 6. VNIR sensor image

Fig. 7 shows the full screen of ENVI software for processing the VNIR camera imagery. Spectral information by pixels was able to be extracted from the photographed imagery by ENVI software. Spectral information on the spectral profile windows in Fig. 8 was saved in ASCII file form, and applied in the Excel, based on the reflectance of 99% white panel, like the case of GER-3700.

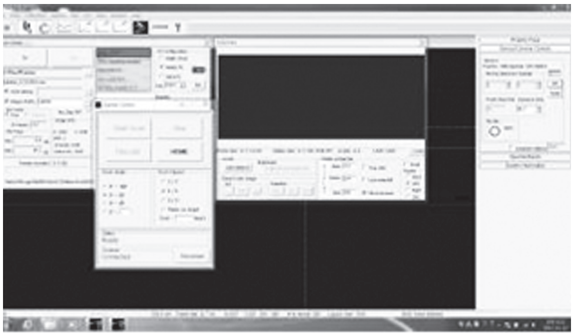

Fig. 7. The full screen of ENVI software for processing the VNIR camera imagery

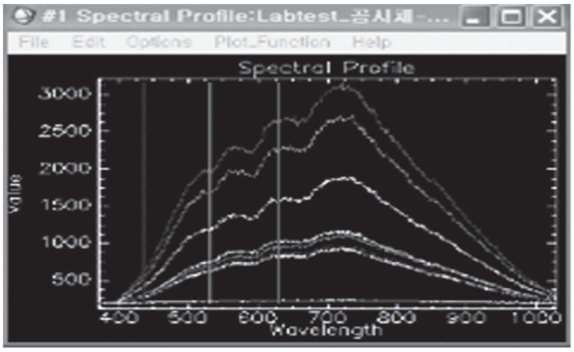

Fig. 8. Spectral Profile

Fig. 9 refers the reflectance and wavelength for four different compressive strength specimens of 22MPa, 27MPa, 37MPa and 36MPa, as well as four different reflectance panels with 99%, 77%, 55% and 2% reflectance ratio, which were divided by the value of 99% reflectance panel.

The VNIR camera can describe the sensitive reflectance characteristics depending on photography conditions, such as locations of light source, and distances between light source and targets in the laboratory. There are two types of hyperspectral cameras resulted in different spectral results. In the laboratory experiment, the result of the spectrometer was considered to have higher reliability than those of VNIR camera, since it generally comes out with more consistent reflectance curve in SWIR(shortwave infrared) range than VNIR range.

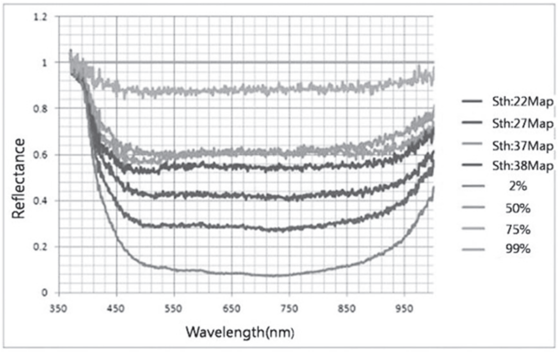

Fig. 9. Spectral characteristics of reflectance panels and concretes extracted by VNIR camera

4. Conclusion

Spectral characteristics of concrete were analyzed in accordance to the concrete strengths that are decided by different ratios of water to cementitious materials.

As a result of the experiment, spectral reflectance of specimens has correlations higher than 80% and the reflectance of actual strength 36MPa was measured to be about 10~20% higher reflectance than that of actual strength 22MPa.

This result suggests that the reflectance spectroscopy ranges of visible, near-infrared and short wavelength can be utilized as a promising tool to evaluate the statuses of concretes. These two types of terrestrial hyperspectral sensor data are also considered as useful reference data for analyzing conditions and making decisions for maintenances of concrete-based structures, buildings and highways using airborne or satellite hyperspectral images. The hyperspectral data for a variety of concrete objects need to be saved in the spectral library to provide referenced information, especially for maintenances of the concrete structures or facilities.

If studies on hyperspectral reflectance characteristics of worn-out concretes, super high-strengthened concretes and concrete aggregate condition will be performed in depth, airborne or satellite hyperspectral imagery for an wide area will be helpful in stability evaluations and maintenances of concrete-based structures or facilities.

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