Analysis on Compressive Strength of Concrete Using Spectral Radiometer: A Preliminary Study

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ABSTRACT- *Concrete, as a construction material requires laborious tests to determine its major properties namely, Strength and Durability. Several investigations are required for the specimen to be tested after being subjected to compression. However, in recent years, Remote-Sensing is used as a non-destructive method to determine any material for its structure and composition using its spectral reflectance signature (Spectral reflectance signature is the variation of emittance of materials with respect to its wavelength). Concrete contains lime (CaO) which reflects high in Visible Near-Infrared (VNIR) region and hence, it is possible to obtain differences in spectral reflectance for various grades of concrete due to differences in composition of the elements. The aim of this study is to determine the potential of remote sensing in characterising the compressive strength of concrete using remote sensing measurements. Conventional concrete grades used in this study are M20, M25 and M30. The compressive strength of three different grades at different periods of curing, i.e., 7 days, 14 days and 28 days are determined and assessed. Tested sample cubes are then used to measure the reflectance using spectro-radiometer in the VNIR region. Spectral reflectance curves of the concrete samples were generated and it was observed that it is possible to relate the compressive strength of concrete with remote sensing measurements in a qualitative manner. In addition, the indices created using 450 nm, 600 nm and 880 nm were used to validate the results.*

KEYWORDS: Compressive Strength, Spectro-radiometer, Spectral Reflectance, concrete index

INTRODUCTION

Concrete, as a construction material, has the largest production of all structural components in construction. Conventional concrete is a versatile material and it consists of cement, fine aggregate and coarse aggregate. The characteristic of concrete varies with composition, ageing, water/cement ratio. The compressive strength of concrete is the most common performance indicator measured by engineers when designing concrete structures (e.g. buildings, pipes, roads and bridges). However, concrete performance often reveals large differences from that of 'test sample concrete'. To resolve specific problems related to environmental hazards and constructional materials, a new approach, including methods for near real-time analysis, is required. Spectral remote sensing has evolved considerably from the early days of airborne scanners and the first Landsat multispectral satellite sensors. Currently, ground, airborne and satellite hyper-spectral sensors provide images and reflectance in hundreds of contiguous narrow spectral channels at spatial resolutions down to meter scale and spanning the optical spectral range of 0.4 to 14 µm. By measuring the spectral reflectance of concrete, the characteristics of the same is determined through non-destructive means. [1]. To examine the potential of this method for predicting compressive strength, several controlled experiments were conducted in which concrete samples were spectrally measured and simultaneously tested for compressive strength [2]. It is believed that spectral analysis would provide accurate predictions of concrete strength. Since low cost, rapid methods are required, measurement of spectral reflectance of concrete might be an ideal tool for concrete strength estimation in-situ in near real-time, and warrants further study [3].

There are many kinds of spectral measurement devices available such as radiometers, spectro-radiometer etc[4]. Recently, many experimental techniques have been employed to investigate concrete properties. These techniques attempt to measure and evaluate concrete properties other than strength, and then relate them to strength, durability, or any other property which has been developed [6]. Nuclear magnetic resonance and Fourier transform infrared spectroscopy (FTIR) are used to obtain chemical information. Morphological information may be obtained by means of scanning electronscopy and transmission electronscopy. Chemical analyses of concrete and cement commonly use diffuse spectroscopic methods [7, 8].

The fundamental vibrations of most building materials generate spectral information in the mid-IR region (2500-14,000 nm), with overtones and combination modes being generated in the NIRSWIR (near IR and short wave IR) region (900 to 2500 nm) [9]. Electronic transitions generate spectral information in the VNIR (Visible and near IR) range (400 to 900 nm) which is seen as colour and is mostly governed by Iron bearing minerals. Spectral reflectance of a composite material can be used as an inexpensive tool to predict the constituents of the material quantitatively. The reflectance spectroscopy was used across the visible, near and shortwave infrared spectral regions (400 to 2500 nm) as a tool to assess the strength of high performance concrete [10]. The suggested spectral measurement method was constructed as a data-mining method that enables differentiating sample reflectance and extracting quantitative information [11, 12]. The authors examined that the potential of this method for predicting compressive strength, several controlled experiments were conducted in which concrete samples were spectrally measured and simultaneously tested for compressive strength [13].

The concrete specimen with different strength classes were tested at University of Vale do Rio dos Sinos between Visible (350 nm) and near infrared (2500 nm) using Spectro-radiometer SR-3500 model that allows [2] readings in the region between (MISSING), in-situ. It is inferred that the Spectroscopy technique is most promising method for assessing the strength of concrete in a Non-destructive manner and inexpensive way [1]. Investigation of Historical heritage buildings in the seismic area of Calabria Region in Italy in order to analysed to evaluate the vibration properties of selected concrete structure which was carried out using AvioInfReC R300SR-S Thermal Imager (NEC R300SR) camera, in-situ which had a Pixel definition up to 640(H) x 480(V) and an instantaneous field of view up to 0.8mrad [3]. Department of Geography and Human Environment, University campus, Israel used DRS technique as a powerful tool for assessment of concrete strength in situ between visible, near and short wave infrared spectral regions (400 to 2500 nm) [4]. An Experimental study on bridge slab and pier in road construction at Yangbuk Bridge & Daejongchun Bridge, korea with a reflectance range from 350nm to 2500nm using spectrometer (GER3700) and a VNIR hyper spectral camera (AisaEagle VNIR Hyper spectral Camera), airborne and in-situ and it is observed that use of reflectance spectroscopy (visible, near-infrared and short wavelength) is an outstanding technique to evaluate the concrete structures. The decision making for maintenance of concrete structure and highway pavement can be done using hyper spectral sensor which is most preferable [5].An Experimental study on various building at Korea has been done using Hyper spectral Sensor Image Aisa-Eagle VNIR hyper spectral sensor, laboratory and it is concluded that strength of concrete is decided with help of water cement ratio and the spectral reflectance study on different grades of concrete has been correlated more than 80%. It also found that Spectral reflectance of 36 MPa Concrete is about 10%-20% higher than 22MPa concrete [2]. Spectral reflectance is the ratio of incident to reflected radiant flux measured from an object or area over specific wavelengths. Although reflectance is a key unit of measure in remote sensing, it is not measured directly and instead must be derived. Accordingly, the conversion of field and laboratory measurements of spectral radiance into reflectance values is a frequent requirement with ground data in support of airborne and satellite remote sensing applications in the environmental and earth sciences. Hence, in this study, the concrete is remotely-sensed.

Measurements of spectral reflectance of different grades of concrete using a spectro-radiometer is undertaken to relate with the compressive strength of concrete. The spectral reflectance characteristics of concrete through basic experiment on concrete specimens and site experiment on actual concrete structures using a field portable spectrometer and a VNIR hyper spectral sensor. In one of the studies on spectral reflectance of concrete, aspectro-radiometer (GER3700) and a VNIR hyper spectral camera were utilised for extracting spectral characteristics of concrete specimens and actual concrete structures [14, 15]. General concretes show similar pattern with correlation more than 80%, while super high strength concrete shows very different aspect from general concretes [17, 18]. The Spectral Characteristics from VNIR hyper spectral sensor image Aisa-Eagle VNIR hyper spectral sensor is 400~970nm in spectral range and 488 in band number. Images collected by a hyper spectral sensor as well as a spectro-radiometer can be utilized as terrestrial truth data for extracting accurate spectral reflectance and furthermore analyzing airborne or satellite hyper-spectral remote sensing images. Using VNIR sensor extracted graph between the characteristics of reflectance vs. wavelength.

METHODOLOGY:

SPECTRO-RADIOMETER TEST:

The reflectance characteristics of earth surface features may be quantified by measuring the portion of incident energy that is reflected. This is measured as a function of wavelength (λ) and it is called as spectral reflectance.

Fig 1 Measuring spectral reflectance of the concrete samples in the laboratory

Where 'ρ' is the spectral reflectance of the material under consideration, Er is the amount of reflected energy and Ei is the amount of incident energy.

Spectral reflectance curve shows the relationship of electromagnetic spectrum (distribution of the continuum of energies plotted either as a function of wavelength or of frequency) with the associated percent reflectance for any given material. For any given material, the amount of solar radiation that reflects, absorbs, or transmits varies with wavelength. This important property of matter makes it possible to identify different substances or classes and separate them by their spectral signature or spectral curves). In this study, the sample cubes for three grades namely M20, M25, and M30 are casted and tested for compressive strength. Samplesare analysed using spectroradiometerat visible near infrared (VNIR) having range 0.4 – 1.0μm. A spectral reflectance is plotted using the software and analysed. From the graph, the wavelength at which there is a significant change in spectral reflectance in concrete are noted and related to compressive strength (qualitatively) of the concrete..

In order to acquire the spectral reflectance measurements of the samples (different grades of concrete), RS3[21], a spectral acquisition software is used to access the measurements of a spectroradiometer. The ASD spectrometer used covers VNIR (visible-near-infrared) portion of the electromagnetic spectrum. In general, the reflectance of concrete exemplify in the SWIR (shortwave infrared) due to the presence of lime in concrete. However, due to the availability of the instrument, spectral reflectance was measured in VNIR portions. For understanding characteristics of concretes, the concrete specimens for compressive strength test were produced not only with different water/cement ratio but also with different concrete curing time.

A total of 54 samples were used to collect the spectra using spectroradiometer. The following combinations of samples are measured: samples covering three different grades of concrete, namely, M20, M25 and M30 at three different curing periods (at 7th, 14th and 28th day). A white reflectance panel of 99% spectral reflectance rate with spectroradiometer were measured first and considered the measurement as reference data and then acquired spectral information by measuring concrete specimens respectively. You should multiply the spectral values of the measurements with the corresponding spectral values of a certified calibrated white referenceAfter the collection of spectra, the reflectance's values for different grades and different periods of curing are processed using the accompanying software [21] and the results are then plotted as follows in Chart 1 to Chart 6.

The reflectances at 450 nm, 600 nm and 880 nm are used to derive several indices. Such indices have already differentiated different construction practices in a controlled experiment [6].

RESULTS AND DISCUSSION

The purpose of this research is to extract spectral reflectance characteristics of concretes through basic experiment on concrete specimens using a field portable spectrometer and a VNIR hyper spectral sensor. Images collected by a hyper spectral sensor as well as a spectro-radiometer can be utilized as terrestrial truth data for extracting accurate spectral reflectance and furthermore analyzing airborne or satellite hyper spectral remote images. Using VNIR sensor extracted graph between the characteristics of reflectance vs. wavelength.

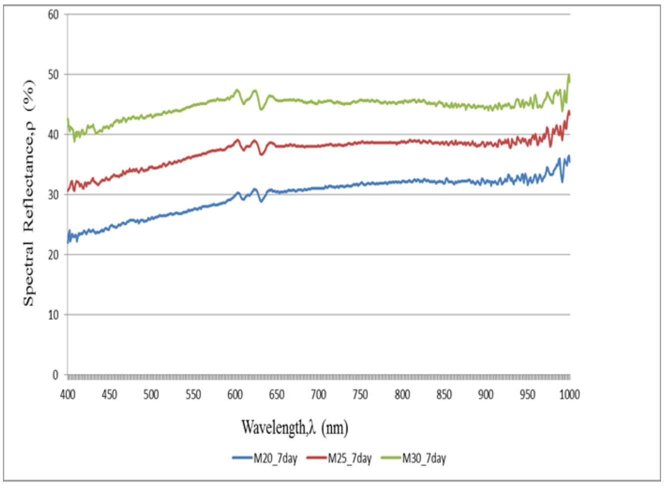

Chart-1 Spectral Reflectance of Various Grades of Concrete at 7th Day Curing Process.

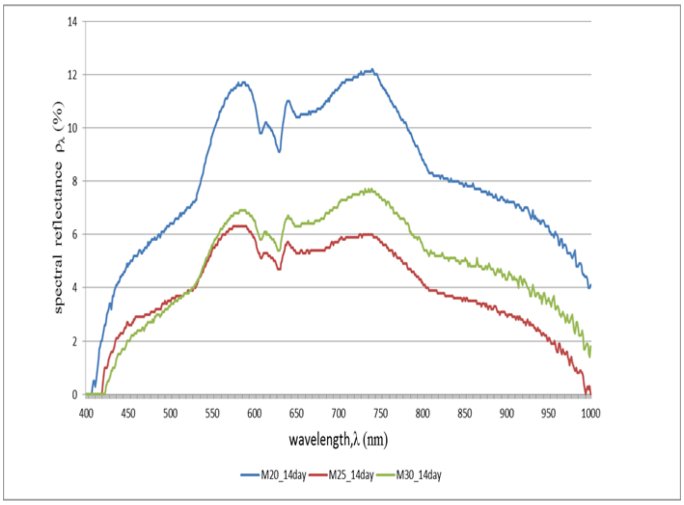

Chart-2 Spectral Reflectance of Various Grades of Concrete at 14th Day Curing Process.

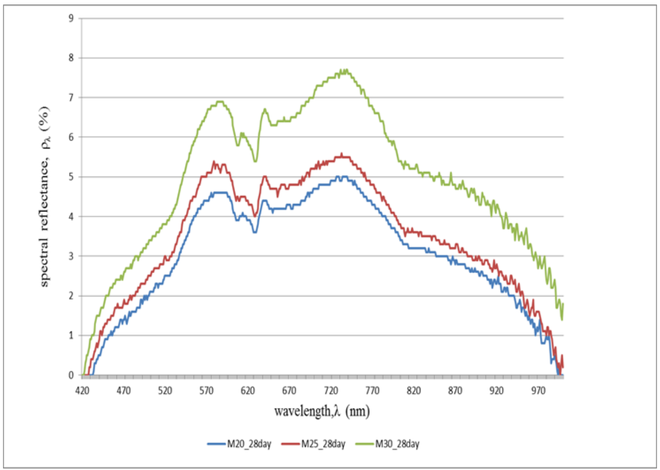

Chart-3 Spectral Reflectance of Various Grades of Concrete at 28th Day Curing Process.

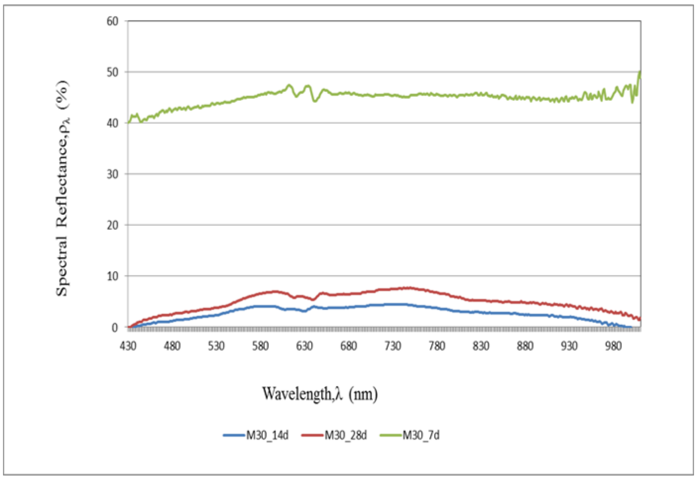

Chart-6 Spectral Reflectance of M30 Grade concrete at Various Days of Curing Process

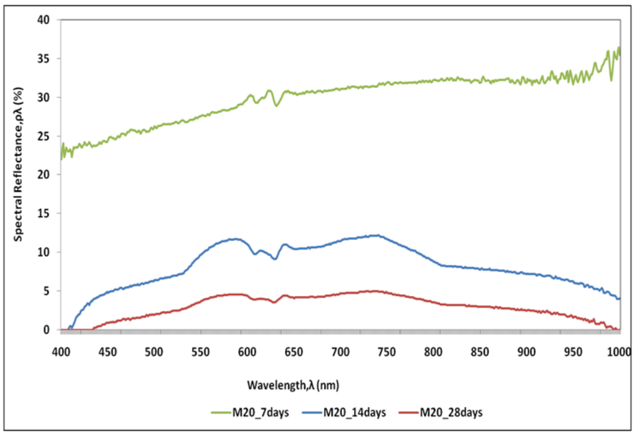

Chart-4 Spectral Reflectance of M20 Grade concrete at Various Days of Curing Process

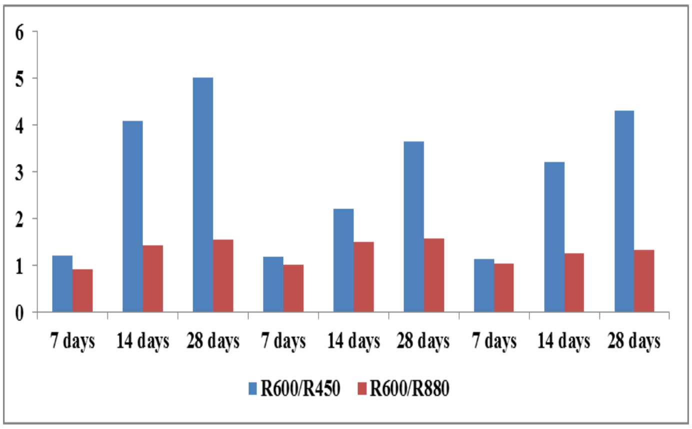

Chart-7 Reflectance Indices for different grade of concrete at Various Days of Curing Process

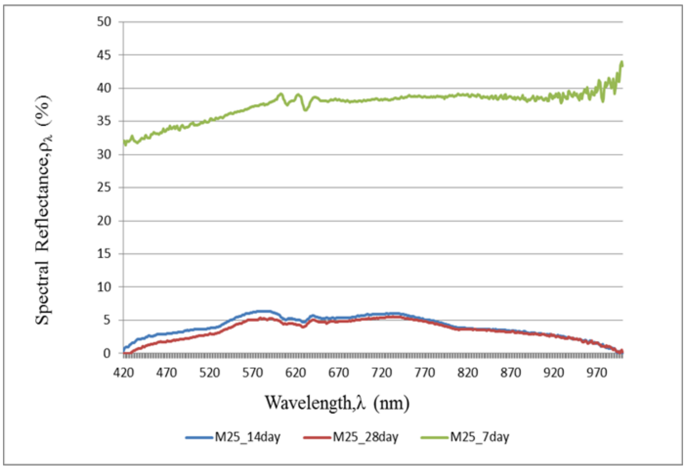

Chart-5 Spectral Reflectance of M25 Grade concrete at Various Days of Curing Process.

The following are the inferences from the several graphs that were obtained as spectral reflectance. In general, the dip that is observed at approximately 600 nm and 630 nm are typical characteristic of the presence of iron-oxide and water content in concrete which absorbs radiation in these wavelengths and there is a decrease in reflectance. Chart 1 shows a comparison of the spectral reflectance of the Different grades of concrete (M20, M25 and M30) at 7th, 14th and 28th days of curing respectively. Chart 1 could be observed that reflectance has reached 48% as maximum for M30 grade in the blue-green portion of the VIS spectrum. There is sudden dip in the 600 and 630 nm wavelengths irrespective of the grade of concrete with peaks in between the wavelength range at 602 nm and 618 nm. There is also an increase of spectral reflectance in all the VNIR portions [5] of the spectrum as the grade of concrete increases, i.e., increasing trend from M20 to M30. The comparison of spectral reflectance at 14thday curing is shown in Chart 2. From the Chart, it could be noted that there is an increase of spectral reflectance dramatically for M25 grade of concrete. But the inference from Chart 3which portrays the spectral reflectance at 28th day follows the same pattern as that of

Chart 1. This means, that on an average, spectral reflectance increase with increase in grade of concrete [1]. In general the distinct spectral variations that represent the grades of concrete represent an interesting spectral contrast that might be used to monitor the types of buildings and settlements in a specific region using remote sensing systems [2]. This is in agreement with a similar type of study undergone by [9] wherein they demonstrated the need for spectrometry in urban mapping. Another striking observation is that as the days of curing increases from 7 to 28, it is observed that reflectance decrease. Hence, it is confirmed that spectral reflectance decreases with ageing of concrete or with time [17].

A comparison of reflectance at Different days of curing for different grades of concrete namely, M-20, M-25 and M-30 are shown in Charts 4, 5 and 6 respectively. It can be seen that as the days of curing increases from 7, 14 and 28, the reflectance decreases. This could be attributed to the fact the visual appearance of the concrete sample is brighter at 7 days due to a comparatively lesser amount of water absorption. As the days of curing increases at 14 and 28 days, there is relatively high absorption of water and hence samples appear darker in tone. This in turn reflects less radiation at 14 and 28 days. And similarly the reflectance values for 14 and 28 days are almost closely-spaced; due the fact about 60% to 70% of compressive strength is achieved in 14 days. Whereas in the case of 7 days of curing, compressive strength of only 30% is attained paving way for high reflectance. While comparing the reflectance of days curing, highest reflectance is observed in 7th day curing of concrete grades. It has been established that it is possible to draw out a relationship between spectral reflectance curves of Different proportions of concrete and compressive strength [3]. The increase in reflectance with increase in the proportions of coarse aggregate and decrease in water/cement ratio as characterised by the Different grades of concrete is strongly noted down. In addition, at Different days of curing, the reflectance varies [4[7]]. With increase in days of curing, the reflectance decreases as is evident for all the grades of concrete.

CONCLUSION

This study has proposed that the compressive strength of concrete may be completely derived as a function of spectral-reflectance. The limitation in this study of spectral reflectance of Different grades of concrete is the availability of a suitable spectro-radiometer in the entire electromagnetic spectrum. The current study focused on measuring spectra in the VNIR regions. The use of shortwave infrared region may further enhance and provide with useful insights on spectral reflectance. This is due to the fact that cement concrete is highly sensitive to SWIR regions that the VNIR region. Presence of lime or CaCo3 in cement is believed to the key factor for high sensitivity in spectral reflectance. Lime has major absorptions at 1.5 and 2.2 µmat SWIR region. Another way of analysing spectral reflectance is through the use of spectral indices which directly give an idea of the amount of lime content in concrete.

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