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ASSESSING AGING IN REINFORCED CONCRETE USING NOVEL REMOTE SENSING TECHNIQUES

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Concrete sets, hardens, gains strength, and exhibits reduced permeability over time, but it is not time alone that causes these effects. Most concrete types are confronted with potential deteriorative service conditions that aggravate their properties irrespective of their age. Thus, there is a critical need to develop an appropriate test method to evaluate and identify concrete aging conditions in various structural components. In recent years, many researchers used hyperspectral technology as a nondestructive test method for assessing properties of concrete structures both in the laboratory and in-situ. The purpose of this paper is to present the results of laboratory research using hyperspectral technology to assess aging in concrete. In this test method, several controlled experiments have been carried out in a controlled environment to retrieve the spectral characteristics of concrete samples due to their exposure in an aggressive sodium chloride environment. The results indicate that spectroscopy can be successfully used as a nondestructive test method for the assessment of reinforced concrete aging.

Keywords: Hyperspectral, Spectroscopy, Reflectance, Spectral signature.

1 INTRODUCTION

In recent times, polymers and other composite materials are used in conjunction with steel in order to improve the life of the structure and delay the need for costly repair and rebuilt costs. The scientific world is constantly striving to design new innovative methods of detecting early signs of concrete deterioration, which costs massive amounts of money to the world economy. The assessment of concrete health is paramount, and it can potentially help reduce costs of repairs and or replacement of such expensive infrastructure, which is generally found around the globe. Nondestructive testing (NDT) is the best possible scenario to combat this massive problem. Many methods have been suggested by engineers to evaluate and assess concrete health (Zaki *et al.* 2015). Safety and cost-efficient management of reinforced concrete (RC) infrastructures are challenging, considering that the expected service life shall be at least 50 to 60 years. Serviceability, durability, sustainability, and bearing capacity of the infrastructure are challenges that many concepts being developed to address (Wan-Wendner 2018). Using NDT Methods to monitor RC structures is currently used widely in the world over (Zaki *et al.* 2015). Most methods include improving and quality control, around these important structures, and use techniques like embedded sensors (Martínez and Andrade 2009), while for old structures some methods provide much-needed feedback in identifying structural damage (Büyüköztürk 1998). In recent years, researchers use satellite remote sensing data for the creation of concrete health risk maps for reinforced concrete structures in urban areas (Neocleous *et al.* 2016). Other researchers use hyper-spectral technology as a NDT Method for assessing properties of concrete structures. This is done by reflecting radiations across the visible near-infrared and approach to predict unknown concrete properties (Shaban 2013). Another method uses a portable spectrometer as an in-situ tool for engineers to monitor and evaluate the status of concrete's strength (Brook and Ben-Dor 2012). Researchers reported that concrete reflectance increases by the hydration process and stabilizes in 6 weeks of age. The average increase was calculated by about 8%, and they have utilized reflectance spectroscopy as a tool to assess the quality of concrete in-situ (Brook and Ben-Dor 2011).

The purpose of this paper is to present the results of laboratory research using hyperspectral technology to assess aging in concrete. In this test method, several controlled experiments have been implemented in the laboratory to retrieve the spectral characteristics of concrete specimens due to their exposure in an aggressive sodium chloride environment. The concrete samples have been examined after applying special treatments, which included measurements before and after the treatment in a salt spray chamber for a known period.

2 METHODOLOGY

The methodology framework comprises of six interconnected steps, as shown in Figure 1.

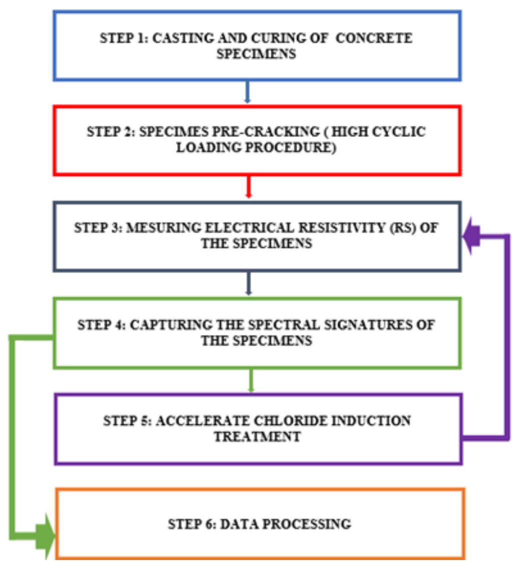

Figure 1. Proposed methodology framework.

Step 1: Fourteen specimens of high strength concrete were cast and cured for 28 days at the Cyprus University of Technology (CUT) laboratory.
Step 2: A high Cyclic loading procedure (elastic area) was applied to the specimens for the creation of service load micro cracks.
Step 3: The electrical resistivity (RS) of the specimens was measured before capturing the spectral signatures.
Step 4: The spectral signatures of the specimen's surface were captured.
Step 5: An accelerated chloride induction treatment was applied, using the salt spray chamber.
Step 6: Data processed.

2.1 Casting and Curing the Concrete Specimens

The fourteen reinforced concrete prisms were cast at the laboratory facilities. The dimensions of the specimens were 100 x 70 mm cross-section and 300 mm in length. The embedded steel rebar exposed in one edge and placed centrally. The dimensions of the embedded steel rebar were of the same length L=330mm, and two different diameters d=10 and 12 mm, class B500c. A high strength Portland cement type (CEM I 52.5N) with a specific gravity (SG) of 3.13 was used for this casting. The coarse aggregates used were crashed diabase gravel with particle sizes of 5/10 mm, and 10/20 mm [Specific Gravity (SG)=2.65, Absorption (A)=2%]. The fine aggregates used were crushed diabase sandstone and crushed calcareous sandstone with a particle size of 0-4 mm. A high range of water Reducer admixture (TSIRCO –FLO SCA43) was also added to achieve the targeted workability. The concrete mixed design Table 1 used for these prisms is an existing high strength concrete (w/c ratio 0.39), which has already been employed for the construction of the Germasogia flyway in Limassol (2006 to 2008). The characteristic cube strength for this mixed design is 60 N/mm^2. Cube samples were cast, cured, and tested in the laboratory with an average cube strength of 75 N/mm^2 for the duration of the 28 days.

Table 1. Concrete mix-design characteristic cube strength 60 N/mm^2.

	Material type	**Design mix* (kg/m^3)SSD**	**Actual mix+ (kg/m^3)**
Coarse aggregate	Crushed diabase 10/20 mm	550	539.5
	Crushed diabase 4/10 mm	335	328.5
Fine aggregate/sand	Crushed diabase sandstone 0/4 mm	370	383.5
	Crushed calcareous sandstone 0/4 mm	355	367
Cement	CEM I / 52.5 N	490	490
Chemical additive (Ltr)	TSIRCO –FLO SCA43	5	5
Water	Potable water	191	200

* based on SSD condition of aggregate
\+ based on the actual water content of aggregate

2.2 Specimen Pre-Cracking Procedure

After the curing period, the concrete specimens were treated under a nondestructive high cyclic loading procedure (elastic area). This application was used to create micro-cracks (service load cracks) for accelerated chlorides induction. The cyclic loading treatment was undertaken to simulate the effect of the service load on the structures. The testing frequency was 5 Hz, while the imposed maximum load was 50 N/mm^2 with a duration of 400 cycles per specimen. The cyclic loading treatment was carried out at the STEELCOR research infrastructure laboratory using a servo-hydraulic actuator with a maximum capacity load of 250 KN in tension and compression.

2.3 Measuring the Concrete Specimens' Electrical Resistivity

Measuring the concrete specimen's electrical resistivity was done by using the Canin+ analyzing instrument and the Wenner probe of the STEELCOR research infrastructure as well as the methodology proposed by the manufacturer of the instrument (PROCEQ 2012). In this process, a current is applied in the two outer probes, and the potential difference between the two inner probes measured. The empirical threshold values for the determination of corrosion are shown in Table 2.

Table 2. Empirical threshold values to determine the likelihood of corrosion (PROCEQ 2012).

When concrete electrical resistivity, ρ, ≥ 12 kΩcm:	**Corrosion is unlikely**
When concrete electrical resistivity, ρ, between 8 - 12 kΩcm:	Corrosion is possible
When concrete electrical resistivity, ρ ≤ 8 kΩcm:	Corrosion is fairly certain

Three measurements were taken from every specimen (at the concrete surface level) in each stage. A total of 84 measurements were measured, 42 for each stage. All the results are shown in Table 3.

Table 3. Electrical Resistivity measurements for all specimens.

Specimen no.	Average resistivity (kΩcm) Condition: NEW*	Average resistivity (kΩcm) Condition: SS2^{+}	Average resistivity (kΩcm) Condition: SS3^{-}
Y10-1	29	12	7
Y10-2	36	13	9
Y10-3	39	15	9
Y10-4	35	10	9
Y10-5	41	12	9
Y10-6	36	14	8
Y10-7	52	14	9
Y12-1	45	13	9
Y12-2	45	10	10
Y12-3	42	13	7
Y12-4	24	11	8
Y12-5	42	11	7
Y12-6	37	13	9
Y12-7	46	14	9

NEW*: Specimens before the accelerated chloride induction treatment
SS2+: Specimens after two months of accelerated chloride induction treatment
SS3-: Specimens after three months of accelerated chloride induction treatment

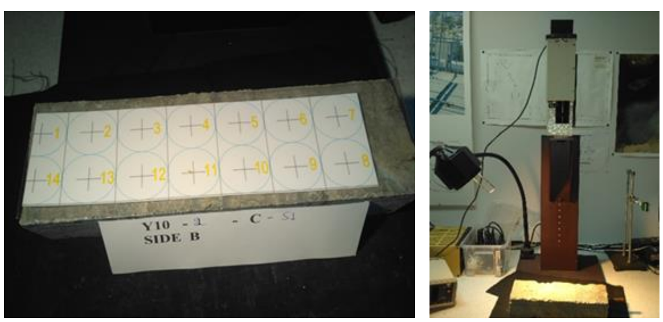

Figure 2. Capturing spectral signatures of the specimens at the CUT Remote Sensing Laboratory.

2.4 Capturing Spectral Signatures

A total of 392 spectral signatures of the specimens were captured (28 per specimen, 14 from each opposite side) under control conditions using the VNIR-SWIR spectroradiometer SVC HR1024 in a spectral range of 350-2500 nm at the CUT Remote Sensing Laboratory (Figure 2). The concrete was scanned from above to keep the spectral measurements constant and stable. The spectral measurements were acquired by using a stabile stand assembly with a white light source (Tungsten- Halogen). A white reflectance panel of 99% spectral reflectance rate was used. The measurement was considered as reference data and then acquired spectral information by measuring concrete specimens, respectively. Before capturing the spectral measurements, all the specimens were dried in the oven to guarantee stable moisture conditions.

2.5 Accelerated Chloride Induction Treatment

After the first collection of the spectral signatures of the concrete samples, an accelerated chloride induction treatment has been applied in the salt spray chamber. This treatment was employed to simulate, as realistically as a possible natural deteriorative process of embedded steel reinforcement. The treatment duration was 2 (SS2) and 3 (SS3) months for all the specimens following the steps in (Figure 1). The EMSURE® sodium chloride and de-ionized water (with conductivity lower than 20 μS/cm at 25° C) were used for the preparation of the 5% salt solution. The temperature of the chamber zone and humidifier were set at 35 °C (± 2 °C) and 50 °C, respectively. The pH of the salt-solution (collected within the chamber zone) was in the range of 6.5 to 7.2. The compressed air pressure was set at the range of 6-7 bar, and the demineralized water pressure in a range of 2-5 bar. The air pressure before the humidifier and the spray nozzle was regulated accordingly to ensure that the collection rate of the salt-solution fulfills the standard's requirements for a collection rate of 1.0 to 2.0 mL per hour.

3 DATA ANALYZING

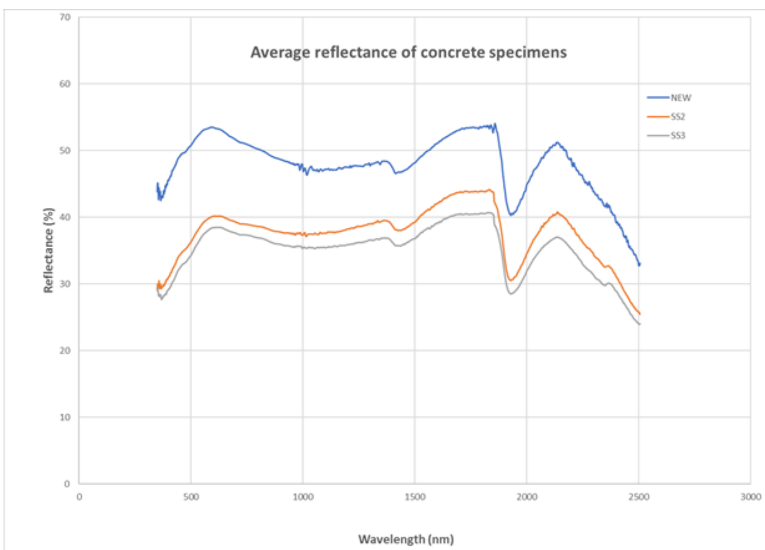

Figure 3. Average reflectance spectrum of all concrete specimen's surface.

A total of 392 spectral signatures of the specimens were captured under control conditions in every step of the procedure. The average reflectance spectrum of all samples is shown in Figure 3. The reflectance of all specimens seems to follow similar distribution through the spectral for each stage examined. A comparison of the three stages examined (NEW, SS2, and SS3) showed that chloride presence in the concrete mass is a critical parameter that highly affects concrete reflectance. Specifically, there is a general reduction of 12% and 15% of the average spectral reflectance from NEW to SS2 and SS3, respectively.

The average results of the specimens' electrical resistivity are shown in Table 3. There is a reduction of the specimens' electrical resistivity due to the accelerated chloride induction treatment.

4 CONCLUSIONS

In this paper, a novel nondestructive method for detecting aging of reinforced concrete introduced. It is based on the use of the reflectance spectroscopy, and it was compared with electrical resistivity measurements. The proposed methodology revolved around the simulation (as realistic as possible) of the natural mechanism of chlorides induction in concrete mass, which is one of the main causes of concrete deterioration in structures. This method showed that the reduction in concrete reflectance (Figure 3) due to the exposure in an aggressive sodium chloride environment is definitely connected to concrete health. Onwards, hyperspectral data need to be studied more detailed, especially in the spectrum areas where reflectance is subject to the most significant reduction.

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