OKU Fen Bilimleri Enstitüsü Dergisi
6(3): 2086-2094, 2023

OKU Journal of The Institute of Science and Technology, 6(3): 2086-2094, 2023

Osmaniye Korkut Ata Üniversitesi
Fen Bilimleri Enstitüsü
Dergisi

Osmaniye Korkut Ata University
Journal of The Institute of Science
and Technology

Direct Analysis of Chlorine Ionized Mortar and Its Sensor Application By 2.45GHz Antennas

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Research Article

Article History:
Received: 14.03.2022
Accepted: 05.10.2022
Published online: 04.12.2023

Keywords:
Ionised concrete
Microwave antenna
Sensor

ABSTRACT

In this paper, a system is proposed that discriminates mortar including sea sand by using microwave patch antennas. The composites with sea sand have vital importance in construction engineering industry because ionised steel reinforced composites could cause life threatening damages. Firstly, to analyse mortar including sea sand, 0%, 25%, 50%, 75% and 100% chlorine ionised sea sand containing concrete samples were produced and relative complex dielectric measurements were conducted. In addition, two 2.45GHz patch antennas were designed in microwave simulator and also it was integrated to the concrete models. Furthermore, simulated results show that this approach could be used as a sensor with nearly 30MHz resonance shifts. Finally, proposed system was supported by experimental investigation. This type of configuration has many advantages as easy design, easy fabrication, cheap and flexible to non-destructive cement based composite measurements.

Klor İyonize Harcın Doğrudan Analizi ve 2,45GHz Antenler ile Sensör Uygulaması

Araştırma Makalesi

Makale Tarihçesi:
Geliş tarihi: 14.03.2022
Kabul tarihi:05.10.2022
Online Yayınlanma: 04.12.2023

Anahtar Kelimeler:
İyonize beton
Mikrodalga anten
Sensör

ÖZ

Bu makalede, mikrodalga yama antenleri kullanarak deniz kumu içeren çimento harcını ayırt eden bir sistem önerilmektedir. Deniz kumu kullanılan kompozit betonlar çelik takviyeli yapılarda kullanıldığında hayati tehlike oluşturabilecek hasarlara neden olabileceğinden inşaat mühendisliği sektöründe büyük bir öneme sahiptir. Öncelikle deniz kumu içeren çimento esaslı kompoziti analiz etmek için %0, %25, %50, %75 ve %100 klor iyonize deniz kumu içeren beton numuneleri üretilmiş ve relatif kompleks dielektrik ölçümleri yapılmıştır. Ayrıca mikrodalga simülatöründe 2 adet 2.45GHz yama anteni tasarlanmış ve beton modellere entegre edilmiştir. Ayrıca, simüle edilmiş sonuçlar, bu yaklaşımın yaklaşık 30MHz rezonans kaymalarına sahip bir sensör olarak kullanılabileceğini göstermektedir. Son olarak önerilen sistem deneysel araştırmalarla desteklenmiştir. Bu tip konfigürasyon, kolay tasarım, kolay imalat, ucuz ve esnekten tahribatsız çimento bazlı kompozit beton ölçümlerine kadar birçok avantaja sahiptir.

To Cite: Öztürk M., Alkurt FÖ., Sevim UK., Akgöl O., Karaaslan M. Direct Analysis of Chlorine Ionized Mortar and Its Sensor Application By 2.45GHz Antennas**.** Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi 2023; 6(3): 2086-2094.

1. Introduction

Cement-based composites are the most common building materials used because of their mechanical properties. It is reported that approximately 25 million tons of concrete were produced and used worldwide in 2016 (Xiao et al., 2017). It is foreseen that the need for concrete, which has become a part of civil life, will not decrease. Due to the advantages, it offers, the need for concrete will increase with increasing population. Thus, maintenance and repair are very important for concrete (James et al., 2019).

The majority of the buildings today consist of reinforced concrete structures. The deterioration of this material is usually caused by chemical and physical effects due to environmental conditions such as acid attack, sulphate attack, fire and chlorine ions penetration (Angst, 2019). Corroded steel bars cause internal pressures in their embedded structures. In addition, corrosion of the reinforcement would cause a decrease in the strength of the reinforced concrete structure as there would be an effective diameter reduction in the reinforcement (Bilcik and Holly, 2013).

Chlorine ions lead to the breakdown of the passive oxide film on the steel bars in the concrete, in other words, the corrosion begins in a shorter time. For corrosion of the steel, moisture, oxygen and chlorine ion penetration into the reinforced concrete is sufficient. Iron ions and chlorine ions react with water to form ferrous hydroxide and hydrochloric acid. Corrosion is severely exacerbated by the conversion of this hydrochloric acid into chlorine and hydrogen ions. Chlorine ions enter the cement-based structures through additives, sea sands, aggregates etc. Detecting chlorine content in the concrete structure would help reduce the risk of deterioration of reinforced concrete structures. It is very important to keep the chlorine ion leaking into the reinforced concrete or in the concrete mixture under control. The maximum chlorine content that can be kept in reinforced concrete structures is determined in international codes (ACI committee 222, 2001; JGJ 52-2006, 2006; Song et al., 2019). These amounts are strictly limited.

Due to various materials such as chemicals, de-icing salts, sea water and sea sand, chlorine ion can penetrate the reinforced concrete structure (JASS 5, 1993). While designing impermeable concrete to limit the ions leaking into the concrete structure (Zhang et al., 2020), it is possible to prevent corrosion by coating the reinforcement inside the concrete (Cui et al., 2019). It is also an effective method to limit the amount of chlorine contained in the mix materials in the concrete structure.

Just as it is important to limit the chloride content in reinforced concrete structures, it is also necessary to carry out inspections in these structures. Risks such as non-compliance or ion leakage into the structure may be encountered. Chemical analyse is one of the methods to determine chloride content and penetration depth quantitatively (ASTM C1152, 2012; ASTM C1218, 2017). Some of others are estimation of diffusion coefficient using steady state methods and measuring partial conductivity of ions (Lu, 1997; Zheng et al., 2018), electrical migration techniques, probabilistic methods (Sun et al., 2019), laser ablation inductively coupled plasma mass spectrometry method (Bonta et al., 2016), etc.

(Arya et al., 1987; Stanish et al., 1997; Lee et al., 1998; Zhang and Xi, 2016; Zhou et al., 2017; Watanabe et al., 2019).

In the past decades electromagnetic analysis are widely used as a non-destructive test method due to its advantages such as low-cost, reliability, time-saving and safety. The electromagnetic tests are based on the relationship between the waves coming from a transmitter to the receiver or the wave from the transmitter to the transmitter. The test is performed by taking into account the losses, reflections, transmissions or absorptions of the waves during the tests. Moisture content, hydration mechanism, carbonation, high temperature, aging, dispersion of fibres, strength, water content is determined by electromagnetic test methods in literature recently (Guihard et al., 2018; Kim et al., 2018; Dexing et al., 2018; Dérobert et al., 2018; Shen et al., 2019; Teng et al., 2019).

In this study, electromagnetic based a novel sensor was designed for the detection of chlorine ions in cement-based structures. Cement-based composites containing different amounts of sea sand were produced. The composites were tested with designed sensors. Finally, a correlation between chlorine content of the composites and output from the antenna was established.

2. Production of Ionised Concrete Samples

Ordinary Portland cement, crushed fine aggregate having 2.6 specific gravity and 4 mm maximum grain size, sea sand having 2.7 specific gravity and 4 mm maximum grain size and tap water were used to prepare cement-based composites. For all mixtures cement: aggregate: water ratio was kept constant as 1:2.47:0.485. A control sample was prepared with the above ingredients except for sea sand. Other samples were prepared by displacing sea sand and crushed fine aggregate by weight in the cement-based composite.

In order to produce cementitious composite, aggregate and cement were dry mixed in the first stage, then water was added and mixed. The mixing by a pan type revolving mixer was continued until a homogenous mixture was obtained. The prepared mixture was poured into 10 cm in diameter and 5 cm high cylindrical moulds for sensor application. The composites were separated from the moulds after 24 hours of pouring. Then the samples were air cured for additional 27 days before the analyses.

3. Relative Dielectric Constant Measurements of Ionised Concrete Samples

The relative complex dielectric constants of five different samples, which were 28 days air-cured, were measured by using Agilent PNA-L network analyser as illustrated in Fig.1a. The measured samples are containing 0%, 25%, 50%, 75% and 100% sea sand in their ingredients. According to measurements, there are dielectric constant differences between five samples as given in Fig.1b. As seen, there are significant differences in dielectric constants; the 0% sea sand included sample has relative dielectric constant about 1.5 in 1-6GHz band. Moreover, the 25%, 50%, 75% and 100% sea sand included samples have mean 1,8, 2.7, 3.2 and 3.7 dielectric constants, respectively. These linear differences caused by ionised particles because these ionised particles change electrical properties of concrete samples (Foudazi and Donnell, 2017).

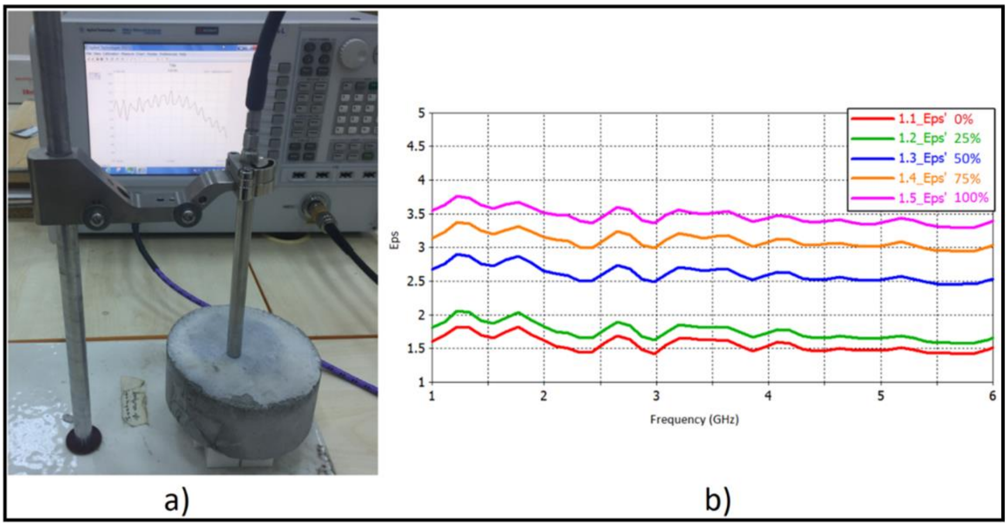


Figure 1. a. Complex dielectric value measurement of samples and **b.** real part of dielectric values of five different samples

4. Sensor Design by Using 2.5ghz Patch Antennas

The measured relative complex dielectric constant values were imported to the finite integrated technique-based microwave simulator and then cylindrical concrete samples, which has 5cm radius and 5cm height, were created by using the imported relative dielectric constants for simulation studies. In the microwave simulation program, open boundaries were set and numerical analysis were done and a discrete port was connected to each antenna to excite antenna elements. In addition, antenna dimensions were given in Fig.2a and antenna S11 characteristics and radiation patterns were also given in Fig.2b and Fig.2c. Moreover, two 2.45GHz patch antennas were designed and integrated to the concrete samples as illustrated in Fig.2d to discriminate the composites. 2.45GHz operating frequency is one of the most used frequency band in many applications such as medical and communication applications, this is the aim of choosing 2.45GHz centre frequency in this study. In antenna design, FR-4 dielectric material is used in substrate layer and copper is used as resonator and ground plane parts. In addition, as shown in Fig.2e, transmission resonance frequencies of patch antennas have a good resonance shifts between 2.36GHz and 2.44GHz with 8dB transmission values. This resonance shift is nearly linear and about 20MHz resonance differences were obtained in each two transmission values. This resonance shifts allows us to use this process in sensing application (Altintaş et al., 2019). As a result, the centrally located 2.45GHz patch antenna is used as a sensor structure in discrimination of sea sand which causes life threatening damages in constructions.

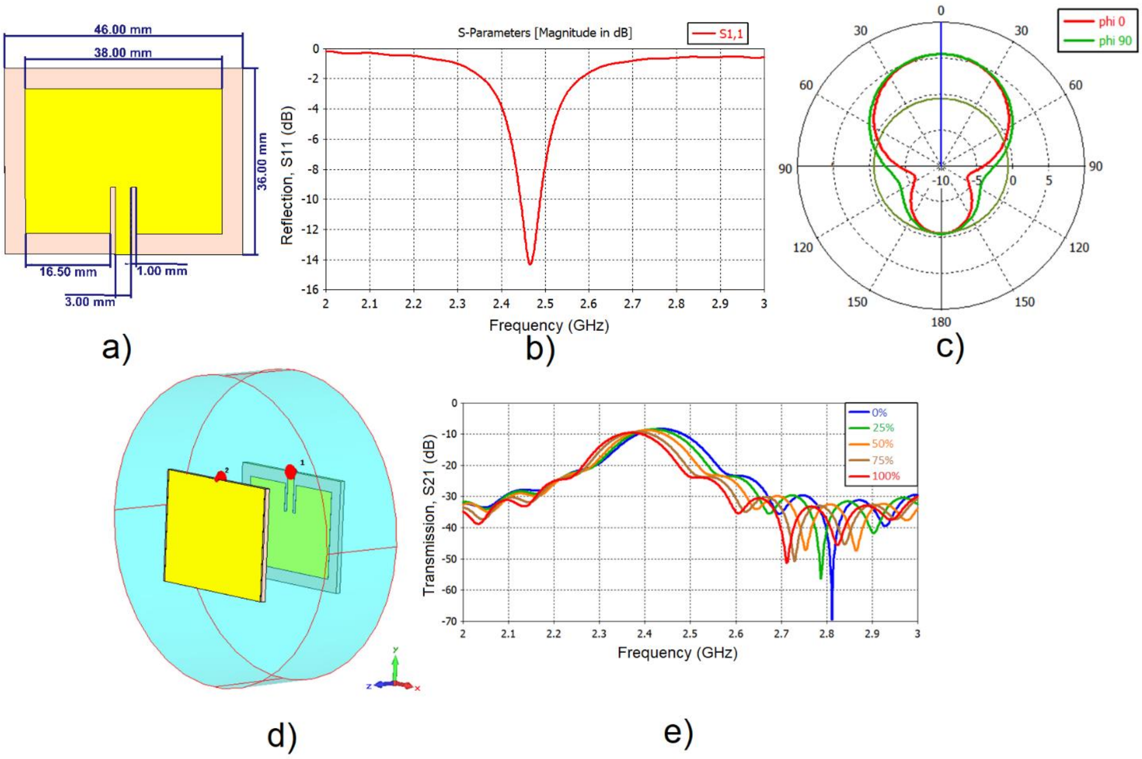


Figure 2. a. Antenna dimension, **b.** antenna S11 characteristics, **c.** antenna radiation pattern, **d.** concrete setup and **e.** transmission values

5. Experimental Investigation

Designed two 2.45GHz patch antennas were fabricated by using LPKF-E33 circuit printer and fabricated antennas are given in Fig.3 by using copper covered FR-4 dielectric plates. Moreover, feed connectors were soldered to the antennas as shown in figure. In addition, Agilent PNA-L network analyser was used in experimental investigation. Before the experimental processes, vector network analyser was calibrated to increase the accuracy of measurements. Experimental setup is shown in Fig.4, two fabricated patch antennas were connected to the coaxial probes. As shown in figure, each patch antennas were located in each side faces of cylindrical concrete samples. Five different concrete samples were investigated and each transmission values were recorded.

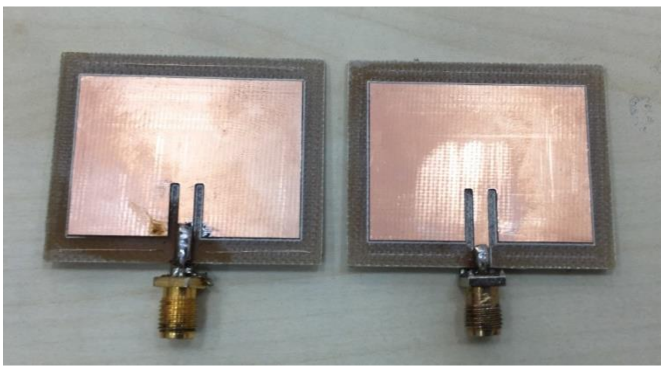
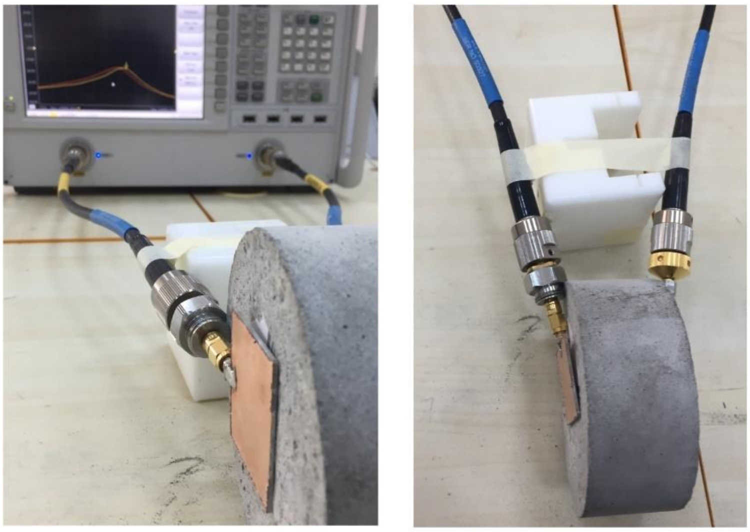


Figure 3. Fabricated antennas



a) b)

Figure 4. Sample measurements

6. Results and Discussions

The experimentally measured transmission values between patch antennas in integration of composite samples are plotted and given in Fig.5. According to experimental measurements, nearly a linear resonance shifts were obtained between the frequencies of 2.550GHz and 2.665GHz. With the reference sample which does not include sea sand, the transmission frequency is 2.665GHz as seen in figure and also composites including 25%, 50%, 75% and 100% sea sand have resonances at 2.625GHz, 2.595GHz, 2.570GHz and 2.550GHz respectively. These resonance differences could be used in sensor application to discriminate mortar including sea sand because this is a vital problem in civil engineering applications. These different resonances caused by the different relative complex dielectric values of chlorine content of the samples.

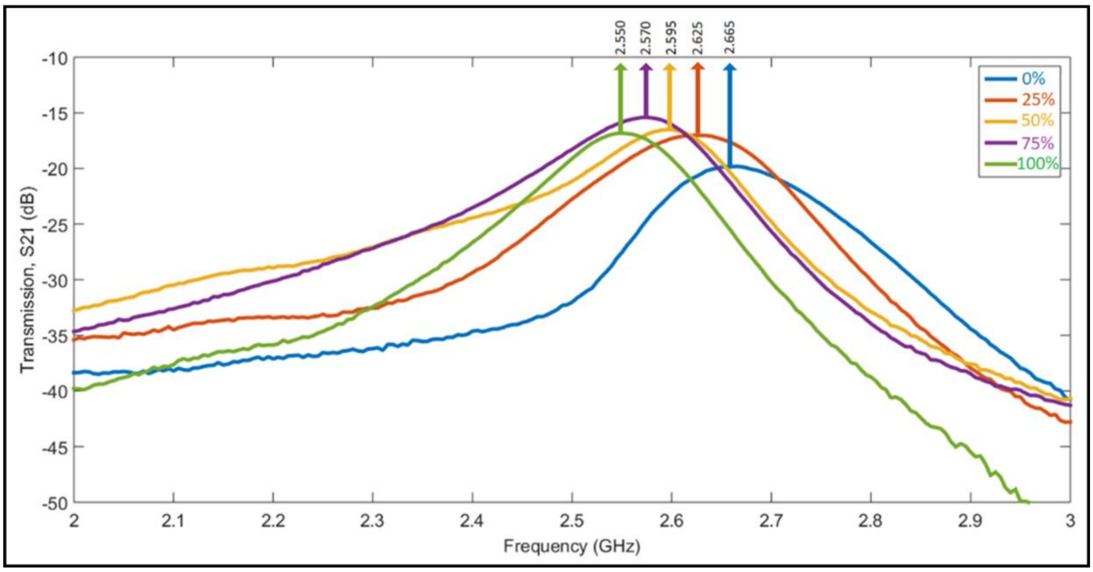


Figure 5. Transmission values of 5 different concrete samples

In this study, antenna-based mortar sensor structure is proposed to detect chlorine ionised sand particles in the concrete composites. As mentioned before, ionised sand particles especially chlorine ions cause corrosions in construction materials so, therefore that situation causes many destructive results in earthquake cases unfortunately. According to sensory model of this paper, proposed model has high sensibility capacity and it has many advantages such as easy fabrication, easy integration and cheap.

7. Conclusions

In this manuscript, we propose a sensor system that discriminates mortar including sea sand to prevent destructive effects in construction industry. Chlorine ionised sand particles are very important because they cause corrosions in steel reinforced constructions and these undesired situations are also important for human life in constructed buildings. Firstly, five different concrete samples were produced by 0%, 25%, 50%, 75% and 100% chlorine containing sands. Moreover, relative complex dielectric constants of produced samples were measured by vector network analyser and measured values were imported to the electromagnetic simulator. According to imported relative dielectric constants, cylindrical samples and two 2.45GHz patch antennas were modelled and simulated. Resonance frequency shifts of antenna transmission values show that mortar including sea sand could be detected by this approach. Finally, simulation results are supported by experimental measurements, fabricated samples and patch antennas tested in microwave laboratory. According to experimental approaches, there are nearly 25MHz resonance differences hence this shows proposed system can be used in civil engineering application with high accuracy.

Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

References

ACI committee. Protection of metals in concrete against corrosion. Farmington Hills 2001; ACI 222R-01.

Altintaş O., Aksoy M., Ünal E., Karaaslan M. Chemical liquid and transformer oil condition sensor based on metamaterial-inspired labyrinth resonator. Journal of The Electrochemical Society 2019; 166(6): B482.

Angst UM. Predicting the time to corrosion initiation in reinforced concrete structures exposed to chlorides. Cement and Concrete Research 2019; 115: 559-567.

Arya C., Buenfeld NR., Newman JB. Assessment of simple methods of determining the free chloride ion content of cement paste. Cement and Concrete Research 1987; 17(6): 907-918.

ASTM C1152. Standard test method for acid-soluble chloride in mortar and concrete. ASTM International, West Conshohocken, PA, USA 2012.

ASTM C1218. Standard test method for water-soluble chloride in mortar and concrete. ASTM International, West Conshohocken, PA, USA 2017.

Bilcik J., Holly I. Effect of reinforcement corrosion on bond behaviour. Procedia Engineering 2013; 65: 248-253.

Bonta M., Eitzenberger A., Burtscher S., Limbeck A. Quantification of chloride in concrete samples using LA-ICP-MS. Cement and Concrete Research 2016; 86: 78-84.

Cui G., Bi Z., Zhang R., Liu J., Yu X., Li Z. A comprehensive review on graphene-based anti-corrosive coatings. Chemical Engineering Journal 2019; 373: 104-121.

Dérobert X., Villain G., Balayssac JP. Influence of concrete carbonation on electromagnetic permittivity measured by GPR and capacitive techniques. Journal of Environmental and Engineering Geophysics 2018; 23(4): 443-456.

Dexing L., Enyuan W., Xiangguo K., Shuai Z., Yanhui K., Xiaoran W., Dongming W., Quanlin L. Mechanical properties and electromagnetic radiation characteristics of concrete specimens after exposed to elevated temperatures. Construction and Building Materials 2018; 188: 381-390.

Foudazi A., Donnell KM. Design of a microstrip patch antenna for microwave sensing of petroleum production lines. In 2017 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM) 2017; 1-2. IEEE.

Guihard V., Taillade F., Balayssac JP., Steck B., Sanahuja J., Deby F. Prediction of cement-based materials' water content with the use of electromagnetic homogenisation schemes. In 2018 Progress in Electromagnetics Research Symposium (PIERS-Toyama) 2018; pp. 164-168.

James A., Bazarchi E., Chiniforush AA., Aghdam PP., Hosseini MR., Akbarnezhad A., Martek I., Ghodoosi F. Rebar corrosion detection, protection, and rehabilitation of reinforced concrete structures in coastal environments: A review. Construction and Building Materials 2019; 224: 1026-1039.

JASS 5. Japanese architectural standard specification for reinforced concrete work. English Version, 10th ed., Architectural Institute of Japan 1993.

JGJ 52-2006. Standard for technical requirements and test method of sand and crushed stone (or gravel) for ordinary concrete. Industry Standard of the People's Republic of China, Beijing 2006.

Kim H., Kang D., Oh SJ., Joo C. Nondestructive evaluation on dispersion of steel fibers in UHPC using THz electromagnetic waves. Construction and Building Materials 2018; 172: 293-299.

Lee JH., Kim JS., Min BH., Kim ST., Kim JH. Determination of anions in certified reference materials by ion chromatography. Journal of Chromatography A 1998; 813(1): 85-90.

Lu X. Application of the Nernst-Einstein equation to concrete. Cement and Concrete Research 1997; 27(2): 293-302.

Shen P., Liu Z. Study on the hydration of young concrete based on dielectric property measurement. Construction and Building Materials 2019; 196: 354-361.

Song J., Li Y., Xu W., Liu H., Lu Y. Inexpensive and non-fluorinated superhydrophobic concrete coating for anti-icing and anti-corrosion. Journal of Colloid and Interface Science 2019; 541: 86-92.

Stanish KD., Hooton RD., Thomas MDA. Testing the chloride penetration resistance of concrete: a literature review, TRID 1997.

Sun B., Xiao RC., Guo J., Zhao Q. Probabilistic chloride penetration models and corrosion initiation probability of RC bridge based on long-term test data. Journal of Bridge Engineering 2019; 24(4): 04019012.

Teng KH., Kot P., Muradov M., Shaw A., Hashim K., Gkantou M., Al-Shamma’a A. Embedded smart antenna for non-destructive testing and evaluation (NDT&E) of moisture content and deterioration in concrete. Sensors 2019; 19(3): 547.

Watanabe A., Furukawa H., Miyamoto S., Minagawa H. Non-destructive chemical analysis of water and chlorine content in cement paste using near-infrared spectroscopy. Construction and Building Materials 2019; 196: 95-104.

Xiao J., Qiang C., Nanni A., Zhang K. Use of sea-sand and seawater in concrete construction: Current status and future opportunities. Construction and Building Materials 2017; 155: 1101-1111.

Zhang R., Liu P., Ma L., Yang Z., Chen H., Zhu HX., Xiao H., Li J. Research on the corrosion/permeability/frost resistance of concrete by experimental and microscopic mechanisms under different water–binder ratios. International Journal of Concrete Structures and Materials 2020; 14:10.

Zhang Q., Xi D. Analysis of testing methods for chloride ion permeability in marine concrete. In 2016 International Forum on Energy, Environment and Sustainable Development 2016; 55-62.

Zheng JJ., Zhang J., Zhou XZ., Wu YF., Ye YM., Wang YH. A three-step analytical scheme for estimating the steady-state chloride diffusion coefficient of mature cement paste. Construction and Building Materials 2018; 191: 1004-1010.

Zhou S., Sheng W., Deng F., Wu X., Fu Z. A novel passive wireless sensing method for concrete chloride ion concentration monitoring. Sensors 2017; 17(12): 2871.