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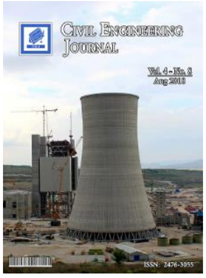

Investigating the Effects of Cement Type and W/C Ratio on the Concrete Corrosion Using the Electrical Resistance Assessment Method

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Abstract

Today, concrete is known as the most widespread material in civil projects. Up to now, many research works have been conducted concerning determination of concrete durability using various methods including the measurement of electrical resistance in concrete. The present article is an attempt for application of a new method for measurement of electrical resistance of non-conductive materials which is well suited for concrete. To determine the effects of cement type and water to cement ratio on the corrosion phenomenon the electrical resistance method was used. For this purpose use was made of 7 different water to cement ratios and two types of cement (type 2 and type 5). Drawing the electrical resistance diagrams, it was shown that with increase in the water to cement ratio, corrosion rate increases in concrete. Also application of type 5 cement results in a higher strength resistance with respect to cement type 2. On the other hand by increase in the age of concrete specimens, they showed greater resistance to the corrosion attacks.

Keywords: W/C Ratio; Cement Type; Concrete Electrical Resistance; Spectroscopy of the Apparent Resistivity.

1. Introduction

Concrete is known as one of the inexpensive and widely used materials in the construction industry. The concrete electrical resistivity is one of the factors which could well exhibit the concrete resistance and durability against penetration of concrete corrosive agents and elements. The concrete electrical resistivity has been under focus of attention in recent decades concerning the corrosion progress of the buried steel in it. Also it is assumed as a criterion for the rate of compaction, permeability, absorption of sulfated materials and other hazardous substances and retention of compressive strength during the operation period. The porous materials like concrete have extensive variation in their electrical resistivity. These changes depend upon its moisture conditions (moisture content) and the micro-structure (porosity and texture). In the Maxwell relation used for composite materials, the concrete electrical resistivity is stated in terms of its constituent elements. This relation is stated as follows [1]:

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$$\frac{\frac{P_m}{P} - 1}{\frac{P_m}{P} + 2} = V_a \times \frac{\frac{P_m}{P_a} - 1}{\frac{P_m}{P_a} + 2} \tag{1}$$

Where:

P_m: Electrical resistivity of cement paste

P: Electrical resistivity of concrete

P_a: Electrical resistivity of rock materials

V_a: Relative volume of rock materials

As the electrical resistance of aggregate is about 100 times the electrical resistivity of cement paste, the mentioned theory has been violated by some researchers in a way. In their belief, these relations are not capable of precise prediction of electrical properties of composite materials like concrete and there is need for another theory. Petting A. et al, after performing various tests on the concrete electrical resistance concluded that concrete in fact acts as an electrolyte with an electric resistivity of about $100\ \Omega.m$ which places it approximately in the semi-conductor substances group [2]. Air-dried concrete has an electrical resistivity about $10 \times 10^3\ \Omega.m$. The electrical resistivity measured in the oven with a temperature over $105^o C$ was about $10 \times 10^7\ \Omega.m$ which could be used as a good insulator.

The basis of concrete electrical resistance is dependent on fluid permeability and ions emission through capillary tubes and related concrete voids and also ionic and textural structure of materials [3]. Many articles have dealt with the relation between concrete electrical resistance and its permeability against destructive ions like carbon dioxide and chloride [4, 5]. These research have shown that concrete electrical resistance could well exhibit its microstructure characteristics [6, 7]. The relation between concrete electrical resistivity and occupied pore space by water could be obtained from electrical conductivity laws using the non-homogenous conductor. Therefore in the ordinary concrete with certain grading, workability and slump, variation in the concrete water is relatively small and the electrical resistivity is mostly dependent on the used cement type. Because the chemical compounds of cement control the existing ions in evaporable water. The research conducted by Tritthart J. and Geymayer H.G showed that the concrete electrical resistivity significantly increases with removal of water within pores and inner pores of concrete. The electrical current within wet concrete is conducted by electrolyte action i.e. by the existing ions in water. By evaporation of water this action is strengthened due to ions precipitation and lack of connection between them which results in increased electrical resistivity and thus when the capillary tubes are cut the electrical current passes through the jelly water [8]. Generally, it is shown that there is an inverse relation between concrete electrical resistance and capillary action within concrete pores [9].

As the electrical resistance measurement test became widespread, many researchers used this method to investigate the properties of various concretes, Afroughsabet and Ozbakkaloglu (2015) for the purpose of determining the performance of concrete containing steel and polyethylene fibers, assessed the electrical resistance of these concrete types. The results of these research showed that by addition of these fibers to concrete, the concrete electrical resistance decreases [10]. As the pieces of rock obtained from demolition of concrete structures could be used in the new concretes, Andreu et al. (2014) measured the durability of these types of concrete by measuring their electrical resistance. The results of electrical resistance test on the 28-days concrete specimens revealed that using the recycled aggregates having low compressive resistance could reduce the electrical resistance and as a result increase the concrete corrosion rate. They attributed this to increased porosity in the concrete [11].

On the other hand according to the research by Hammond E and Robson T.D. who conducted various tests on the concrete specimens containing cements with different characteristics, the following test results on three types of cement are presented [12]:

TI: Ordinary Portland cement (OPC)

TIII: Rapid hardening Portland cement (RHC)

TL: High Alumina cement (HAC) (non-Portland)

Table 1. Effect of concrete curing time on the electrical resistance [6]

Mix Ratios and W/C Ratio	Cement Type	Dry periods in the air (day)	Electrical Resistivity ($\Omega.m$)			
			2500 Hz	500 Hz	50 Hz	DC
1:2:4	TI	7	9	9	9	10
		42	30	31	31	
		113	73	80	82	90
	TIII	39	27	27	28	
0.49	TL	5	139	173	189	
		18	275	351	390	
		40	441	577	652	

Some researchers examined the effect of cement on the electrical resistivity by considering different cement contents of 300, 350 and 400 kg/m^3. According to these studies, by reduction in the water to cement ratio, the electrical resistivity increases in a concrete specimen with a constant cement content and by increase in this value from 300 kg/m^3 to 400 kg/m^3, the electrical resistivity value decreases.

Also according to Ganin (1964) research, the electrical resistivity of concrete specimens made of constant cement ratios of non-Portland high alumina cement was 10-15 times that of concrete specimens made of ordinary Portland cement [13]. Whereas the research performed by Goñi (1991). reveals that the chloride ions in concrete specimen made of high alumina cement resulted in a more aggressive situation in comparison to the Portland cement, and in concrete specimens containing high alumina cement, the concrete had a lower resistance against penetration of chloride ion with respect to the concrete with Portland cement [14].

Medeiros et al. considered the effect of using different types of cements with different water to cement ratios on the concrete electrical resistance. They assumed the water to cement ratios to be 0.4, 0.5 and 0.6. They also used 4 different cement types which contained different amounts of lime stone, pozzolan and slag. Their findings showed that the cement containing slag, and cement containing pozzolan had the highest electrical resistance, respectively and the cement containing lime stone had the lowest electrical resistance. On the other hand the specimens made of water to cement ratio equal to 0.40 had the highest electrical resistance, and by increase in the water to cement ratio the amount of electrical resistance decreases [3].

The age of concrete specimen is stated to be one of the effective factors on the concrete electrical resistance. So that the concrete electrical resistance during some hours after its ultimate setting significantly increases with a steep slope up to 24 hours, and after an age of one hour the rate of increase in resistance decreases [15]. The research have shown that by passing of time and increase in cement hydration, the amount of concrete electrical resistance in specimens increases. The researchers attribute this to reduced connections between the pores in concrete and consequently reduction in the concrete electrical conductivity [16].

As noted, during the recent decades many articles have been written on the concrete electrical resistance and the impact of different factors on this resistance. In most of the references, the effect of one certain factor on the electrical resistance has been investigated and the simultaneous effect of different factors has been neglected. In this article we would investigate the relation between the electrical resistivity and the permeability by the cube shaped concrete specimens.

2. Used Materials

Due to some limitations and the existing types of cement in the market, the Portland cement type 2 produced in Jovein Cement Co. and cement type 5 of Tehran (Iran) have been used in all the specimens. The sand and gravel are of fine grained and crystalline texture with a layered and compacted structure from Shahriar (Iran) mines and the used gravel has a coefficient of fracture equal to 47%. The used water in all the specimens was the urban drinking water. The used oil for the molds belonged to Shimi Sakhteman Co. (Iran).

According to Iran's National Standard No. 390, the cement softness and also based on ASTM C 188-89 Standard the cement specific weight were determined [10]:

Table 2. Technical specification of the used cement

Cement type	Cement softness (cm^2/gr)	Minimum cement softness, based on standard (cm^2/gr)	Cement specific weight (Kg/m^3)
Type II (Jovein)	3150	2800	3116
Type V (Tehran)	3070	2800	3220

Also according to Iran's National Standard No. 4983-4980-4982 the amount of water absorption in aggregates used in this research is as follows:

Table 3. Materials specification

Aggregate type	Water absorption percentage of dried sample to SSD in 24 hours	Effective water absorption percentage (Free moisture)	Specific weight (kg/m^3)
Sand and gravel mixed	3.91	3.6	2526

3. Test Procedure

This test was performed by the electrical resistance measurement device which is capable of exhibiting the concrete electrical resistance both in Ω and $k\Omega$, it also exhibits the concrete capacitance degree and frequency. The experiment is performed using two copper or brass (with zero ohm resistance) plates which are in contact with two parallel sides of the saturated concrete specimen (smeared with cement paste).

Figure 1. Electrical resistance measurement device

The concrete electrical resistance is obtained by applying an alternative current with a certain, through solution of Equation 2:

Where:

L: Distance between two plates of the device (m)

Ω: Concrete electrical resistance

R: Concrete electrical resistivity ($\Omega.m$)

A: Contact area between the plate of electrical resistance measurement device and the specimen (m^2)

In this research the test frequency was always kept as 1 kHz and the cement paste was of Portland cement type I from Abyek –Qazvin (Iran) which had a W/C ratio equal to 0.4. The thickness of cement layer was about 3-5 mm to completely cover all the pores at the concrete surface. The electrical resistance test in this research was conducted on fully saturated specimens which were submerged in water and their surfaces lacked any sealants. Attempt was made to keep the ambient temperature between 21-24 Celsius degrees during the experiment and the water used for cement paste was urban drinking water. The test is performed in this way that after turning on the device and preliminary checking the plate's electrical resistance and preparation of cement paste with a water to cement ratio of 0.4, the concrete specimen is removed from the water and is dried by a dry cloth for 30-60 seconds, then the plates are smeared with cement and the concrete specimen is kept between the plates and the contact between plates and specimen was examined and ensured by hand. Here it should be noted that the cement paste at the upper layer should not flow over the concrete face toward the lower plate, also care should be exercised to prevent any connection between the clamps of the cable which connects the plates and the device

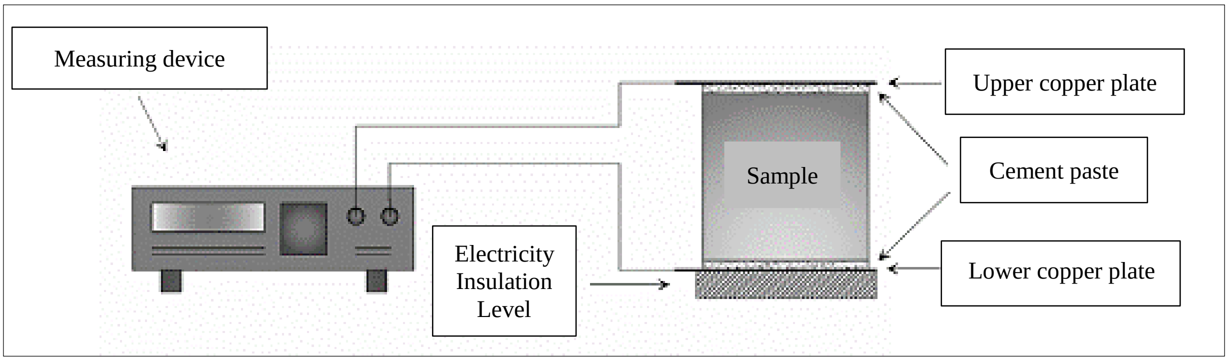

Figure 2. Schematic of the test device

The more the concrete is compacted and its durability increased, the more would increase its electrical resistivity. According to the following proposed table, the probability of corrosion by chloride ion and other aggressive ions is measured:

Table 4. Amount of concrete electrical resistivity and its corrosion

Electrical resistivity R ($\Omega.m$)	Concrete strength against chloride ion and corrosion possibility
$R < 50$	Insignificant
$50 < R < 100$	Very little
$100 < R < 200$	Medium
$R > 200$	High

4. Making of the Specimens and the Results

First, all the materials are mixed in the mixer, then cement and the cemented mixed materials are added to it. Afterwards, dry mixing (about 20 seconds) was performed by turning the materials up and down for a better homogeneity and next water was added for two minutes to the mixing materials. The wet mixing was performed for about 4 minutes and the slump of specimens was measured according to the standard and again concrete was mixed for two minutes for better uniformity. This time was increased up to 4 minutes in concretes with reduced water to cement ratio and low slump. After mixing, the cube shaped molds were filled in 3-6 layers and vibrated to attain the considered compaction. The specimens were removed from the molds after 24 hours and cured in water for 28-days age. The electrical resistance of the specimens was measured at 7, 14 and 28- days periods and the following results were obtained. In Figures 3 to 9 the effect of cement type is assessed. In these figures the cement types 2 and 5 are compared to each other.

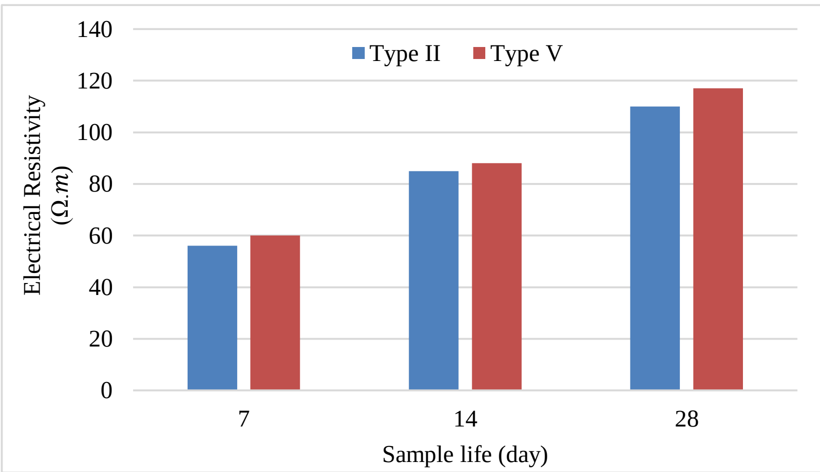

Figure 3. Water to cement ratio of 20%

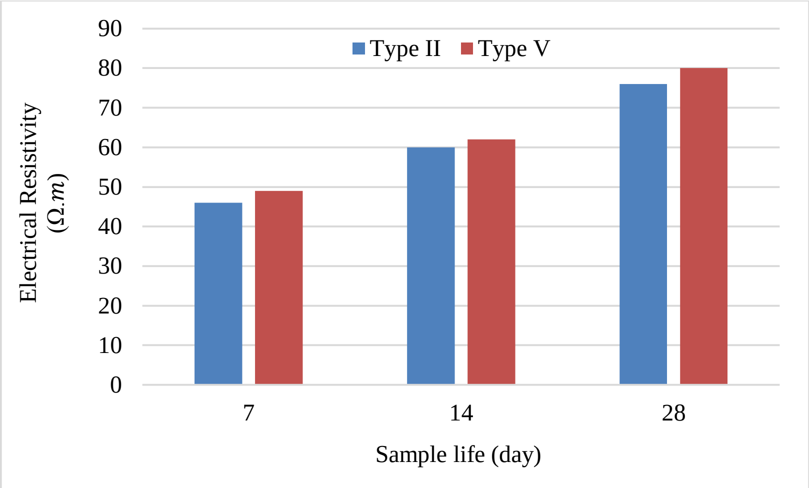

Figure 4. Water to cement ratio of 30%

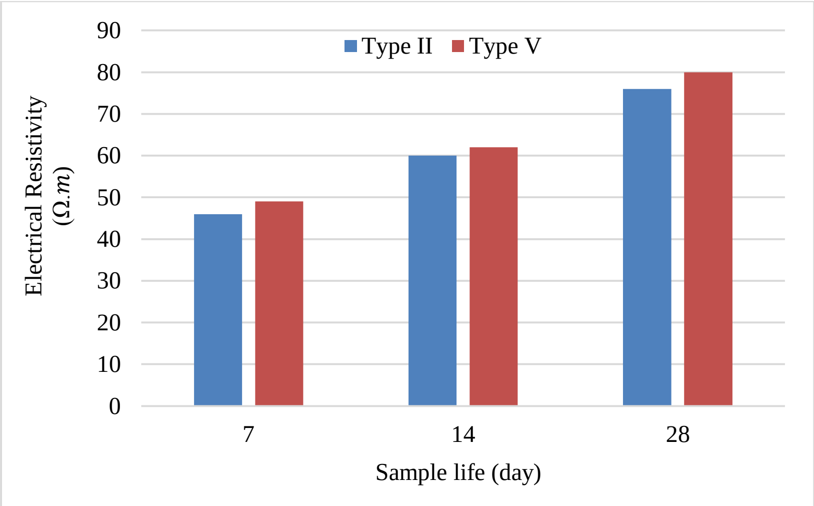

Figure 5. Water to cement ratio of 35%

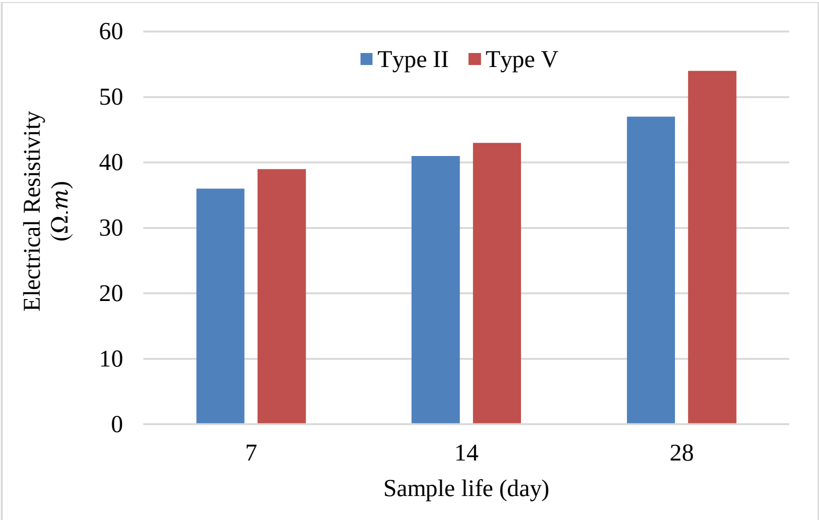

Figure 6. Water to cement ratio of 40%

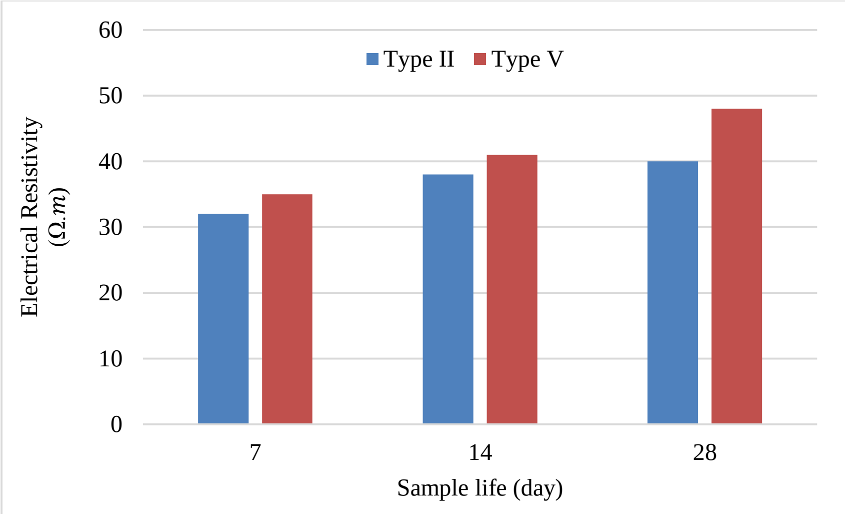

Figure 7. Water to cement ratio of 50%

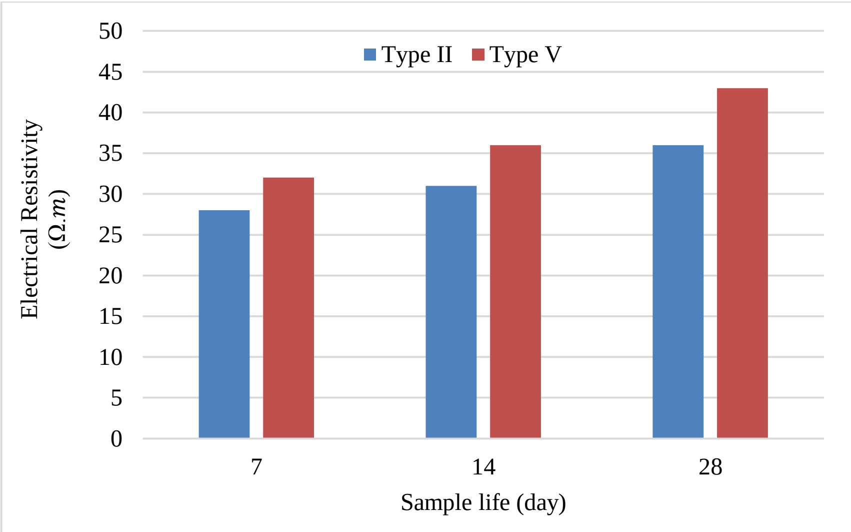

Figure 8. Water to cement ratio of 60%

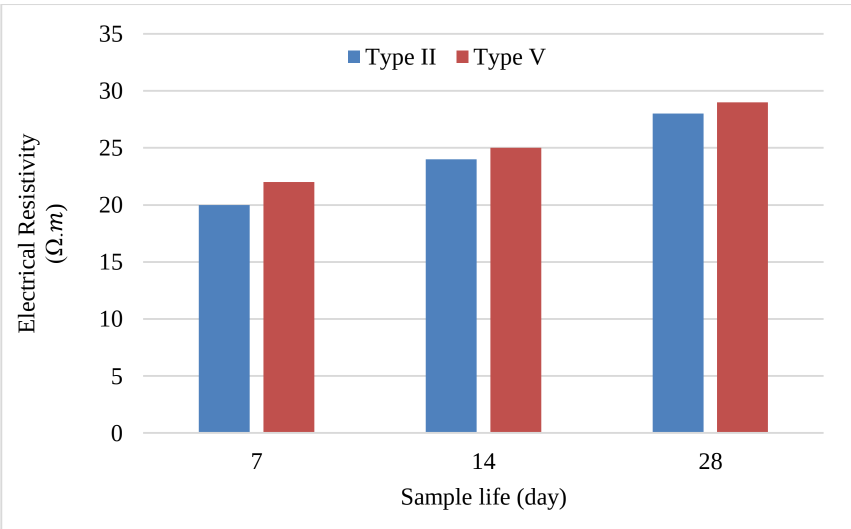

Figure 9. Water to cement ratio of 70%

As is seen in Figures 3 to 9, by selecting the appropriate cement type, one could increase the concrete electrical resistivity. This increase in resistance for 28-days specimens and for water to cement ratios of 70, 60, 50, 45, 40, 35, 30 and 20 percent was 4.7, 19, 20, 14.8, 18, 5.2 and 6.3 percent, respectively. Regarding these figures, one could state that the rate of attaining electrical resistance for specimens having lower water to cement ratios is much higher than that of the specimens with higher water to cement ratio. In fact this shows that when the water to cement ratio is lower, the rate of concrete hardening is much higher. This issue could be of great importance when there is need for higher resistance in short times. On the other hand comparing the specimens made of cement types 2 and 5, it could be stated that generally the rate of attaining resistance in concrete specimens made of cement type 5 is higher with respect to that of the specimens made of cement type 2. Although, according to these figures, it could be stated that the effect of water to cement ratio on the rate of attaining resistance in concrete specimens is much higher than the effect of cement type used in these specimens. Also to measure the effect of water to cement ratio on the concrete electrical resistivity, the water to cement ratio of 7% was applied. It was seen that the effect of decrease in water to cement ratio on the increased electrical resistivity for both types of cement is obvious.

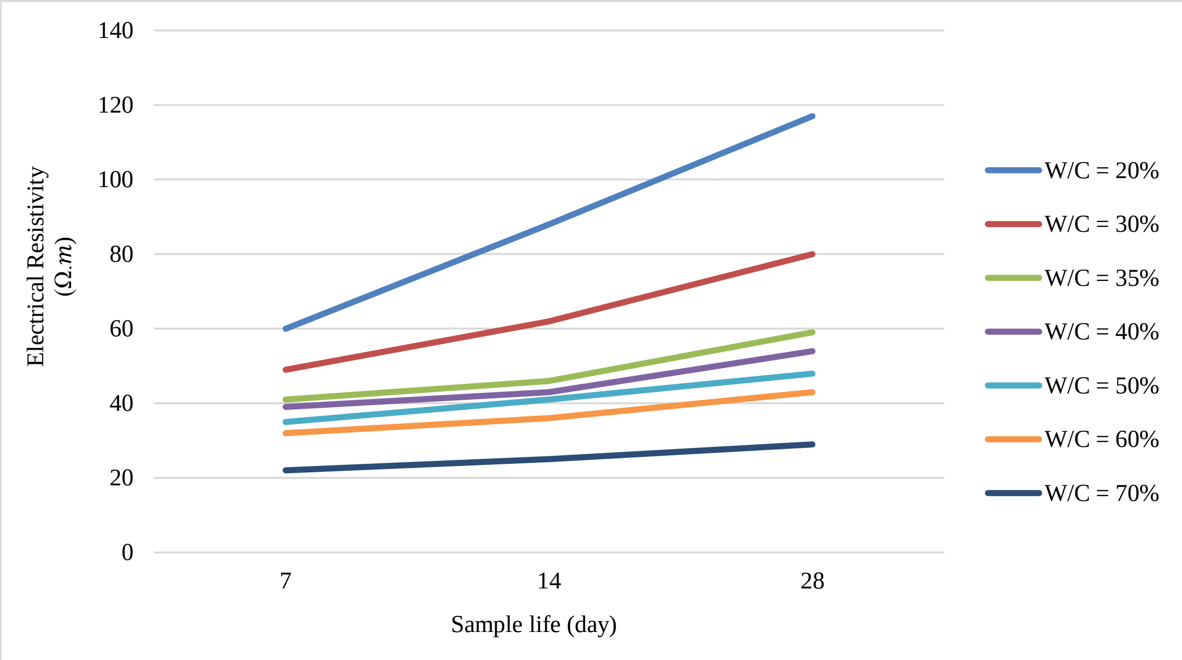

Figure 10. Variation of electrical resistivity for cement Type V

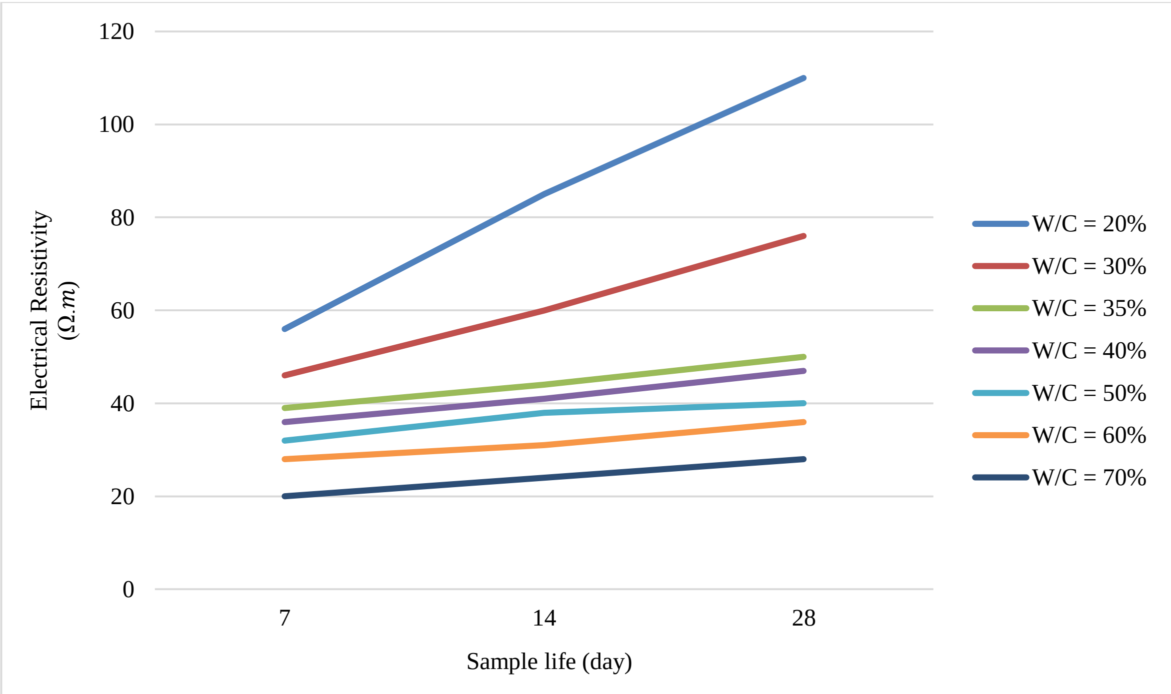

Figure 11. Variation of electrical resistivity for cement Type II

According to Figures 10 and 11 it could be concluded that the water to cement ratio has significant effect on the electrical resistivity. So that by decrease in water to cement ratio from 70% to 20%, the concrete electrical resistivity increases up to 303% and 293% for concrete specimens containing cement types 5 and 2 , respectively. In fact this issue shows that reduction in water to cement ratio causes increase in resistance against corrosion and enhances concrete durability. The rate of attaining electrical resistance during the ageing of concrete specimens reveals that in higher water to cement ratios, the electrical resistance of 7-days specimens is not much different than that of 28-days specimens. Whilst for lower water to cement ratios, the concrete electrical resistance increases with the age of cube shaped concrete specimens.

5. Conclusion

As many concrete structures are constructed in unsuitable environmental conditions, the age of concrete structures is reduced significantly. Various methods have been proposed for measurement of concrete durability and its resistance against corrosion. One of the inexpensive and advantageous methods for non-destructive test of concrete durability is the measurement of concrete electrical resistance test. In this article, by measurement of electrical resistivity in 28-days period, the durability of concrete specimens made of different materials and various water to cement ratios was assessed. Accordingly, the concrete specimens with water to cement ratios of 20%, 30%, 35%, 40%, 50%, 60% and 70% were made. To investigate the effect of used cement, the cement types 2 and 5 were utilized and the electrical resistance of concrete specimens with 7, 14 and 28-days age was measured. Considering the performed electrical resistance test it could be stated that:

- The cement type and water to cement ratio have significant effect on determining the concrete behavior against corrosion attack.
- By increase in the water to cement ratio, concrete becomes more vulnerable against chloride attack and the more the water to cement ratio decreases in the specimens, the electrical resistivity of the concrete specimens would increase.
- Use of Portland cement type 5 in comparison to Portland cement type 2, results in higher durability against corrosion attacks.
- Gradually, by increase in the age of concrete specimens, the electrical resistivity of these specimens increases, so that this increase is more significant for specimens with cement type 2.

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