Investigation of Durability Pozzolanic Efficiency Factor by Means of Surface Resistivity Measurement

Ali A. Ramezanianpour[1], Payam Vosoughi[2], Faramarz Moodi[2]

[1]*Head of Concrete Technology and Durability Research Center, Amirkabir University of Technology, Tehran, Iran*

[2]*Concrete Technology and Durability Research Center, Amirkabir University of Technology, Tehran, Iran*

p.vosoughi@aut.ac.ir

Abstract

Supplementary cementitious materials (SCMs) are used in concrete due to their properties such as reduction of cement consumption, reducing cost, enhancing concrete compressive strength, and boost durability of concrete against aggressive environment. In this paper, durability pozzolanic efficiency factor of four types of raw natural pozzolans (natural Zeolite, Trass, Tuff, and Pumice) and a type of artificial pozzolans (Rice Husk Ash) with respect to durability of concrete against corrosion of the reinforcement are determined and compared with each other. For this purpose, surface electrical resistivity of 17 kinds of diverse concrete mixture design are measured at two ages (28 and 90 days) using the Wenner four probes apparatus. The results show that natural Zeolite has the highest durability pozzolanic efficiency factor; Trass and Rice Husk Ash are in the second rate, also Tuff and Pumice are in the last place.

Keywords: Durability pozzolanic efficiency factor, Reinforcement corrosion, Surface electrical resistivity, Wenner four probes apparatus, Water per cement ratio.

1- Introduction

According to the fact that Ordinary Portland Cement (OPC) production causes many environmental problems, reduce consumption of it is one of the main reasons of using Supplementary Cementitious Materials (SCMs) in concrete. But then it was realized that several SCMs can have some beneficial effects on concrete properties, such as increase workability, decrease permeability, enhancing resistance to sulfate attack, reducing the rate of heat hydration, improving the ultimate strength, and boost durability of concrete [1].

The most of SCMs, which mainly compose of silica and alumina oxides, react with hydrated lime (calcium hydroxide), whose the largest part produce in result of hydration of portland cement, and form additional Calcium Silicate Hydrate (C-S-H) with binding properties [2]. In this reaction, the volume of cement paste void and connection of them are greatly decreased, so it is expected that permeability of concrete will be declined.

Some investigations on high active SCMs such as silica fume indicated that charge passed through the specimen in RCP test according to ASTM C1202 could strongly fall down up to 15 times [3]. However, the permeability of concrete does not drop pertinent to conductivity. Conductivity of the concrete is depended on parameters such as relative humidity, quantity of aggregate, type and amount of cement and SCMs, free water per cement ratio (W/C), age, and etc. In a specific concrete specimen, due to the fact that the current is carried by ions in the pore liquid, and equivalent conductivity of OH^- is about 2.5 times more than other ions in pore solution [4], devouring it in the second order pozzolanic reaction has a significant effect on raising electrical resistivity of concrete. According to the fact that high resistivity limits the corrosion rate, using appropriate SCMs with suitable replacement percentage is one of the efficient ways to enhance durability of reinforced concrete against reinforcement corrosion.

In this paper, according to the proposed model, durability pozzolanic efficiency factor of some SCMs including four types of raw natural pozzolans (natural Zeolite, Trass, Tuff, and Pumice) and a type of artificial pozzolans (Rice Husk Ash) with respect to durability of concrete against corrosion of the reinforcement are determined. For this manner Surface Resistivity (SR) of specimens with different replacement percentages of SCMs in two ages (28 and 90 days) are measured. Eventually, durability pozzolanic efficiency factor of SCMs are compared with each other.

2- Model used to evaluate durability pozzolanic efficiency factor

The relative performance of various SCMs in rising surface resistivity of concrete can be compared with that of OPC by using the practical concept of the durability pozzolanic efficiency factor (k_d). The coefficient of k_d generally depends on the mixture proportion (especially amount of OPC and W/C ratio), concrete age, and the SCMs type and quantity. According to Equation (1) equivalent binder (B_{eq}) defined as the sum of the quantity of cement (C) plus k times of other binders (B).

$$B_{eq} = C + k_d \times B \qquad \text{Equation (1)}$$

Base on previous works done, it is known that the resistivity of a specific concrete is in good correlation with free water per OPC ratio (W/C) [2, 5-7]. In cases that W/C is in range of 0.4 up to 0.6, using linear function has a good accuracy. But, using exponential function for expressing the relation between these parameters are recommended in out of this range [6]. Figure 1 which is derived from CTDRC[1]'s data indicates that SR decreases with increasing amount of OPC in a mixture design with constant W/C. However, in cases with constant water, SR is raised by increasing the amount of OPC and decreases the W/C in result of it.

In the cases using SCMs in concrete mixture proportion, based on model that is shown in Figure 2 the coefficient of k_d can be determined by using SR. In fact, by means of given SR and proper model between SR and W/C for a specific concrete (made by only OPC), amount of B_{eq} can be estimated. Then, by Equation (1) the coefficient of k_d will be calculated.

[1] Concrete Technology and Durability Research Center at Amirkabir University of Technology

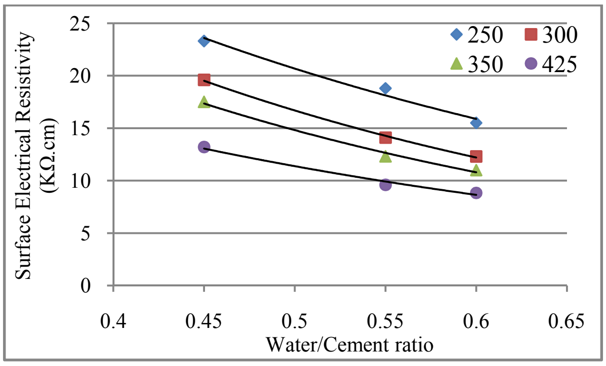

Figure 1 – Relationship between SR and W/C ratio among concrete with different grade cement

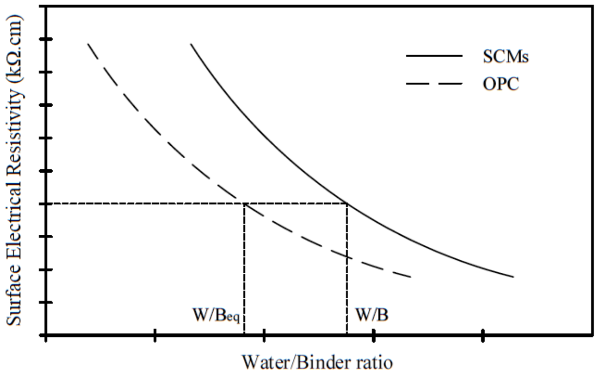

Figure 2 – Equivalent cementitious material of a mixture with SCMs

3- *Experimental Program*

All of concrete mixtures were made, cured, and tested in CTDRC. Three cylinder specimens (size 100*200 mm) were cast for each mixture, cured in lime-saturated water at 23±2 °C to prevent possible leaching of $Ca(OH)_2$, and surface resistivity at the ages of 28 and 90 days were measured. A superplasticizer was employed to achieve a constant workability.

2-1- Materials and mixture proportions

ASTM C 150 type I Portland cement was used for all of the concrete mixtures. All SCMs meet requirements of class F raw or calcined natural pozzolan based on ASTM C618, except Zeolite whose LOI is equal to 11 percent. Rice Husk Ash (RHA) produced by a special designed furnace at 650 °C for 60 min burning time. Table 1, and 2 represent the chemical analysis and the physical properties of OPC and SCMs, and concrete mixture proportions respectively. Coarse aggregates were crushed calcareous stone with a maximum size of 19 mm and fine aggregates were natural sand.

Table 1 - Chemical analysis and physical properties of Portland cement and SCMs

	OPC	**Rice Husk Ash (RHA)**	**Trass (Tr)**	**Tuff (Tu)**	**Pumice (Pu)**	**Zeolite (Ze)**
SiO_2	21.5	89.6	65.7	62.6	67.7	67.44
Al_2O_3	3.68	0.04	12.2	15.2	15.8	10.9
Fe_2O_3	2.76	0.22	2.05	4.47	3.39	0.84
$SiO_2+Al_2O_3+Fe_2O_3$	27.9	89.9	80.0	82.3	86.9	79.14
CaO	61.5	0.91	2.87	6.83	3.9	1.24
SO_3	2.5	0.15	-	0.38	0.33	0.47
MgO	4.8	0.42	0.96	1.71	0.99	0.33
Na_2O	0.12	0.07	1.92	2.77	2.95	3.71
K_2O	0.95	1.58	2.02	2.09	2.0	4.39
P_2O_5	0.23	0.41	0.03	-	0.12	-
TiO_2	0.04	0.02	0.29	-	0.33	0.19
LOI	1.35	5.91	8.5	2.88	2.3	11.05
Fineness (cm^2/gr)	3200	3700	4500	4500	3500	10000
Density (cm^3/gr)	3.12	2.15	2.66	2.56	2.54	1.91

Table 2 – Concrete mixture proportions

Mixture Code	OPC (kg/m^3)	SCMs		Water (kg/m^3)	Aggregate (kg/m^3)
		Type	Weight (kg/m^3)		
C350	350	---	0	175	1756
C350RHA07	325	RHA	24.5	175	1756
C350RHA10	315	RHA	35	175	1756
C350RHA15	297.5	RHA	52.5	175	1756
C350Tu15	297.5	Tu	52.5	175	1770
C350Tu20	280	Tu	70	175	1770
C350Tu25	262.5	Tu	87.5	175	1770
C350Pu10	315	Pu	35	175	1770
C350Pu15	297.5	Pu	52.5	175	1770
C350Pu20	280	Pu	70	175	1770
C350Tr15	297.5	Tr	52.5	175	1770
C350Tr20	280	Tr	70	175	1770
C350Tr25	262.5	Tr	87.5	175	1770
C350Ze10	315	Ze	35	175	1715
C350Ze15	297.5	Ze	52.5	175	1715

2-2- Surface electrical resistivity test

In 1915, Wenner presented a practical way to measure the earth resistivity by means of a four probes apparatus whose distance were up to hundreds meters.[8] In this method, known current is applied to the two outer probes (I), and the potential difference is measured between the two inner probes (V). Then, the surface resistivity could be calculated based on Equation (2).

$$SR = \frac{2\pi a\,V}{I} \qquad \text{Equation (2)}$$

For the first time, FDOT standardized this method to use in concrete technology in 2004, and then AASHTO approved it in 2011.[9, 10] Surface Resistivity (SR) test is a rapid, low-priced, non-destructive, and reliable electrically based method for investigation of concrete properties by its conductivity. Today, many engineers and scientists are using this method for evaluation of chloride permeability, on site assessment of curing efficiency, indication of variations in the water/cement ratios within a specific concrete structure, strength of self consolidation concrete (SCC) against static segregation, etc.

For measuring the SR in this experimental work, a four-point Wenner apparatus complied with FDOT standard[9], whose schematic figure is shown in Figure 3, is used. Other features of this toll are indicated in Table 3 [11].

Table 3 – Features of the four-point Wenner apparatus which is used

Span of probes	Rated current (I)	Frequency	Accuracy
3.8 mm (1.5 in)	180 µA	72 Hz	±1 kΩ.cm

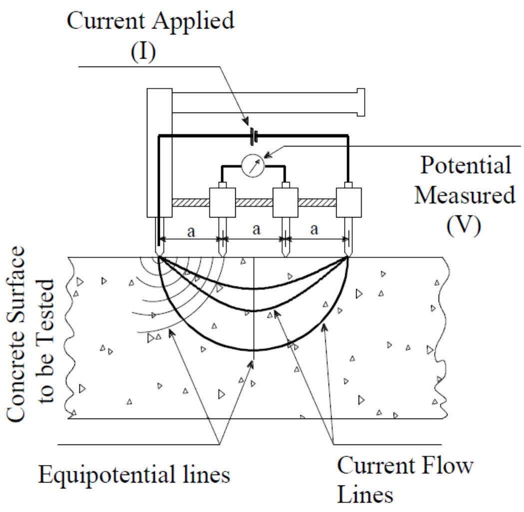

Figure 3 - Four-point Wenner Apparatus [12]

4- *Results and Discussion*

Figure 4 indicates the relationship between surface resistivity and W/C on concrete with similar material in CTDRC at two ages (28 and 90 days) [5, 13]. Seven specimens with five different W/C between 0.35 up to 0.5 are used to offer these models. By these models and measured resistivity, B_{eq} of each mixture is estimated. Then, by means of Equation (1), durability pozzolanic efficiency factor of pozzolans in the each mixture, which are expressed in Table 4, is calculated. In the general case, durability pozzolanic efficiency factor of SCMs depend on properties of concrete mixture design, and age. Therefore, it could not be given an exact number for each SCM.

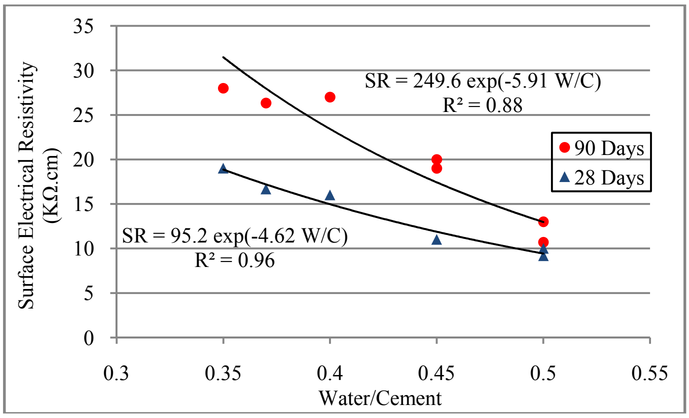

Figure 4 – Relationship between SR and W/C ratio at two ages

Zeolite, which is actually a kind of clay minerals, is an active raw natural pozzolan which has the highest durability pozzolanic efficiency factor based on Table 4. In addition to chemically properties of its components and the amount of amorphous silica oxides, having a high fineness can be one of the reasons of this issue. It is noteworthy that using Zeolite in producing concrete usually leads to fall down the workability of fresh concrete, but in this investigation, W/C was equal to 0.5 and workability was stable for all of the concrete by means of appropriate amount of superplasticizer.

Trass and Rice Husk Ash have the second rate durability pozzolanic efficiency factor. Trass is a raw natural pozzolan, and better to use wherever it is available; furthermore, it has the slightly greater factor based on Table 4. Optimized replacement percentage of Trass is about 20%, Table 4 indicates that because of $Ca(OH)_2$ shortage and porosity of cement paste in result of OPC reduction, durability pozzolanic efficiency factor of it will be decline by higher replacement percentage. Rice Husk Ash is an artificial pozzolan which is produced from agricultural waste, and usually has higher price than Trass; so, it is usually used with lower replacement percentage.

Some SCMs such as Tuff and Pumice have low durability pozzolanic efficiency factor in comparison with the rest in early age, but their performance will be better over time. Table 4 shows that difference between durability pozzolanic efficiency factor of Tuff and Pumice with others at the age of 28 days are decline at the age of 90 days. Besides, it is expected that it will be lesser at older age, but they cannot reach durability pozzolanic efficiency factor of active SCMs such as Zeolite, in the general manner. The main reasons of using these low active SCMs are related to decrease the cost and pollution of concrete producing by means of high OPC replacement percentage, so having slightly lower compressive strength or even resistivity is passable.

Table 4 – Durability pozzolanic efficiency factor of SCMs

Kinds of SCMs	Mixture Code	Durability Pozzolanic efficiency factor	
		28 Days	90 Days
Zeolite (Ze)	C350Ze10	6.1	8.2
	C350Ze15	7.7	7.5
Rice Husk Ash (RHA)	C350RHA07	3.2	3.7
	C350RHA10	4.3	4.6
	C350RHA15	6.5	5.0
Trass (Tr)	C350Tr15	5.2	5.8
	C350Tr20	7.1	7.6
	C350Tr25	5.7	6.8
Tuff (Tu)	C350TU15	1.6	3.2
	C350TU20	2.3	4.5
	C350TU25	2.2	4.2
Pumice (Pu)	C350Pu10	0.7	2.8
	C350Pu15	2.1	3.0
	C350Pu20	1.8	3.3

5- *Conclusions*

If there is a minimum requirement resistivity for durability design against reinforcement corrosion, this paper indicates that if a concrete contains proper SCMs with suitable replacement percentage, much less OPC is required to obtain a specific obligation. In addition, using these SCMs leads to have more durable and low cost concrete (green concrete).

According to quality, amount of amorphous crystal, and fineness, Zeolite has the highest durability pozzolanic efficiency factor among the five other pozzolans which were investigated. Trass and RHA coefficient are slightly close to each other, so they should be used due to their availability and price. 20% is the optimized replacement percentage of OPC with Trass, to have the highest durability pozzolanic efficiency factor; usually lower RHA is used.

Tuff and Pumice are raw natural pozzolans which have the lowest durability pozzolanic efficiency factor. Regardless of this matter, the main reason of using them is to produce green and low cost concrete with high reduce in consumption of OPC. Nevertheless they have better performance in the later ages, their resistivity is less than the others.

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